35th International Conference
on Production Engineering

ICPE 2013

Conference Proceedings

ORGANIZATION SUPPORTED BY:
Ministry of Education and Science, Republic of Serbia

Faculty of Mechanical and Civil Engineering in Kraljevo
Department of Production Technologies

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

621.7/.9(082)
621.7/.9:669(082)
681.5(082)
005.6(082)
004.896(082)

INTERNATIONAL Conference of Production
Engeneering (35 ; 2013 ; Kopaonik)
Proceedings / 35th International
Conference of Production Engeneering - [ICPE
2013], Kraljevo-Kopaonik, 25-28 September
2013 ; [organized by] Faculty of Mechanical
and Civil Engineering in Kraljevo. - Kraljevo
: Faculty of Mechanical and Civil Engineering
in Kraljevo, 2013 (Vrnjačka Banja : Satcip).
- 370 str. : ilustr. ; 30 cm

Tekst štampan dvostubačno. - Tiraž 100. -
Str. I: Overview / Zoran Petrović. - Str.
II-III: Welcome Adress / Miomir Vukićević. -
Bibliografija uz svaki rad.

ISBN 978-86-82631-69-9
1. Faculty of Mechanical and Civil
Engineering (Kraljevo)
a) Производно машинство - Зборници b)
Метали - Обрада - Зборници c) Системи
аутоматског управљања - Зборници d)
Управљање квалитетом - Зборници
COBISS.SR-ID 204080908

Conference venue

The 35th Conference on Production Engineering will be held in the Apartments "Konaci" on the mountain of Kopaonik, in the period 25-28 September 2013. Kopaonik is a famous ski resort in central Serbia, 100 km far from Kraljevo and 280 km far from Belgrade. The highest peak of Kopaonik is Pančić's Peak with 2017 m above sea level, which was named after the botanist Josif Pančić (1814-1888).

Thanks to its natural resources, Kopaonik was proclaimed a national park in 1981. The National Park Kopaonik covers the area of 11,810 ha and represents, by its endemic species, one of the most impor-tant centers of flora and fauna in Serbia.

Besides the old churches and monasteries such as Djurdjevi Stupovi, Studenica Monastery, Sopoćani and Gradac Monastery, there are also several early and mediaeval fortresses built by Serbian dynasties. The nearest Serbian mediaeval castle is Maglič.

Overview

The Conference will cover current topics on production engineering with an emphasis on new technologies – the effects and importance of their introduction into manufacturing processes, the globalization of industry and technology transfer. The aim of the Conference is to offer an opportunity for the specialists in the field from all over the world to present results of their activities, both the very latest results and results achieved over the last 2 years. The Conference will also enable participants to become acquainted with the work of others, to promote further development by means of discussions and comments, and to profit from making new personal contacts. Overall, the Conference will help to define new directions for future technical research and development. The accompanying exhibition of industry achievements will be the opportunity for companies to present their plans, products and accomplishments. There will be a space dedicated for the exhibition and special sessions for oral and audio-visual presentations. Wishing to improve the Conference by our joint effort and results, we invite you to contribute to the achievement of these goals with your presence and your papers.

Conference chairman
prof. dr Zoran Petrović

WELCOME ADDRESS

Dear colleagues,

We wish you a warm welcome and a pleasant stay on our beautiful mountain as well as successful participation in the 35^{th} International Conference on Production Engineering in Serbia.

We feel free to say that we are satisfied and proud, and we hope you feel the same, because we have contributed to the preservation of the tradition which started in 1965, at the initiative of Prof. Dr Vladimir Šolaja. One of the founders of the Association of Scientific and Research Institutions of Production Engineering of Yugoslavia was Prof. Dr Pavle Stanković from the Faculty of Mechanical Engineering in Belgrade, an outstanding person who established production engineering on the territory of the former SFRY and has remained an important name in mechanical engineering in general in this region. The Conference is biennial so that is the reason why it is now the 35th one. The nominal organizer of the Conference is the Executive Board of the Association of Scientific and Research Institutions of Production Engineering of Serbia. Two years ago that task, in operational sense, was, for the second time, entrusted to the Faculty of Mechanical and Civil Engineering in Kraljevo, i.e. its Department of Production Technologies.

We are aware of the fact that the authors of papers from abroad have covered a long way to take part in this Conference, so we express our sincere gratitude for their respect to this gathering. The domestic authors have coped with different problems, but they have obviously overcome them successfully so, appreciating their efforts, we would like to thank them.

The Conference could be organized without the financial and moral support of the Ministry of Education, Science and Technological Development, the Ministry of Natural Resources, Mining and Spatial Planning and the Ministry of Economy, but it is of great importance that all the three ministries have shown significant understanding for the content of the Conference, the Round Table and presentation of companies from this region and from abroad (exhibition).

We extremely appreciate the help provided by the companies from our region and from abroad. The unselfish support was also given by:

– The Mayor of Kraljevo, Dragan Jovanović,
– The President of the Regional Chamber of Commerce in Kraljevo, Petrašin Jakovljević,
– The Vice-President of the Serbian Chamber of Commerce, Vidosava Džagić.

The Conference is held in the Congress Centre of the tourist complex “Konaci”. The congress hall with its 600 seats and all necessary facilities is available for the Conference. The Holiday Club with 140 seats, the President Hall with 45 seats, the Malo Jezero (Small Lake) Hall with 90 seats and the VIP Hall for a small number of participants will be used for parallel sessions.

At this 35th ICPE, we expect presentations of over 80 papers, out of them 15 from abroad. Such gatherings are a nice challenge, but also an opportunity for industrial companies to introduce themselves to the scientific and research public. The papers are divided into 18 sessions.

The next Conference is to be organized to mark the 50th anniversary from establishment of the Association of Scientific and Research Institutions of Production Engineering of Yugoslavia. No matter how much the governmental, political and other influences divide us, our economy is the one that should inevitably establish contacts and be an important factor in encouraging the renewal of the Association. Big success and a step toward increasing the significance of the Conference would be accomplished if all the members of the former Association from the territory of the former SFRY would gather together on that occasion and accept its common organization in the future.

The Organizing Committee of the 35th International Conference on Production Engineering in Serbia has made great effort to provide all participants with pleasant memories from their stay on Kopaonik so that they could gladly join us at our next Conference. However, the main contribution is given by you, the authors and coauthors of papers, by deciding to present your valuable scientific and research results which should help the revitalization of our industry.

Looking forward to meeting you again in two years, we remain

Yours sincerely,

Prof. Dr Miomir Vukićević

CONFERENCE TOPICS

Manufacturing engineering – new technologies and globalisation of engineering

Product development – product design

Machining technologies

Forming and shaping technologies

Nonconventional technologies (Advanced machining technologies)

Joining and casting technologies

Processing of nonmetal materials (plastic, wood, ceramics, ...)

Assembly and packaging technologies

Surface engineering and nanotechnologies

Tribology

Eco technologies and ecological systems

Automatisation, robotisation and mechatronics

Metrology, quality systems and quality management

Production system management

Revitalisation, reengineering and maintenance of manufacturing systems

CAx technologies (CAD/CAM/CAPP/CAE systems) and CIM systems

Rapid prototyping and reverse engineering

IT and artificial intelligence in manufacturing engineering

Education in the field of manufacturing engineering

Engineering ethics

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35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
Faculty of Mechanical and Civil Engineering in Kraljevo

FACTORIES FOR THE FUTURE – A MENTAL LABYRINTH OF COGNITIVE REVOLUTION

Vladimir R. MILAČIĆ

The world of today is facing the point of no return from the zone of decay. This refers to certain countries, but also to the ever growing number of people on this planet.

Hopelessness is the state of the 'valley of death' of human creations, and groups of people and countries. Here we are referring to the 'valley of death' of industry or its axis, 'the factory', as one of the epicentres of our civilisation. The past is filled with numerous short- and long-term efforts to exit the hopelessness ruled by mental destruction embodied in hunger, epidemics, wars, changes of social systems though revolutions, etc.

In the past two centuries, it was believed that capitalism and industrial revolution were 'the doors' to exit that hopelessness by creating an environment conducive to the growth of individuals and nations with different social organisation.

The new, twenty-first century began with a deeper uncovering of the cause of human hopelessness as certain 'buildings' of civilisation's construction which represented countries or certain zones on our planet started to collapse before people's eyes.

The intention is not to assume a sociological cleanse of the future with prosperity potential and without hopelessness, but to attempt and propose the type of scaffolding construction to use and build a bridge between the banks of the 'valley of death' and cross from hopelessness to prosperity. This scaffolding, and later the bridge, is to be built by small and poor nations which will thus become big and wealthy.

It should be pointed out from the start that the seemingly paradoxical comparison used here looks at the constructive mental infrastructure found in the territory of Serbia and the USA. Starting from the premise that we are all on the boat sailing in the seas of hopelessness, these two countries, each on its own level of historical development and existence, have entered, each its own way, the state of hopelessness, which is characterised by two modern-day parameters: discontinuation and decrease in generating wealth and high rate of unemployment. Both parameters are scaffolding project parameters for construction of the bridge across the 'valley of death'.

Common 'ideological-mental' platform within each of these two environments (Serbia and the USA) at present is the conflict between 'making – producing and spending – renting'.

However, before we set out to build the school for our 'bridge', a necessary precondition is to reach the optimal biological brain level in its cognitive and technological environment, or more broadly defined (Clark, 2003): 'The role of the brain is crucial and special, but that is not the whole story. In fact, the true power and beauty of the brain lies in its function as a mediating factor in a wide variety of complex and interactive processes, which continually build the connection between the brain, the body and the technological environment, and as a greater system, they solve problems'. The scaffold of thinking and reasoning is comprised of many elements that it emerges from.

To explain the above quoted thoughts on strategic exodus from the current crisis we then use an example from nature highlighted by Clark (2003). This example refers to the mangrove forest in the Thousand Islands archipelago, near Key West (Everglades).

This marshy area is the home to islands 'built' by the mangrove trees. The process of creation that took place here went as follows: Mangrove plants emerge from the floating seedlings which grow complex vertical roots into the water looking for shallow marshland mud. The first result of this process is what appears as a 'crutch' in the water. However, very soon, the growing roots start gathering dirt and waste floating in the water and that is how they become small islands. Sometimes several small islands merge and form a coastline. In this marshland we would expect that trees needed soil to grow. Here, the largest portion of visible land is built by trees. First came the trees, and then the land followed.

Clark (2003) connects this with human cognition as a moving target through the following: 'Our words and inspiration are the swimming roots that actively catch the cognitive pieces which we use to construct new thoughts and ideas.'

This example of finding a way out of a seemingly unpromising situation could be associated with the example of constructing a cognitive map for the defence of Moscow in World War II and Marshal Zhukov, who is often credited with the plan. The initial state of defence was characterised by scattered defence points isolated from one another with no connection whatsoever. Marshal Zhukov went from point to point and, speaking to the commanders, through a cognitive process for defence, he started connecting them mentally into an integrated chain of command to form a line of defence (coastline contours of our islands in the previous example!).

Using the perspective of these two examples we will try to explain how to promote cognitive revolution at the core of which is the new industry whose epicentre is manufacturing.

The first case study on this topic is about the USA – Made in the USA (Foroohar & Satorito, 2013). This analytical piece claims that manufacturing was brought back to the USA and thereby jobs as well. It also states that 500,000 new jobs were created over the last three years in manufacturing[1]. In the USA, manufacturing employs 12 million people or around 9% of the workforce, while in 1979 that figure was 19.6 million[2]. In 2011, people working in manufacturing in the USA had an average wage of $77.060 compared to $60.169 with all other industry workers. These data pinpoint the 'exclusivity' of manufacturing jobs. Every dollar invested in manufacturing activities has a return of $1.48 in economics. In modern times, the path of emergence of manufacture workers from their training to handling machines has changed. Earlier, that worker was a manufacturer on the assembly line, making $2.57 an hour in 1960, while today they make $24.11. This worker was employed in the car, electronics and textile industry. Today's worker handles an automated production line in a factory. 53% of them have college education, while 1 in 10 has a degree or professional education. Nowadays the leading industries are food, chemicals, and complex machines production. Manufacturing renaissance should allow for high added value, not a large number of jobs.

America is slowly abandoning the offshore concept of production and industry and they are introducing the new 'inshore' concept, thereby also changing the concept of the factory. The number of workers at the production facility itself is decreasing, and there is an increase in the number of workers in logistics, design, marketing, R&D, etc. Manufacture engineering takes up 67% of R&D in the private sector, which secures a 30% productivity rise in the USA. If there is no production, there can be no innovation. This is the axiom of today. The main generator of innovation processes are factories of the future – factories to come!

However, before we discuss those factories, let us look at Serbia as a large area of 'industrial swamp'. The process of creating this swamp has been spread over the last thirty years. That is how in the 1970s in Serbia there were around 1 million industrial workers, in 2001 that number was 604,054, while in 2012 the number dropped to 289,286.

The minimum wage in Serbia is 115 dinars, while in China the minimum wage of $0.50 in 2000 (app. 40 dinars) is to rise to $4.5 by 2015 (380 dinars at current exchange rate). Our worker today gets $1.35 an hour, whereas on the employer's side that cost is 459 dinars. On the other hand, it takes only 13 hours for a miner in Norway to make a Serbian salary of €289 earned over 185 hours. In Croatia, a worker earns this Serbian salary in 77 hours (Spasic, 2013).

Sociologist R. Bozovic warns that 'the Serbian worker will never see any improvement because the Serbian working class went to hell instead of heaven a long time ago.'

The explanation for this pessimism can be illustrated by the pictures published in daily paper Politika on Labour Day 2013. The first picture of Labour Day in 1947 shows confectioners parading with cakes in their hands. The following Labour Day in 1948 - there is a large shoe in the picture symbolising manufacture, but it is at the same time the announcement of the change in the mental image of Serbia, and so on Labour Day in 1951, in Belgrade's main square Terazije, there is a 'parade' of Serbian made tractors. That process of creating a new mental image of manufacture catches on with a vast number of people in Serbia and former Yugoslavia, and a reporter of Politika writes in 1963: 'The atmosphere is festive, streets are filled with flowers, flags and crowds that gathered early in the morning blocking the approach to Revolution Boulevard so they could see the magnificent parade.'

In this Labour Day edition of Politika, journalist G. Volf describes the industrial complex in Rakovica saying: 'The workers are not causing any trouble to anyone anymore; they're not making any helicopters, motors and refrigerators either – because there aren't any workers.'

Rakovica Municipality has a population of 108,143, 28, 79% of whom are unemployed and it has 4% of manufacture companies. Within the last twenty years, 1988-2012, Motor Industry Rakovica (IMR) made 56,000 motors and 7,000 tractors at the beginning of that period only to see a fall in production which went as low as 5,500 motors and 1,200 tractors. Another big factory shares a similar destiny. 21 May Rakovica (DMB) used to make 182,000 motors, while it has not made a single one this year.

Other big production companies in Belgrade such as IMT – Industry of Machines and Tractors, FOB – Mould Factory Belgrade, Zmaj – Agricultural Machine Factory, IKARBUS and others also met this or similar destiny.

Today, Fiat's factory in Kragujevac is talked of as the new 'miracle' as it produces 500 finished Fiat 500L cars a day with a current capacity of 30 vehicles an hour, which makes for an annual production of 200,000 vehicles. There are 330 robots installed and 2,500 workers whose training has so far been an investment of over a million hours (Danas, 2013).

Although Fiat cars are actually an Italian product, and, as one worker from Rakovica commented, 'only the tyre air in those cars is Serbian', this good example of car industry is used by politicians to glorify the above listed data claiming that Serbian industry is leaving the 'valley of death'. How, we ask, with only 2,500 employees! There used to be Zastava Automotive with a production of nearly 300,000 in the 1980s. Part of this story is the export of FIAT cars to America skipping the fact that FIAT is one of the owners of the American Chrysler, America's third car manufacturer.

The digested overview above is intended to point out that a 'seed' for the birth and growth of a new technological tree has been sown in the soil of former technological space, which, for a long time, was being turned into a 'technological slough'.

Nowadays we speak of reindustrialisation in Serbia as a new strategic direction without the essential understanding of the fact that the technological mind map is in a condition worse than the Soviet army at Moscow back in the day. Entire industrial centres across Serbia, like those in Belgrade, Kikinda, Nis, Kraljevo, Krusevac, Leskovac, Cacak, Uzice,

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1 In Serbia, not so long ago, certain so-called "experts" with political background claimed that 300,000 new jobs would be created in Serbia over a short period. How naive!

2 In those years Serbia had around 1,000,000 industry workers, while in 2012 that number dropped to just over 300,000

Valjevo, etc. have actually been destroyed. However, all those cities still have the mental substance of genetic and technological content to serve as a 'seed' used as a base for creation of new industry in Serbia. But we cannot simply design and realise that because the top of the local ambience does not accept the necessity of development of a mindset as mental infrastructure for long-term construction of the cognitive industry road as a joint platform for creation of mental tissue in people for manufacturing which allows consumption.

Following are some examples listed to illustrate construction of the new generation of factories of the future.

The first example looks at General Electric's (GE) battery factory worth $170 million (Time, 2013). This company has 200 years of experience. They produce large batteries for charging mobile telephone network transmitters. These are Durathron sodium batteries which take three weeks to manufacture. The production process takes place as follows: the starting chemical raw material is powder which is mixed and in the shape of a pipe placed in carts (600 pieces) which are taken to the furnace (six carts at a time) where they become hardened ceramic pipes. Afterwards, they are cooled outside the furnace, and from there the carts travel to the packing station where they are placed in plastic containers. The whole production process consisting of four operations is controlled by a manufacturing engineer using his iPAD which monitors over 10,000 sensors at the factory. The engineer receives information such as time and temperature in real time so that potential failures could be detected in time. Metal and chemical components come in second. Casings are added to the chemical assembly turning them into battery cells. Battery cells made in this way are initially charged and emptied prior to delivery.

This factory of highly sophisticated design spreading over 18,000 square feet employs 370 full-time workers, 210 of which work in the plant. The factory manager uses iPAD and sensors to allow the batteries to communicate with GE over the Internet even when they leave the factory. The Internet communication with the product is maintained throughout its life. This is not paid work but high technology. That is how there are fewer battery plant workers but the company has started a global research centre, which should soon hire 400 highly paid software engineers, data analysts and designers. They are to develop the Industrial Internet which requires another 200 employees.

If this 'ideological platform' is compared to the former approach in Serbia, we can find certain similarities. Machine and tool industry in Serbia and former Yugoslavia can be used as an example. In the early 1980s, our country was listed between the 12th and 14th places on the global list of machine tool manufacturers. Factories had their own designers and technological units, most of which had foreign licences for their products. Moreover, the Institute for Machine Tools and Tooling was founded in Belgrade and a similar one in Zagreb. Today there is no production or scientific and professional infrastructure, that is, no creative and innovative mental potential as a precondition for industrial development.

Another example looks at choosing locations for building factories. As in the example of islands emerging in marshlands, it is useful to mention the emergence of powerful companies which started off in garages. Similarly, the present-day industry generator in America has a new form. An often used example of the concentration of engineering power is Carnegie-Mellon University near the former steel mills in Pittsburgh, where American power was built in the twentieth century. This university was home and an incubator for companies that developed special metals, robotics, and bioengineering as a foundation for creation and manufacturing. That is how fast tool and product prototyping technology was developed. This was called additive manufacturing and today it is known as 3D printing. Namely, by applying stainless steel powder or ceramic material with liquid, a piece is formed in the desired way. A 3D production line costs $400,000. It produces parts and products of very complex shape, which saves several days in the process between the designer and realisation of a product conceived or redesigned in that way.

There are six steps from powder to complex product. Digital design of the piece on a computer is the first. Then the program is transferred to a 3D printer, which repeats the application of these layers of powder, the printer head releases the hold keeping the materials together and the product goes through a furnace before it is finalised, and the piece can be used in power, automotive or any other industry.

The University of Belgrade developed industry in its surroundings that was created by the former students using the knowledge from that university. At the same time, the collapse of the University meant the collapse of the industrial complex in Belgrade and Serbia. Nis had built electronic industry and the University of Nis emerged to serve its needs. Even more directly, the Faculty of Electronic Engineering was opened at that university.

From a former giant, EI Nis dwindled to pauper (Todorovic, 2013). In the decades following World War II, EI Nis became a giant and had about forty factories and companies manufacturing 'cutting edge electronic and microelectronic machines', such as TV sets, radios, VCRs and music players, telephones, cutting edge military optical equipment, semi-conductors, household appliances, power meters, x-ray machines and other medical equipment and tools. It had a research, development and design centre.

This program was joint with programs of leading European companies, like Siemens. Even the author of these lines tried in the 1970s to negotiate cooperation with an American factory. EI Nis also established cooperation with the electronic industry R. Cajavec from Banja Luka.

At that time, this giant had 27,000 employees, and today, in 2013, 168, who cost the administration about thirty millions, but it is still there. The parking area for employees at that time had 2000 cars. Today, this is an empty space occasionally used to store waste.

The technological culture and mental-technological capacity of EI have disappeared! And this struck the entire territory of the Republic of Serbia.

Industry, its role and perspective are a regular item on the EU policy discussions agenda. A document on strengthening European industry in order to facilitate economic growth and revival (Rifkin, 2011) highlights the poor situation stating that manufacturing in Europe decreased by 10% and that 3 million industrial workers have lost their jobs. That is why Europe must change its industrial policy and the following priority lines of action are often stressed:

- new production technologies,
- key future technologies,
- bio products,
- sustainable industrial and construction policies, including new materials,
- clean vehicles, and
- smart networks.

The importance of industry is supported by the fact that 100 new jobs in industry create between 60 and 200 indirectly related jobs in one economy. Also, the current level of 16% share of industry in GDP should rise to 20% by 2020 in order for a 'strong industry to be the base for wealth and economic prosperity of Europe.'

The pillars for strengthening industrial policies according to the above mentioned document are investment and innovation, better market conditions, access to capital, and human capital and skills.

It is said that we are amidst the Third Industrial Revolution (Rifkin, 2011), which is focused on new energy, information, production technologies. The market demands new products made by new technologies which revolutionise engineering through, for instance, intelligent machines and goods manufacture type. 3D printing is also mentioned here (explained above through 'box factory' in the USA) alongside new market base through smart networks, clean vehicles and bioplastics.

The European labour map consists of 75% workers who are employed through 17.6 million new jobs. This is considered very ambitious considering the current rate of unemployment in Europe. This especially refers to the younger population.

When the numerous elements which are to be the building blocks for the scaffolding and setting the general direction of the Factory of the Future are presented in such fragments, it should be pointed out what qualitative jump is made in defining the mental infrastructure of the factory itself.

Nowadays, the scaffolding for factory construction has the following mental infrastructure:

- little new knowledge – ample existing knowledge;
- little new experience – ample existing experience.

The new generation factories (factories of the future) have an altered mental infrastructure:

- ample new knowledge – little existing knowledge;
- little new experience – ample existing experience.

These two postulates on factories seem to build a bridge between the view of the past and view into the future emphasising the need for the following sub-domains such as:

- sustainable manufacturing,
- ICT – to enable intelligent manufacturing,
- high performance manufacturing, and
- researching new materials through manufacturing.

For the period 2010-2013, the research budget allocation to Factories of the Future is €1.2 billion. The economic revival plan within the program of public-private sector in the domain of factories of the future refers to the goals formulated as follows (EC DG for Research and Innovation, 2011): 'Apart from the goal to support manufacturing in the EU in various sectors, especially MAS companies, in the manufacturing sector, the initiative for the future should buffer global competition pressure through development and integration of future technologies such as engineering technologies for adaptive machines and industrial processes, ICT, new materials'.

The policies published by research and innovation groups for new forms of manufacturing insist on changing the strategic goal when it comes to competitiveness based on expenses so that there can be a shift to a new doctrine of 'generating high added value'.

Within the research of Framework Programme 7, Europe finances projects in the domain of development technologies for the Factories of the Future through ManuFuture (EFFRA, 2010). Through cooperation and joint effort, European engineers should 'develop new manufacturing technologies which will be applied in aeronautics, automotive industry, consumer electronics, energy production, footwear, medicine, microsystems, optics, and textile industry.' 25 projects were prepared for the first phase (2009-2014) with a budget of €1.2 billion.

Vision of the new industry based on factories for the future revolves around the following two domains:

- information and communication technologies, and
- productivity in the manufacturing areas.

From these two main domains of development, visions are made for the following strategic technological 'islands' of the Factory of the Future:

- 'smart' factories,
- virtual factories,
- adaptive equipment manufacture, and
- high precision manufacturing.

Each of these strategic technological links in the first stage (2009-2014) of emergence was placed in groups of research and development projects which are introduced as public-private partnership, or translated to our situation, government-private partnership.

The mentioned strategic areas are based on available knowledge and applied technologies, and from that spring new forms of manufacturing and generating wealth and happiness. The common denominator of these activity programs is expansion and the new development potential of humans together with the environment and the machine (the basic artefact) and its newly emerged developmental capacity for manufacturing the construction elements for the development scaffolding of humans and their communities – polity.

These two factors for further prosperity of each community start from expanding continual or periodical achievement of the mental-physical capacity and the ever stronger symbiosis of man and machine.

Simply looking at the development of humans and their mental capacity in combination with the body and the environment, it can be concluded that it takes place in cycles of varying length where they master knowledge and its application in everyday life. However, the foundation for this was nature (environment) and human mental capacity with the ability to develop. Let us take the example of development of human understanding of stone in nature. Stone was part of some rock that simply lay somewhere in nature as still mass. However, people discovered that when they pick it up and throw it, they can obtain game as food. Einstein adapted this dynamic property of stone into a formula of mass and speed. But humans were already able to build flying crafts made of natural materials and to use energy and transfer the power of its hands onto machines. That is how in the tens of thousands of years they came to insights such as the rocket, which functions according to the principle of the first thrown stone, while today we even have physical communication with remote parts of the world and our planet's surroundings.

A similar thing happened to our factory which emerges through connecting energy generating machines (steam engine) with manufacturing machines (machine tools). Humans need a third machine which is closer to the world of its mind, and that is computer. Man's communicative capacity developed through car manufacturing (machine that changed the world) and the information web.

In the meantime, a new technological creation called robot appeared (the name comes from the word for 'work'), which actually infiltrated human life on a large scale and is slowly changing its very nature.

Smart factories can emerge when a new industrial environment embeds information and communication technologies so that knowledge, man, machine, material and process are integrated. ICT has connected into a network, for instance, the banking system, people in social networks for varied activities, including entertainment, etc. 'Landing' of ICT in factories, its input and materialised output elements together will form integrated manufacturing through digitalisation of the work process.

Humans with their 'wired' and natural mental structure get a new 'associate' through ICT and machine tools – the robot, with ever so powerful sensory and drive structure which makes it a machine with growing mental capacity and that machine influences the shaping of other manufacturing machines.

Virtual factories are actually the factories that have 'torn down' the walls surrounding the factory for mass production and they virtually entered customised production of various goods via the web network.

Customised production is large-scale but small series or even individual product for a customer. It is particularly important to stress here that this makes manufacturing dependant on the customer - consumer and is made personalised for their use. That is how collaborative systems of manufacturing and exploiting are created together with a new form of industry, called service.

Apart from the ICT industry, another pillar of the concept of the Factory for the Future is adaptive manufacturing equipment. These are primarily intelligent machines with adaptive control systems and industrial robots. The focus is on the development of a hierarchical and adaptive smart component for forming various manufacturing designs.

The centre piece of this group of projects is a machine tool which would raise the level of functionality through, for instance, dynamic stability. In the past, there was intensive activity in the domain of machine tool dynamics. Even back then, steps were made towards adaptive controlling of machine tools. The author himself has dedicated a large portion of his scientific and research work to this problem. However, the new principle is to enter the overall structure of machines with coordinated connective elements to save on materials and energy with this type of machines. Something that testifies to the importance of this work is the fact that around 1 million machine tools have been installed across Europe and that annual production reaches 70,000 units.

Low cost robots of diverse structure and application with increasing component of 'intelligence' are the way to go. High precision manufacturing or 'micron breaking', as they used to call it, falls into a special group of research and development. The central technology here is 3D integration of microsystems from production to assembly. Some of the interesting directions in production are the development of laser printers in nanodimensions, pressure casting, self-learning modular manufacturing platform in medicine, or the platform for production of glass optics.

The structure and contents of the 25 projects of the Framework Programme 7 are presented in a table (Figure 1).

When deciding on the direction of activities in the Factory of the Future, it is useful to emphasise another two possible directions:

- Industrial SME – companies with home research (EC DG for Research and Innovation, 2009a), and
- Transformation of manufacturing tools (EC DG Research and Innovation, 2009b).

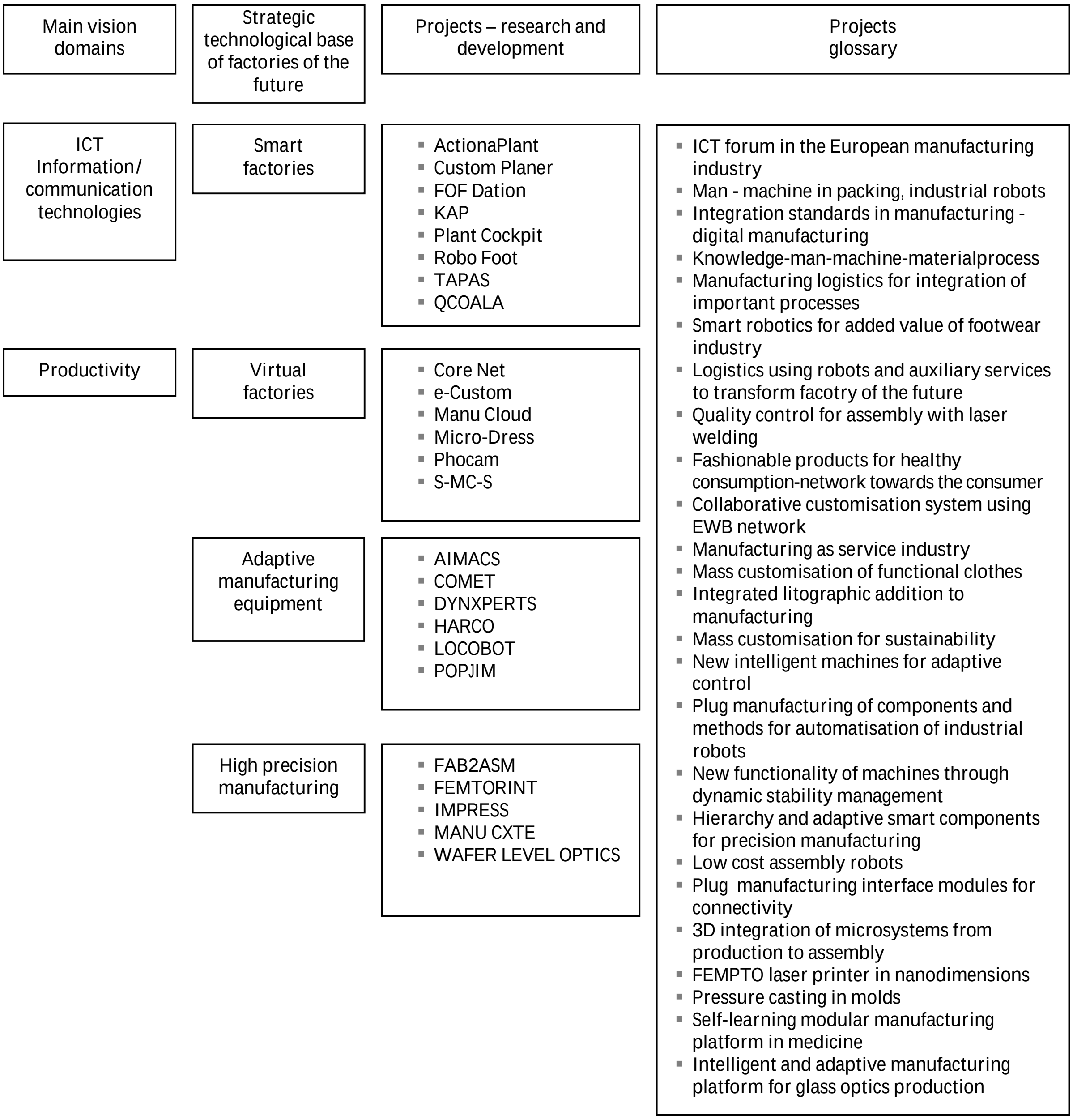

Fig. 1. Structure and contents of 25 projects of the Framework Programme 7

Research in SMEs is vital to the industrial future of Europe. Europe has 20 million private production and servicing units whose employees make up for two thirds EU workers. €2.3 billion were allocated to this research in the Sixth Framework Programme (FP6). Several examples of technological projects are listed:

- Textile SME – Research through innovative network – high added value products – AVALON project – memory materials,
- Engineering materials from biomass – substitute for conventional plastic made of oil and wood – BIOCOM project,
- Rapid prototyping – product customisation – product divided into operations – customer-oriented manufacturing – CUSTOM – FIT project),
- Mould production – Euro Tooling 21,
- Renewable multilayer composites based on textile, leather, and paper – FLEXI FUNBAR – project, and
- Hybrid polymers to replace metals in electromagnetic protection – POLYCOND.

Small and medium enterprises with big company programmes present powerful synergy potential for new industrial development. There is an air of superficiality in Serbian treatment of SM manufactures as they are not connected with large companies, which are the pillars of industrial development. This is practically advocating developmental failure or at least creating a misleading image of development.

Increase in machine tool application or manufacturing machines in general has been initiated through research for the NEXT generation. This was set as part of FP6 programme and left to be analysed in detail later in FP7 programme. This programme is closely connected with MANUFUTURA European technology platform. This project emphasises the need for radical innovative processes from design to manufacturing through adaptation of alternative technologies and new approaches. The following research directions are listed:

- 'green machines' which reduce the adverse effect on the environment,
- autonomous machines according to application,
- introduction of new manufacturing types,
- new business politics for manufacturing and machine application, and
- new contents of training, marketing, and dissemination regarding manufacturing equipment.

Joint force for innovation in microprocessing through LAUNCH MICRO programme which encompasses micromilling, microlaser peeling, wire treatment - electrical discharge and electrochemical treatment.

Special research deals with energy and material saving machines. Mechatronics is replacing mass (weight) of objects. More details follow later.

Processing techniques for ceramics are presented in the MON CERAT project. In Europe alone, this market has an annual growth of 5-7%, and so it reached 1.5 billion in Europe and 2 billion in the USA in 2009.

This list of projects has automated certain quality control inspection under the title DYNAVIS – Dynamically Reconfigurable Quality Control for Manufacturing and Production Processes as well as in mouldless deformation processing project SCULPTOR.

There is an ever wider presence of research and development of reduced size factories called Desktop Factories (DTFS) in Japan or Microfactories in South Korea. And so in the domain of microprocessing we have microlathe (32mm x 25mm x 30.5 mm); micromill (170mm x 170mm x 102mm); micropress (111mm x 66mm x 120 mm); micro hand transfer (200mm in height), etc. All these machines have low energy consumption.

This program was introduced in Germany as well.

The Department for Manufacturing Machine Engineering at the Centre for New Technologies has, from 1970s onward, developed a research system and its industrial engineering application in new fields, such as cybernetics, CAD/CAM/CAE, FTS, quality management, manufacturing system management, NC, robotics, intelligent technological systems, etc.

In the domain of knowledge and skills for design and realisation of the program for Factory of the Future, as suggested by professor Kornel of the Northwestern University and visiting professor of Belgrade University, a Cyber Manufacturing Systems Laboratory – CMSYS is being established and it will work on miniaturisation, mechatronics, and cybernetic technologies.

The manufacturing paradigm is cybernetically distributed manufacturing where 'fabrication' is 'synergetic merging' of information processing (Computing Cloud) and object processing (form of physical object – Hardware Cloud). The picture below shows a simplified overview of the analogy between the PC and the fabricator divided into individual executive systems.

The source document (Ehmann, n.d.) gives a proposal of a strategic framework for the CMSysLab based on the requests which also include miniaturisation. The equipment is cheap, while the manufacturing system itself should be flexible and distributed. The second group of requests refers to products and desired outputs. Requests set out in this fashion are met through a threefold structure:

- distributed manufacturing systems;
- available technologies (mechatronics and communication), and
- fundamental knowledge on manufacturing processes (micro, mechanics, dimensions, and manufacturing).

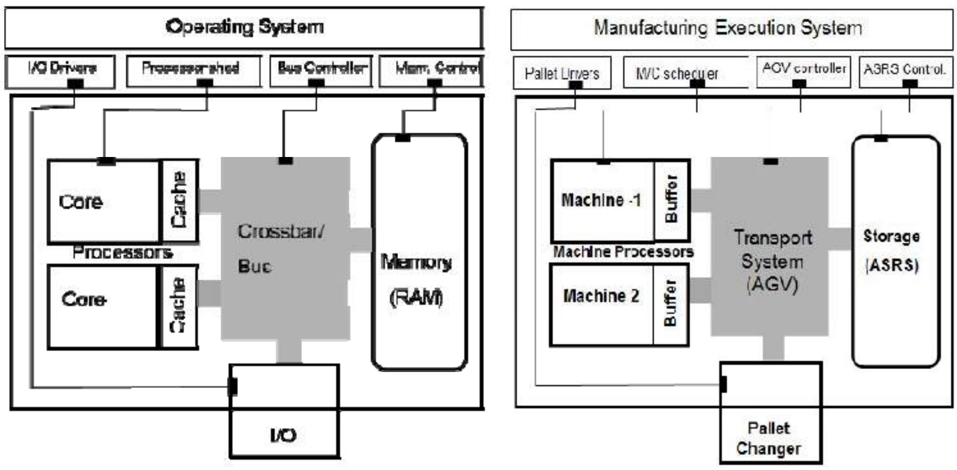

Fig.2. Analogy between a PC and Fabricator with a Manufacturing Execution System, two Manufacturing Processing Units /Machines and Embedded Services.

Connecting scientific, technological, and commercial obstacles, through its diffused activities, a laboratory of this concept should make the Factory of the Future system possible in the new Serbian industry.

European industry insists on high added value manufacturing (Flegel, 2011) based on the following facts: European industry has 33 million directly employed workers, which is 24.2%, while there are 70 million working in related services, which is over 50%. 21 million companies have been founded with the revenue of €7.196 billion, while the added value achieved is €1.670 billion or 27.1%. These are all impressive numbers, but still insufficient for sustainable development of wealth and happiness of European citizens, while Serbia cannot even be mentioned here since it has disintegrated this European concept on its market.
In the coming period, the following sectors will make up over 70%:

- transparent environment,
- electrical and optical devices,
- food and drink production,
- chemicals,
- base metals and manufacturing metal products,
- machines and appliances,
- smart growth – green, increased efficiency of resources and competitive economy, and
- internal development – high employment rate provides social and territorial cohesion.

High added value manufacturing is based on the industry which has reduced pollution machines, efficient resources, and knowledge-based economy. It all boils down to the connection between people and knowledge.
It was pointed out earlier that there is no innovation from idea to commercial realisation without advanced manufacturing which leads to fruitful work. This type of environment is defined by the following units:

- basic research and applied research,
- research and development,
- finance,
- policies and network regulations,
- entrepreneurship,
- skilled workers, and
- functional market.

The European Union allocates 2.0% of its GDP to research and development, while South Korea and Japan allocate around 3.5% of their GDP. Serbia allocates just under 0.3% of its GDP. Moreover, the other stated factors in innovative policies in Serbia deviate from this mainstream and so, as a rule, manufacturing done for foreign companies is low-technology work, production of car transport covers, car cables, cutting out and sowing part of footwear and clothes, etc.
In a word, as a rule, there is no embryo technology for SME units that will ensure timely technological and financial growth.
It is as if in formulating the vision of the future we can still rely on Napoleon's: "There are but two powers in the world, the sword and the mind. In the long run the sword is always beaten by the mind."
In our case the 'sword' is machine and technology, so the new phase of industry for construction of factories of the future is based on intelligent machines, which will be dominated by a robotic platform. Just as the computer industry and especially PCs stormed into all human activities deep and wide in the late 1980s, both in business and in private life, so will the robot be that new machine that will become more and more integrated with humans into one whole.
According to the UN report from 2007, there were 4.1 million household robots, and in 2010 55.5 million personal robots.
The future of industry is like a 'robotic gold mine' in terms of intelligent machines and devices created and controlled by intelligent robots. Man will design and build a new generation of factories surrounded by a newly built work and life environment.
Once again, the crucial question is how to develop the human mind to create and innovate the world they should work and live in, in the near and distant future. In the world of machines, including robots, their replacement can be done nearly instantaneously, while it takes over 10 years to train humans with their mental and physical build to perform work. Human mental infrastructure is the bottleneck for designing and building a new industry and factories of the future in it.
The three main gradients that humans should develop are: quick thinking - to think, working skills - to work, management skills - to manage.
In these three aspects, Serbia is looking at decades of cognitive and industrial platform design before it joins the European mainstream.

REFERENCES

[1] CLARK, A. (2003). Natural-Born Cyborg. OUP, p. 76.
[2] DANAS (2013). Response to high foreign demand for Fiat 500L. Danas, May 6, 2013.
[3] EC DG for Research and Innovation (2009a). Changing the Perspektives for Manufacturing SMEs, Unit 62 “New Generation od Product“. EC DG for Research and Innovation - Industrial Technologies, Brussels.
[4] EC DG for Research and Innovation (2009b). Transforming the Tools of Production, Strategy For a Sustainable European Machine Tools Industry. EC DG for Research and Innovation - Industrial Technologies, Brussels.

[5] EC DG for Research and Innovation (2011). Interim Assessment of the Research PPPs in the European Economic Recovern Plan. EC DG for Research and Innovation - Industrial Technologies, Brussels.
[6] EFFRA – European Factories of the Future Research App. (2010). Developing Techologies for Factories of the Future. Brussels.
[7] EHMANN, K.F. (n.d.). Cyber – Manufacturing Systems Laboratory – CMSysLab. Private communication with P.B. Petrovic and V.R. Milacic.
[8] FLEGEL, H.A. (2011). European Industry in High Added Value Manufacturing – Facts and Challanges. Daimler AG, Wroclaw.
[9] FOROOHAR, R. & SATORITO, B. (2013). Made in the USA. Time, April 22, 2013.
[10] RIFKIN, J. (2011). The Third Industrial Revolution. New York: McMillan.
[11] TODOROVIC, T. (2013). EI - From a Giant To a Pauper. Politika, May 30, 2013, p. 17.
[12] VLADIMIR SPASIC, V. (2013). We have the lowest pay in Europe. Kurir, April 30 –May 2, 2013, p. 11.

35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
Faculty of Mechanical and Civil Engineering in Kraljevo

THE IMPACT OF ROMANIA'S ADMITANCE INTO EUROPEAN UNION ON ITS ECONOMIC PERFORMANCE. PRODUCTIVITY IMPAIRMENT OF PRODUCTION FACTORS

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Abstract: *The first part of the paper examines the huge gap between estimated and actual benefits of European Union widening. Dysfunctions of European widening are analyzed and judged based on official data from Eurostat on population, Gross Domestic Product (GDP) and resources efficiency.*
The second part shows the situation of Romanian industry sectors equipped with high technology and robotics, which benefited of a positive production capacity development, with a focus on human resources issues related to possibilities of graduates from higher education (technical) to get employed in productive enterprises.

Key words: *dysfunctions, niche, market, robotisation*

1. INTRODUCTION. EXTENSION OF THE EUROPEAN UNION

As known, the extension of the European Union (EU) during the last decade by including ten countries of the former communist area and former Yugoslavia (EU10) started under the sign of generalized optimism. But over time, this optimism has diminished as politicians, experts and the public found huge gap between expected and actual benefits of EU expansion. From this perspective, the text presented below aims to highlight the main negative effects and dysfunctions emerging from the EU enlargement in the past decade.

2. EMERGING NEGATIVE EFFECTS AND DYSFUNCTIONS EMERGE

Analyzing the data in the table 1, one can see that people living in the EU 10 decreased between 2005 - 2011, both in number and percentage/share of people of the EU27. Thus, during that period the population of EU10 decreased by 677 631 people (-0.66%) and the share of these countries in the EU27 population decreased by 0.6% (20.84% versus 20.24 %). Population decline in the EU 10 in the period after accession is therefore the most important negative effect of EU enlargement emerging in 2005 - 2007.
On the other hand, the data indicate for the same period a growth in real GDP (Gross Domestic Product) of EU10 by 19.81% and by 5,24% in EU17. Obviously, this positive gap between indicators of GDP growth is a positive effect of EU enlargement. However, this effect should not be overated as 60% of GDP in the period 2005-2011 in the EU10 is due to Poland and the negative gap in terms of real terms GDP per capita between states EU10 and other EU countries (EU17) has not decreased significantly over the period (table 2).

Table 1

	2005		2011	
	Population	**GDP (Billion euro)**	**Population**	**GDP (Billion euro)**
EU27	491 134 938	11 092,813	502 369 201	11 769,233
UE17	388 761 720	10 439, 642	400 673 614	10 986, 677
EU10	102 373 218	653,171	101 695 587	782,556
Bulgaria	7 761 049	23,256	7 369 431	27,059
Czech Rep.	10 220 577	104,629	10 486 731	121,614
Estonia	1 347 510	11,182	1 340 194	12,194
Latvia	2 306 434	12,928	2 074 605	13,095
Lithuania	3 425 324	20,969	3 052 588	23,378
Hungary	10 097 549	88,765	9 985 722	89,436
Poland	38 173 835	244,420	38 529 866	321,606
Romania	21 658 528	79,802	21 413 815	92,693
Slovakia	5 384 822	38,489	5 392 446	49,912
Slovenia	1 997 590	28,731	2 050 189	31,569

In this context, we can ask: What determined the emerging negative effects outlined above? Obviously, identifying the main dysfunctions generating demographic decline and economic growth below expectations involve a systematic and laborious analysis of the specific economic situation of EU. On the other hand, in such cases the relationship between causes and effects usually involve a Pareto distribution, meaning that the long-term effects are generated emerging ultimately by very few malfunctions or strategic factors impact.

The case study presented below confirms this paradigm. The dynamic indicator resource productivity (calculated as a ratio of gross domestic product in constant prices and material consumption at the macroeconomic level) presented in table 3 indicates very clearly the nature of the main specific dysfunctions emerging to the majority of EU 10: mainly extensive typology of growth based on unsustainable multiplication of economic activities involving unskilled and costly consumption of material resources.

Indeed, from the previous analysis it is obvious that the demographic decline and economic growth mainly specific to the majority of EU10 in 2005 - 2011 was determined mostly by the extremely low productivity of material resources consumed at the macroeconomic level. Thus, if in 2005 the ratio of resource productivity registered in EU17 and EU10 was 4.15 to 1, in 2011 this ratio became 4.76 to 1. Or, this flagrant disparity between productivity of material resources - an indicator of high informational value as it regards the macroeconomic development - actually reflects an extremely risky polarization of the economies in the EU: an area with a high level economic development (EU17) and an area economically underdeveloped (EU10).

Table 2 *Table 3*

	GDP per capita (euro)		**Resource productivity (euro per kg)**		**Growth Index (%)**
	2005	**2011**	**2005**	**2011**	**2011/2005**
EU 27	22 586	23 427	1,40	1,60	114,28
EU17	26 854	27 421	1,66	2,00	120,48
EU10	6 380	7 695	0,40	0,42	105,00
Bulgaria	2 296	3 672	0,18	0,22	122,22
Czech Rep.	10 237	11 597	0,56	0,69	123,21
Estonia	8 298	9 099	0,39	0,42	107,69
Latvia	5 605	6 312	0,30	0,32	106,67
Lithuania	6 122	7 568	0,51	0,56	109,80
Hungary	8 791	8 956	0,47	0,90	191,49
Poland	6 403	8 347	0,44	0,40	90,91
Romania	3 685	4 329	0,24	0,21	87,50
Slovakia	7 148	9 256	0,51	0,67	131,37
Slovenia	14 383	15 398	0,78	1,07	137,18

In conclusion, enlargement in the period 2005 - 2007 was and continues to be negatively affected by very large gap between the level of economic development of countries in EU17 and EU10 states. From the foregoing statements, it results that this emergent dysfunction is a major risk especially in the case of Bulgaria and Romania, and also of Poland. Under these circumstances, the economic recovery of the EU 10 members requires appropriate policies to increase significantly the level of qualification of the labor force and to reduce the unnecessary consumption of material resources. In other words, long-term improvement of the economic situation of EU27 necessarily implies a significant macroeconomic effectiveness and efficiency of labor and capital. Otherwise, the economic situation of all 27 EU states, especially those in the EU10 is expected to deteriorate in the coming years. Because, at least for now, the EU is not a common functioning market, but a common fractured market.

3. PRODUCTION IN THE CONTEXT OF AUTOMATION AND ROBOTIZATION

Productivity and thus production is intrinsically linked to advanced technologies intertwined with the modern informatics systems (Computer Integrated Manufacturing - CIM, Computer Aided Design - CAD, Computer Manufacturing Planning - CAP, Computer Aided Manufacturing - CAM, Computer Assisted Quality Management by CAQ). The presence of industrial robots (IR) in the automated production processes in the context set is a substantial indicator, which can be characterized in terms of quality as „advanced“/„high“ productivity.

In communist Romania's economy there were very few robotic manufacturing capabilities. For the indigenous, knowledge and experience of implementation were irradiated (starting with the 80’s) from the technical universities to industry, being imposed on the „rules“ of communist planning. At the „Politehnica“ University Timisoara there was an interdisciplinary team[1] for robotics research, that worked (somehow) without a proper administrative center. The manager was Prof.Ph.D. Francisc Kovacs. The team implemented robotic cells in industrial companies, based on research and development contracts involving hard work and enthusiasm of pioneers.

After the fall of communism, a period of increasingly massive closure of domestic production capacity followed and the few existing robots disappeared from Romanian industrial landscape, landscape constantly narrowing its horizon. During 1990-1993/1994 there were no industrial robots operating in Romania…

Attractiveness of the Romanian market and resources, once the accession to Western structures opened, led to entering of investors from large companies in Romania. They brought advanced technologies, so that, slowly, the industrial robots appeared. But until 2002 (inclusive) they are not even in the statistics, reaching the day before of EU accession to only about one hundred. Annual inflow barely reaches the order of tens of units installed even in the first period after accession. The endowment process finally appears in the „enhanced“ statistic data on 2004 as highlighted in international publication World Robotics (editor, International Federation of Robotics / IFR hosted by the VDMA Robotics & Automation-specialized federation in Germany, due to the effort of the Romanian robotics society ROBCON[2]). Table 4 shows the number of robots entered into operation in 2004÷2010, emphasizing an increased rate in annual facilities after accession.

Table 4

Year	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Total units in including:	**18**	**26**	**16**	**51**	**74**	**53**	**70**	**Cca 400**
Linear/Cartesian		*20*	*12*	*13*	*16*	*13*	*27*	
SCARA							*1*	
Articulated		*6*	*4*	*38*	*57*	*40*	*42*	
Other (parallel)					*1*			

The total operational stock of industrial robots in Romania amounted in 2010 about 320. And the cumulative total of those that existed in the Romanian economy since ... 1982 (!) barely exceeded 400 units.

Analysis becomes very interesting when taking into consideration the changes that occurred after the recent financial crisis. Observe the delay of 2009 compared to the previous year. In 2010 figures return almost to the level before the crisis

Table 5

Class	**Application Area**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
000	Unspecified	2	0	5	3	4	4
100	Manipulation	20	12	17	36	17	54
160	Welding and soldering	2	4	5	17	23	7
170	Coatings (paint, etc.)	2			18	8	1
190	Processing			24			
200	Assembly-disassembly					1	3
900	Other/services						1
	Total units	**26**	**16**	**51**	**74**	**53**	**70**

But - as shown in table 4 - what followed was really spectacular: in 2011, with economic contraction throughout EU, the number of existing operational ***IR*** in Romanian industry doubled, the rate of endowment of equipment coming to more than 100%. It is estimated that in early 2012 a number of 807 ***IR*** worked in Romania. That shows that large companies (mostly multinationals) have moved specialized production capabilities in a narrow niche „with technological finesse" in Romania. It did not happen with other ex-communist countries, which exceeded by far the cumulative amount. We assume - based on arguments - that this is due to an optimum (investors standpoint) of the wage offered on the Romanian market and training of „specialized" human resources.

[1] The second author was part of that team
[2] Independent survivor of robotics team of Timișoara (manager, PhD N. Joni, whom we thank for data)

Table 6

Code	Category of eco-nomic activities	2005	2006	2007	2008	2009	2010
A +B	Agriculture & Forestry, Fishing & Hunting						
C	Mining						
D	Manufacturing	**20**	**13**	**21**	**65**	**49**	**61**
	D1.Plastics / Chemicals	*20*	*12*	*12*	*8*	*6*	*14*
	D2. Metal processing		*1*	*7*	*22*	*5*	*7*
	D3. Electrical / electronics						*1*
	D4. Automotive industry			*2*	*33*	*27*	*9*
	D5. Transport/other				*1*	*8*	
E	Construction		**3**	**1**			
	Unspecified	**6**		**29**	**9**	**4**	**9**
	Total units	**26**	**16**	**51**	**74**	**53**	**70**

A statement should be made on how the data on ***IR*** are handled: operating time/life is considered to be (in advanced economies) 10 to 15 years, but in terms of Romania, it is, after findings from the field of 20 years or more. It is also important to show that different situations are implemented in newly installed production capacities (newly purchase or second-hand ***IR***).
Distributions highlighted on areas (only from 2005) applied on the above criteria (presented in table 5 and 6) may indicate the nature of IFR productive units that are installed in Romania.

4. ON HIGH TECHNICAL HUMAN RESOURCES

After the fall of communism there has been an explosion of private higher education institutions especially of the „humanist" type, the number of graduates in this sector increasing exponentially. Along with restricting production capacity, there was a significant setback of the technical education. Furthermore, the more educated from before lost their jobs. Economy and society could not absorb existing and new „coming“, so, especially after the accession occurred an exodus of Romanians in the West, many (except for some areas) rendering work below in skill level. Macro-economic demand for unskilled labor in Romania increased, as previously revealed.
Further on, an analysis is presented, regarding the local level of „Politehnica“ University Timisoara, Timis county area (one of the 41 counties of Romania), which has always been among the most developed areas. At this time, the county is the second economic and dynamic place in respect with the investment rate (as Arges, benefits mainly from the productivity of the plant Dacia/Renault). Bucharest area which "exceeds" county administrative and economic entities do not fall in the same category.
First steps for suitability to market economy were made by our own efforts or/and by means of European funding (Tempus projects are a good example). But by year 2000, Timisoara „Politehnic“ graduates found very hard a job in their competence areas, most of them being hired in services or „pure commercial“ activities. With one exception: electronic profile professionals, especially those in the IT field. With the arrival of high profile companies in the area (Alcatel, Siemens, then Continental are just a few examples, but they emerged domestic profile companies), especially since year 2000 more and more of them were employed even before graduating faculty, especially in the software field. The phenomenon has grown around EU accession and beyond. Real estate (housing) boomed during the last decade and brought to the forefront also the civil constructions, which however, as we know, suffered a sharp downturn after the financial crisis, „pulling“ also the adjacent areas.
Technical/ technology education in the mechanical field did not received a „visible public appeal" so that (compared to the communist period) in the last two decades at the Faculty of Mechanical Engineering has been a decrease in the number of students, 8-9 times and even more (from about 4.000 to 400-500, depending on the academic year)!! A numerical deficit brought a lot of problems as funding in Romanian education is „per-capita" type.
However, in our country, especially after the year 2003/2004, the majority of graduates found employment in many mechanical engineering firms that have opened branches in Timiş County and in the wider area, Banat. Around accession and afterwards almost half of our students worked part-time during years 3 and 4 at such firms: in the mechanical design or high-tech manufacturing. This statement is especially true for students of (our) Mechatronics Department (which changed its name in 2002). The mechatronics profile contained most of the period a mechatronics department itself and one of industrial robots (pre-existing). Very many disciplines of mechanical and electronic border were implemented precisely to the application of such companies. The success of robotics students contributed and made a permanent collaboration of the Department with specialized research institutions and/or education in Germany: Fraunhofer-Institute IPA Stuttgart, University of Dresden. Partly, the production practice of the students is carried out in Germany's top companies. Also projects diploma and doctoral thesis are developed within a Romanian-German joint,

there are teachers exchanges, all of which have led to a polling operation of the section of the ***IR*** in German, over 5 generations of graduates.

Table 6

	Number of students		Losses/generation	
Study year	**Admitted/freshmen**	**Graduates (year) IV/V**	**No. of students**	**%**
2002/2003	81			
2003/2004	95	64		
2004/2005	108	64		
2005/2006	162	56		
2006/2007	130	50	31	38,27%
2007/2008	129	50	45	47,37%
2008/2009	135	59+60[3]	49+102	55,93%
2009/2010	78	72	90	55,56%
2010/2011	89	46	84	64,62%
2011/2012	73	59	70	54,26%
2012/2013	77	29	106	78,52%

The positive trend manifested in human resources specialized in mechatronics and robotics - after a brief rebound from crisis - continued, confirming the finding (contrary to expectations and generated economic trends) to increase the intake of high-tech robotic/automated (into an unique/singular niche) the statistics presented in the previous section.
We believe that the success of these specialists is due to the great training they have acquired during their studies. The negative aspect of large „losing“ numbers are found in the statistical inputs and outputs over the years (according to table 7) - in the same generation - the students of our department can be explained by the socio-economic situation of many students, that lead or leave all studies to earn living, or are put unable to prepare properly, which can be interpreted as an illustration of the requirement manifested in education (and reputation of „heavy section“ for Mechatronics, circulated among engineering students).
In our opinion, there is sufficient summary data for analysis of mutations occurring in the labor market in Romania and EU in the demand for highly qualified mechanical engineers. For lack of space, we summarize the states that the Department of Mechatronics at the Faculty of Mechanical Engineering, „Politehnica“ University Timisoara managed the last decade several specializations of the master who could enroll graduates with various specializations. In most of these specializations the number of students was generally twice higher than planned from the Ministry. This reflects very clearly that the labor market in Romania for mechanical engineers specialized in high technology was very high during this period.
Direct reports from our graduates who were able to engage in foreign companies in Romania unofficially confirmed the existence of a crisis of mechanical engineers at EU level.
Latest information on the unprecedented increase in the number of college freshmen shows that, at least in Timisoara is a revival of mechanical engineering education.

5. CONCLUSIONS

This paper highlights some clear dysfunction of the Romanian economy in recent years. The productivity of production factors decreased compared to year 2000. This paradox - in the context of multinational firms access to capital and advanced technologies has become an extremely important opportunity compared to autarky before 1989 - is due, in our opinion, to several causes. First, there were major disturbances in the privatization of land and state companies. Second, government policies after 1990 in the economy lacked vision and effectiveness. Third, the huge increase of secondary and higher education caused a huge disjunction between labor market needs and skills acquired by numerous high school and university graduates. Then massive migration of labor in the West has led to a shortage unprecedented skilled labor in agriculture, industry and services. All these „perverse“ effects of globalization could be mentioned discriminatory wage policy practiced by multinational companies that have created jobs in Romania, especially after year 2000. And last but not least, of course, tough amputation budgetary measures applied by the Government in the period 2009 - 2012 as a result of obligations to the international financial institutions (International Monetary Fund and World Bank).
The data presented before reflect other contradictory trends in the Romanian economy. On one hand, increased productivity through automation and advanced tech, through a niche-phenomenon (located within a few development/growth poles, for example: Bucharest or Timiș and Argeș counties). On the other hand, increasing the number of jobs requiring low qualifications. For this reason, resource productivity - GDP / kg materials is still small in Romania. Just as in Bulgaria.

[3] Simultaneously graduated series with 4 (entry 2005/6) and 5 years of study (entry 2004/5); following only 4 years series.

From this perspective, a doubling in the medium term of production factors productivity (labor and capital) is a priority requirement for Romania. This necessarily involves both a significant increase in the absorption of EU funds earmarked Romania (absorption unsatisfactory so far) and their proper use, especially further increase the technological level of manufacturing industry and „irradiance“ of robot automation and high level technologies throughout the economy. Which cannot be done without the contribution of education and research, which are unfortunately in a situation of chronic underfunding for many years.

REFERENCES

[1] Eurostat/Statistics, Population;
[2] Eurostat/Statistics, Sustainable consumption and production. | Real GDP growth rate – volume;
[3] International Federation of Robotics/VDMA Robot.&Autom. Germany, World Robotics, ISBN 978-3-8163-0615-3

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THE INDUSTRY OF KRALJEVO AND THE SURROUNDINGS – ITS PAST AND FUTURE

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Abstract: *An industry development overview in Kraljevo and towns along valley of the Zapadna Morava river is described in the work. Social transition provokes strong changes at a mostly industrial surrounding. A radical decrease of industrial production, markets losses, reduction in number of employees and a lot of other breakdowns have come. That is how this area has the present and no industry. What can be done on recovery of industry and development of small and medium enterprises? This work gives no answers, but offers some intellectual challanges..*

1. INTRODUCTION

The early years of the twenty-first century have been marked by the global configuration of civilization [1]. It is a process whose duration is uncertain. It is certain, however, that this process is not based on natural phenomena. Civilizational crisis arose as a result of the conflict of existential interests of human society and, it turned out, the man was unable to resolve them in a peaceful manner. Opposition of the basic elements between money-technology-ideology, whether the reason or outcome, is their basis. The first modern major global crisis, embodied in the Great World War, which next year marks the first century, and later in the thirties, whose resolution began with peaceful means and ended in another great war, first of all led to a redistribution of the world's wealth. Both cataclysm were primitive but the only possible means of resolving the colonial problem of the great powers by which some lost, some increased and some only gained the right to dispose of and manage the natural resources of other countries and peoples. The only natural phenomenon in their understanding is the fact that the most valuable and the most natural resources are possessed by the most densely populated and mainly the poorest nations. It is unnatural, but such planetary distribution is not equivalent to the distribution of financial resources. Hence the owners of financial capital are vitally interested in keeping the owners of natural resources in poverty by making so needed difference in interests as basis of domination. The interests of big capital are indestructible as based on historical experience as well as from the standpoint of the future. Metamorphosis of methods to solve the crisis is always present, and nowadays instead of the world wars, wars of limited territorial, political and time action (from World War II, out of a total about 196 local wars and armed conflicts, the United States explicitly involved in 54 operations), as well as submission based on financial, technological and ideological domination are used. Based on previous experience it is difficult to predict whether the conditions for appearance of a balanced world order will be created in the future. However, the existence of such hopes may not necessarily be based on the ambition of creating of an unipolar world and the corresponding relations on the Planet. Although globally achieved, its presence and influence will be limited or absent at lower levels of organization of social community.

Relations crisis in the former Yugoslavia has grown in several previous decades so in the last decade of the last century, the solution was found in the most primitive form: war, destruction and killing. It is certain that the final outcome could be there in a different way. The other way would probably prevent the realization of the most powerful participants' interests in a money-technology-ideology chain?

In global, interests of the great powers over this area were more manifestational than essential ones. The only value that, from their point of view, should be achieved is contained in population becoming primitive by particulation on a national basis, realized with the war methods of spatially and temporally limited effect. Despite the number of areas that are affected, the main effects are the destruction of the milieu and education system. Large financial capital was poured abroad through foreign banks, the rest is concentrated and distributed among few owners and the ideology of primitivism supported and financed by money of newly created capitalists is created.

What is the future of the local population? Domestic and foreign 'minds' "offer beneficial solutions to the development of agriculture (farming, livestock ...), SMEs, renewable energy and tourism (religious, mountain, country ...). Recipes are reduced to return the exploitation of natural resources at the lowest technological level, which is typical for very culturally backward and uneducated milieu, industrial underdeveloped countries and areas where the most unemployed among the population that is in the most productive years of life.

2. A BRIEF HISTORY OF KRALJEVO

One way of looking at the history of the city of Kraljevo is through changing its name. The first settlement called Rudo Polje appears in 1476. Around 1540, a dual name is used: Rudopolje and Karanovac. King Milan Obrenovic at Karanovac, at the request of citizens, gives it the name Kraljevo on 19 of April, 1882. After the Second World War (1949 -1955) the name Rankovićevo is used and then returned and still kept the Kraljevo name.

Fig.1. A view of the city of Kraljevo in the thirties of XX century

Archaeological finds in Ratina, Kovanluk and Konarevo as well as numerous individual findings in the vicinity of Kraljevo show that this area is always a colony of people. Since the creation of the first Serbian state, this area plays an important role in the economic, social and political life. At the end of 12th century, the monastery Studenica was built, founded by the Grand Zupan Stefan Nemanja, founder of the independent Serbian state and the founder of the Nemanjić dynasty. At the beginning of the thirteenth century the monastery Zica was built, foundation of Stefan Prvovencani (Stefan the First-Crowned) where he was crowned as the first Serbian king in 1217. Since 1219 the monastery Zica was the seat of the autocephalous Serbian Church and the first Serbian archbishop Saint Sava.

With Pozarevacki mir/Pozarevac peace in 1718 and the establishment of the Austro-Turkish border along the Zapadna Morava, Karanovac became a border town that is rapidly evolving. After construction of the church in 1824 the space between Stara Čarsija and Pljakin Šanac becomes the current center of Kraljevo. The first city plan of Karanovac was done by Laza Zuban in 1832. Implementation of the plan began in 1836 when "the three main lanes" were formed. By the end of the nineteenth century, new lanes created a network of streets up to nowadays with retained characteristics of regular intersection starting from the central circular square into the four directions identical with cardinal points. The development of the city was followed by an increase in the number of residents. In 1846 town had 1022 inhabitants and in 1931 reached the number of 7022.

3. INDUSTRIAL HERITAGE OF KRALJEVO

At the Congress of Berlin in 1878 Serbia was recognized as an independent state and four new districts of Nis, Pirot, Vranje and Toplica are gained. Austria-Hungary helped Serbia to gain new territoroies but their attitude was restricted by concluding a special convention. It has imposed the obligation to build the railway line from Belgrade to Vranje and the border with Turkey and Bulgaria for three years.

Two years later, the National Assembly discussed the issue Uzice railway line. The project was supposed to be from Krusevac over Kraljevo, Cacak and Uzice connecting Pomoravlje with southwestern Serbia and further in the direction of Visegrad, with the Bosnian border; the intersection, that is crossing with the main railway line Beograd - Nis would be at Stalac. Convincingly documented rail project was submitted by a group of 67 deputies. There were members who felt that the priority should be given to Kragujevac-Kraljevo - Cacak - Pozega – Ivanjica option. The Stalac – Kraljevo railway line was completed in 1902, the connection to Cacak in 1910 and toward Uzice in 1912.

Before the First World War, the development of rail and road transport (Kraljevo-Raska road, 1886) led to the appearance of the first production and industrial activities. In the town itself, agriculture tools factory was founded, the production of marble products was established, the steam mill and sawmills were opened in Ribnica and Sokolja. On the river Ribnica (near Kraljevo) industrialists Knezevic and Radovanovic erect the first hydroelectric power plant (capacity 58.9 kWh), which fed their mill, and illuminated central square, a few surrounding streets and some jurisdictions and residential buildings.

Industrial development had a direct influence on the urban layout of the city, raising the cultural level, to promote sports (tennis is played), the presence of European fashion and improving of overall social relations. The city was developing dynamically thanks to the arrival of foreign workers and experts to work in state aircraft factory. Thus, crafts and trade small town (2800 people) turned into a modern industrial center. The decision to build a standard gauge railway line from Kragujevac to Kosovska Mitrovica enabled Kraljevo to become an important railway junction and to form a railway workshop. In those years, it was decided that the development of industry for military needs, because of strategic and geographic reasons in the Kingdom of Serbs, Croats and Slovenians, to be carried out within a Belgrade-Sarajevo-Kraljevo triangle. It is believed that this was the reason to choose Kraljevo to locate the State Aircraft Factory.

But it was the circles of no previously acquired industrial experience, no skilled labor and experts of any profiles (either technicians or engineers alone).

Fig. 2. A view of the railway station in the thirties of the XX century

3.1. Wagon Factory

It was built in the period from1922 to1936 as a railway workshop that then grew into a Wagon Factory Kraljevo.
An excellent geographical and communicational position of Kraljevo as an important railway junction, where, from the beginning of the fourth decade of the twentieth century, the railroads connecting Belgrade with Skopje and Nis with Sarajevo and Dubrovnik (North-South and East-West) were crossed, and "strategic reasons" were the decision making factors for the state authorities departments of planning, development and improvement of rail transport to locate the industrial plant of this type right here. Equipment, tools, fixtures and metal structures for its construction were purchased in Germany shortly after the end of the Great War, in the name of war reparations, while the foundations of future factory halls set in 1924. By 1932 the iron structure was assembled and the production facilities were built, while the installation of the equipment delayed due to disconnection of Kraljevo by track of standard gauge until 1929 and therefore was placed in the railway workshop in Nis.

Fig. 3. Wagon Factory in 30's of XX century

The factory complex stretching over an area of about ninety acres, of which eight acres were covered space, so that the wagon factory represented the largest Yugoslav and one of the largest railway workshop in Central Europe.
In 1941 World War Two interrupted the development of the factory, the same year it delivered 10 standard gauge wagons and 100 wagons intended for a narrow track and the factory had 800 employeed with 14 engineers and 10 technicians.

3.2. State Aircraft Factory

In September 1926 in Divlje polje near Kraljevo, building of a military institute for the production and repair of metal structure aircraft begun, where means and equipment received from Germany as war reparations after the First World War are used. In June 1927 a contract with the famous French manufacturer of aircraft, Louis Breguet, was concluded. He was given a new factory with all equipment with his obligation to organize the production of 425, at that time, the famous light bombers and reconnaissance planes of metal structure Breguet 19 and over the next five years to train domestic technical and production personnel to produce independently these aircraft.
The first 75 aircraft is made entirely in France and only the assembly is carried out in Kraljevo, and then share of parts and equipment produced in Yugoslavia is gradually raised, so starting from the third series in 1929 consisted of 125 aircraft is produced entirely in Kraljevo in cooperation with Icarus and other local companies. In this plane was built into many types of series and starlike engines including Hispano, Lorraine and Jupiter engines in the range of 420 to 680 hp. The last batch of 50 aircraft Breguet 19-8, which had new round shape wings, was considered as a reserve and remained unfinished until 1937 when the Icarus inbuilt Wright-Cyclone engines of 778 hp on these planes. Processing was the work of local designers, led by engineer Zrnić.

Fig. 4. Entrance to the state Aircraft Factory (now the entrance to the building of the Faculty for Mechanical and Civil Engineering

Fig. 5. Disposition of complex of State Aircraft Factory

As a part of the modernization of the Air Force, a license for the production of twin-engine bombers Dornier DO-17 was purchased from Germany in 1938, in which, at the request of our experts and military authorities, Gnome-Rhone K-14 engines of 860 hp from the factory in Rakovica being incorporated in.
It was soon clear that the complicate military administrative regulations inhibit the production of the then very modern and complicated bombers, and the output is found in the formation of special government aircraft factory, as an autonomous state-owned company that has operated on the industrial and commercial basis. This plant started to operate in May 1939 and in plants where Breguet types were previously manufactured, the production of an initial batch of 36 DO 17-Kb was organized. The first 16 bombers were ready for delivery in mid 1940 and the entire series was delivered at the end of 1940.

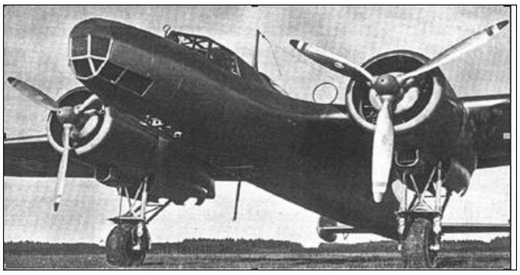

Fig. .6 Breguet 19

Fig. 7. Dornier 17

Weapons and other equipment were not inbuilt at the factory in Kraljevo, but it was subsequently done only after being checked by Dornier's controller. Thus, our planes have better features and equipment than German's. As the production of the second series of 40 DO-17 began, only some assemblies were done at the time of the attack on Yugoslavia. Our army mined the factory in April 1941 and disabled it to produce. The enemy was able to turn the factory into war production to a minimum extent. In October 1941 when partisan units surrounded Kraljevo and when the Germans fearing a mass uprising in the city executed citizens of Kraljevo and its surroundings, when more than 470 workers and employees of an aircraft factory were killed. A meager fleet left after the mining the plant was swiped, and the main installations and facilities severely damaged, so after the war no aircraft production in Kraljevo was renewed.

4. KRALJEVO AFTER WORLD WAR TWO

The Second World War left terrible consequences in Kraljevo. Tremendous loss of the population in war operations increased by firing squad of almost a third of Kraljevo inhabitants as a revenge for German victims made in attempting to liberate a city in 1941 already. The city area was bombed several times, including bombing by the Allies in 1944 (on August 11th and September 2nd). Kraljevo was freed on 29 November, 1944.
Aircraft factory has been destroyed. All the technological equipment from it, as well as from the wagon factory was taken by the Germans. Through war reparations, a part of equipment from the Wagon Factory was returned. The part of Aircraft Factory buildings left over after the demolition functioned as NCO school by mid-eighties of the twentieth century. Having taken over the area, the municipality has two facilities adapted and equipped for the needs of Mechanical Faculty. A positive idea of forming an university campus existed, but is quickly abandoned. This year again, timidly at first and then, after a statement of the current minister, more freely expressed wish to form the university.
An intensive development of Kraljevo industry has been realized in the postwar period that is characterized by three phases:

- Reconstraction of the pre-war industrial enterprises,
- Erection and putting new economic capacities into operations and
- Development of the integration process.

Based on the available data on the status of the area of Chamber of Commerce in Cacak, Table 1 shows that in the post-war years economic and other activities are primarily directed to the population's basic needs such as food and textile products.
Industrial production, expressed through participation of metal products in total production, Table 2, mainly has been based on medium (42%) and small (37%) enterprises. Structurally it is well organized but still does not meet the needs of employment and provides a great social income. We would be well satisfied with such a structure today.

Table 1 The share of products in the retail trade turnover[2].

Type of product	Year			
	1954	1955	1956	1957
Food products	25.7	26.8	37	32.7
Fodder	1.1	1.1	0.6	0.5
Tobacco products	5.8	5.9	6.5	5.9
Textile products	28.9	24.5	21.8	21.7
Leather and rubber	7.2	7.3	6.1	5.9
Metal products	10	11.1	7.5	12.3
Porcelain, glass and ceramics	1.9	1.6	1.7	1.7
Electrical supplies	1.5	1.3	1.5	1.7
Chemical products	3.4	3.7	3.7	3.7
Paper and paper products	2.6	2.7	3	2.5
Wood products	2.8	3.5	3.2	2.7
Liquid fuels and lubricants	1.8	0.9	0.7	1.1
Building Materials	2.7	4.1	2.4	3.4
Other products	4.6	5.5	4.3	4.2
Total	100	100	100	100

Table 2 The number and structure of companies[2].

Type	Big	Medium	Small	Total
Industry	51 (21)	98 (42)	89 (37)	238 (100)
Agriculture	2	38	58	98
Agriculture	0	0	2	2
Building industry	4	19	27	50
Transport	2	15	22	39
Trade	18	39	25	82
Tourism and Catering	1	10	20	31
Crafts	0	4	45	49
Others	0	22	41	83
Total	78 (12)	245 (36)	349 (52)	672 (100)

4.1. Kraljevo until the disintegration of SFRY

In the following period, from World War II, Kraljevo experiencing a dynamic socio-economic development in all areas due, in particular, to an extremely favorable geographical position and developed traffic connections with regional and main traffic arteries, roads and rails.
Major successes have been achieved in the development of the industry. In the field of light industry, food industry and wood processing are developed, so by the beginning of the nineties of the last century two largest complexes existed; Poljoprivredni prehrambeni kombinat Kraljevo and Drvno industrijski kombinat Jasen. The achieved technological knowledge and resources have been used as the basis for the formation of many small companies in the field of milk processing: “Farmad", “Milkop", “Barbi", “Perkom", “Tršo", “Euro milk”, and KTB NS".
Large agricultural plant, in the field of production of cured meat products and the slaughter industry, is replaced by the smaller companies such as: "Kotlenik-promet", “Kim eksport", “San", “Nid"...
The tradition in wood processing is based on the extensive domestic raw material base (more than 70,000 hectares of forest). Heirs of a great and powerful “Jasen” are: “Gir", “Zlatić", “Vuković", "Blažeks", “Eко Studenica", “Ramin", “Tri jele", "Tri omorike", "Đuđa"...[6]
Holders of production programs in the field of metal processing and electrical industry are:: “Amiga", “Radijator-inženjering", "Metal servis", “Jugometal", “Valve profil", “Tehnograd-inženjering”, “Evrotehna"... They are formed on the experience, knowledge and technologies developed in "Magnohrom", "FVK", "Gibnjara" and "Elektron".

During the eighties, business and economic growth continues, which results in an increase in industrial production, Figure 8 and Table 3. Metal industry, in the area of MRZ Kraljevo, participates with 39% and a growth of 19% is expected in the future (for Serbia growth of 8%, and for Yugoslavia growth of 9%).
The values of the index of output growth encourage expectations of the greatest growth in the production of elements of hydraulic and pneumatic systems. The expected large increase in the production of construction machinery is supported by an increase in production of machine parts and equipment. The greatest rate of decline is forecast in manufacturing of freight and special wagons. Based on data on the total income generated during 1989, the economy is dominated by industry, Figure 9, with a share of just over 60%. Trade achieves a share of 22%, agriculture about 7%, and crafts only 0.85%.

Table 3. The planned increase in production of some products in the period 1975÷1980[4].

Product	1975	1980	Index
Springs	16726	24134	144
Construction machinery and equipment	14573	32690	224
Freight and special wagons	37792	25000	66
Dishes and cutlery	7114	9125	128
Conveyors and cranes	4338	4390	131
Plate and iron structures	7358	6920	94
Parts for motor vehicles	5590	14847	266
Tractors	892	1111	125
Parts of machines and devices	2051	5216	254
Connections	632	2300	364
Castings	13000	17500	135
Sanitary facilities	1900	4300	216

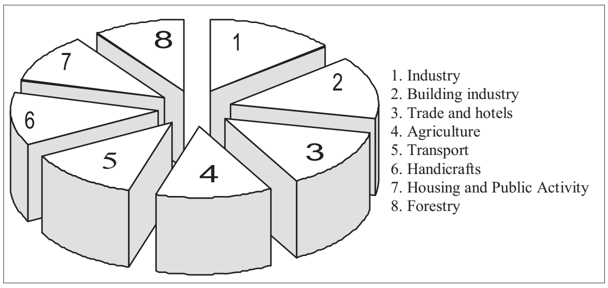

Fig. 8. The economic structure of Kraljevo and surrounding in the period from 1971 to 1975[5]

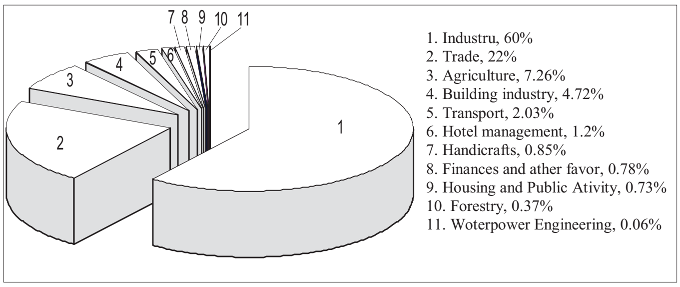

Fig. 9. The economic structure at rhe area of MRZ Kraljevo, 1989[5]

Such proccessed plans of companies represent a good basis for production planning and its development and allow decision making on the establishment of new production programs that should follow the needs of existing ones.

4.2. Kraljevo after the disintegration of SFRY

The importance and the economic power of companies shown in Figure 10 is reflected in the ratio of exports and imports. The largest exporter from the area of the Regional Chamber of Commerce Kraljevo is, in the same time, the largest importer but achieves higher imports than exports. The most favorable balance is expressed by Magnohrom, in which exports almost three times higher than imports (2.78 times), and the worst is expressed by Merima Krusevac in which imports are greater than exports over ten times (time 10.29).

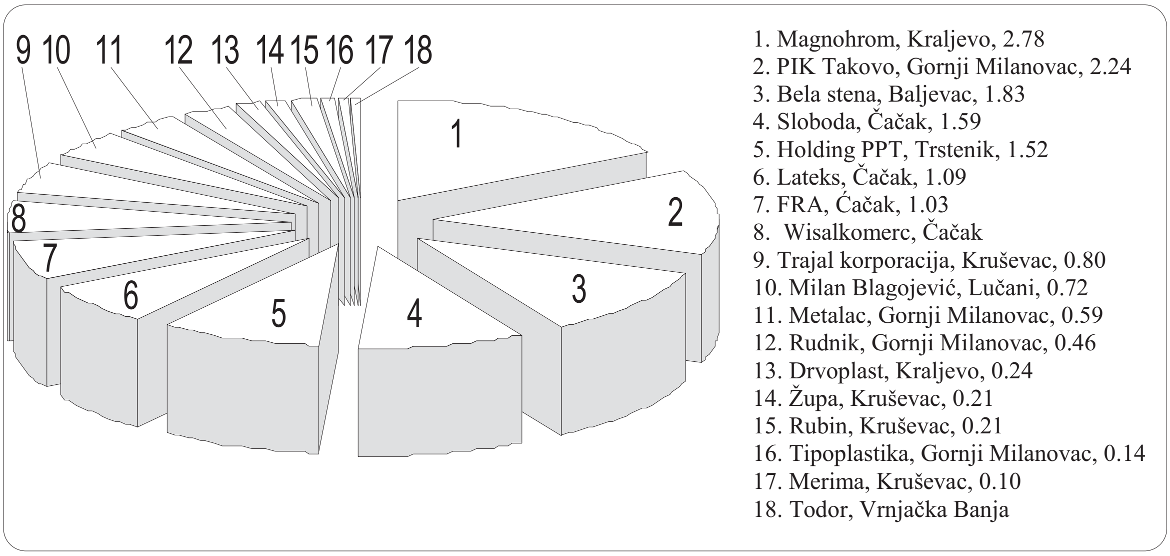

Fig. 10. The relative ratio of exports and imports in the economy of MRZ Kraljevo[3].

5. EPILOGUE

1. Large industrial production systems in Kraljevo and its surroundings are almost no longer exist; Wagon Factory shows the last twitches and is in front of the final shutdown.
2. Industrial capacities in wood proccessing (Jasen), non-metal (Magnohrom), in trade (Trgopromet, Gvožđar, Stoteks, Poljopromet), no longer exist.
3. Small and medium-sized companies do not have the economic strength to meet the needs of utilities, education, health, transport and other vital fields of the area in which they exist.
4. Small and medium-sized companies neither have their own development and research functions, nor can have them, so they do not present a source of professional upgrading and are able to generate new production programs and technological solutions.
5. The so-called greenfield investments are less desirable in the domain of large companies with respect to licenses and mixed forms as contributing to the genocide of the profession and knowledge.
6. Any local community, not only Kraljevo, is not able to lead the development policy in the domain of large companies so, due to the obvious lack of systematic plans and programs and first of all the solution, falls into deeper crisis, that is, economic collapse.
7. University institutions are able to offer development ideas and projects, but if these challenges appear, the local community does not have the necessary economic power which would enable the implementation, and system support is absent or insufficient. It is therefore understandable indifferent attitude of the authorities of the city of Kraljevo and political structures to the only university institution, its needs and future development.
8. If the development of the economic structure had a proportional support such as "Ski Resorts of Serbia", "Fiat", or some other foreign companies, Kraljevo and its surroundings could fight and achieve development opportunity whose rate would certainly not be small.
9. All these data indicate that the Companies use their own knowledge to develop the existing and new products. In doing so, we bear in mind that the use of the license allows upgrading of existing knowledge and experience.
10. Publicly underlined the highest expectations in this area are related to the vicinity of the military airport Lađevci, which in perspective is to grow into a cargo port and Civil Aviation (Airport "Morava"), as well as infrastructure land equipping in its surroundings in order to create the basis for the establishment of industrial zones. Will these expectations become reality, primarily depends on the willingness to engage the own knowledge and work.

6. LITERATURE

1. Milačić, R.V.: "Misterija ekonomskog rasta i propadanja države – doba mega krize", KGI Kompetitivnost (nacije) i globalizacija industrije, knjiga 4, Beograd, 2009
2. Izveštaj o radu Trgovinske komore Čačak, Učešće proizvoda u prometu trgovine na malo, 1958, fascikla br. 1, str. 26, Istorijski arhiv Kraljevo, 1958
3. Izvoz/uvoz privrede Regiona Kraljevo za period I-IX 1997, Regionalna privredna komora Kraljevo, 1997, Istorijski arhiv Kraljevo, 1997
4. Ocena razvojnih mogućnosti privrede regiona Kraljevo u periodu od 1976. do 1980. godine, Regionalna privredna komora Kraljevo, Kraljevo, 1975
5. Rezultati poslovanja pravnih lica iz privrede na bazi godišnjih obračuna za 1989.g, na području Regiona Kraljevo, str. 44, fascikla br. 4, Istorijski arhiv Kraljevo, 1989
6. http://www.kraljevo.org/OPSTINA-KRALJEVO-Industrija
7. Grupa autora Fabrika Vagona, Monografija, 1986
8. Virijević, V.: Kraljevo grad u Srbiji, 2006
9. Filipović, M.: Kraljevski avioni, Kronos, 1995

35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
Faculty of Mechanical and Civil Engineering in Kraljevo

A REVIEW OF RESEARCH, ISSUES AND APPROACHES FOR MOLD DESIGN SOFTWARE DEVELOPMENT

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Abstract: *Injection molding, extrusion and blow molding are the most widespread technologies for plastic products manufacturing, which implies a strong need for mold design automation. In this review paper, authors present the problems and approaches to the development of software for plastic injection mold design. In conclusion, we predict tendencies for the development of program systems for mold design in the future.*

Key words*: KBS, CAIDMS, mold design*

1. INTRODUCTION

Injection molding is a very popular molding process for making plastic parts. Mold design is a knowledge-intensive process. An injection mold design process is composed of two steps: the initial design and the detailed design. The initial design is composed of decisions made at the early stage of the mold design, such as the type of mold configuration, the number of cavities, the type of runner, the type of gate and the type of mold base. The detailed design is composed of the insert (core/cavity) design, the ejection system design, the cooling and venting component design, the assembly analysis and the final drawings.
Nowadays, the development of a computer-aided injection mold design system (CAIMDS) is becoming a focus of research in both industry and academia. CAIDMS must be a total solution for plastic injection molding process and mold design.

2. REVIEW OF DEVELOPED MODULAR MOLD DESIGN SYSTEMS FOR PLASTIC INJECTION MOLDING

Modern CAIDMS are built on a modular principle. The overall system integrates CAx systems for general purpose with specially developed modules (applications). There are a number of KBSs which have been are specially developed on a modular basis and integrated with commercial system Pro/E [4, 8, 10, 11, 13, 14, 19, 20, 21, 24, 25, 26, 29].
Lee et al. [15] have developed expert systems with integrated mold base for mold design, and injection molding process such as IMOLD, ESMOLD, IKMOULD and IKBMOULD. The IMOLD system guides the user through four phases: automated modelling of parting surface, automated core and cavity design, gate design and selection of standard mold elements. Hybrid and collaborative system "IKB-MOULD" contains a knowledge base and data base necessary for the mold manufacturing (CAM). Huang et al. [12] developed a modular mold design system for injection molding for plastic products. The authors conduct decomposition of plastic products in terms of modularity in design (MID), modularity in use (MIU) and modularity in production (MIP).
General mold design process consists of plastic product design and mold design. The plastic product design process requires five major procedures: defining main pulling direction, defining core and cavity, calculating shrinkage, defining draft angle and radii, and parting line. The mold design process mainly includes mold base selection, positioning the molded part on IMM, modelling core and cavity, designing components, designing waterlines, ejector and return pins, gate and runners, adding locating ring and sprue bushing in mold assembly. The modular system consists of five modules: clamping, runner, molding, ejecting module and guiding module. Their study applies modular design to specific injection molds via a five stage process, as follows: (1) product classification and IMM specifications, (2) division of injection molds into modules based on functionality, (3) division of individual modules into multiple units with sub-functions, and the relationship between design and assembly for each unit, (4) standardization of structural units, and (5) coding of standard structural units.
Matin et al. [9, 25, 26] developed a knowledge-based, parametric, modular and feature-based integrated CAD/CAE system for mold design. The system integrates Pro/E with the specially developed module for calculation of injection molding parameters, mold design, and selection of mold elements. The system interface uses parametric and CAD/CAE

feature-based database to streamline the process of design, editing, and reviewing. The developed interactive software system allows: 3D modeling of parts, analysis of part design and simulation model design, numerical simulation of injection molding, and mold design with required calculations. The system allows full control over CAD/CAE feature parameters, which enables convenient and rapid mold modification. The module for numerical simulation of injection molding allows the selection of injection molding parameters. The module for calculation of parameters of injection molding process and mold design calculation and selection improves design faster, reduces mold design errors, and provides geometric and precision information necessary for complete mold design. The knowledge base of the system can be accessed by mold designers through interactive modules so that their own intelligence and experience can also be incorporated into the overall mold design.

Mok et al. [27, 28] and Chan et al. [3] define the general characteristics that modern CAIMDS must possess. First, in the design of the system architecture, it is necessary to analyze what engineers in industry have and what they require from the system. For this purpose, the program system for plastic injection mold design must be taken into account:

- The customer requirements regarding the product and mold. This includes the detailed geometry and dimensions of the product and mold.
- Ensuring the functioning of the system with an existing standard or pre-designed mold base elements and libraries.
- Expert-level knowledge and experience of mold designers in the factory. Expert knowledge of both initial and detailed designs for the injection mold is primarily obtained from the experienced mold designers. Such knowledge includes material selection, shrinkage suggestion, cavity layout suggestion, IMM specifications and other.
- The size of the factory.
- Command hierarchical structure of employees' responsibilities and the previous level of mode of IT communication.
- An intelligent and interactive mold design environment, etc.

Chan et al. [2, 3] investigated the developed commercial software packages and patented technologies related to mold design. The authors conducted a comprehensive literature review in the field of mold design automation and optimization. In addition, they presented knowledge and market gaps found in the field of family mold design.

Few modular systems integrate selection of IMM (Injection Molding Machine). Bozdana et al. [30] developed a frame-based, modular and interactive expert system (called EX-PIMM) for the determination of injection molding parameters of thermoplastic materials.

Based on a review of the feature-based and object-oriented technology, Yin et al. [32] focused on the modelling of intricate relationships among the features of different design aspects. Their research is intended to support the continuous construction of features at various stages of the design process, where features are created by engineers concurrently according to their design patterns and intent from different engineering aspects. The authors classify the features such as conceptual feature (CF), assembly feature (AF), component basic feature (CBF), and component detailed feature (CDF). Similar feature classification could be also applied for the development of CAIMDS.

Several knowledge-based systems were developed to assist plastic material selection and capture injection mold part design features. GERES, FIT, CIMP, HyperQ/Plastic, PLASSEX, EIMPPLAN-1, CADFEED, IKMOULD, KBS of Drexel University and KBS MD from Massachusetts are used for plastic material selection, while, the CAE system developed at the University of Zagreb allows mechanical, thermal, rheological and mechanical calculation for injection molding parameters and mold selection.

However, these KBSs consider only certain aspects of the total design, analyse moldability, automate the mold design process and develop mold design for manufacture. Examples of such systems are IMPARD for simulation model modeling; IMES solved injection molding part-quality problems, etc.

3. APPROACHES FOR BUILDING CAIDMS

Up to date, many design methodologies and systems have been developed. Most of them apply individual AI techniques such as expert systems, neural networks, fuzzy logic, genetic algorithms, case-based reasoning or evolutionary design to generate complete mold design and injection molding process. In general, modular systems for design can be divided into the following types: Convential application, Expert system (Knowledge-based system), CBR system, ANN system, GA system and Hybrid system.

4. KBE TECHNIQUES FOR MOLD DESIGN SYSTEM DEVELOPMENT

KBE techniques for building CAIDMS are: LP-linear programming, NLP- non linear programming, SA-simulated annealing, IR-iterative redesign, PDT-parametric design template, GBA- gradient algorithm, BB - branch and bound, HR-heuristic rules, RBR-rule base reasoning , CBR-case based reasoning, MHS-meta-heuristic search, TS-tabu search, GA-genetic algorithm, SPA-space allocation, AR-analogical reasoning and evolutionary design.

Every technique has particular properties (e.g. ability to learn, explanation of decisions) that make them suited for particular problems and not for others. There is now a growing realization in the modular systems community that many complex problems require hybrid solutions. Hybrid systems combine knowledge based (expert) system, neural network, fuzzy logic, and genetic algorithms to provide hybrid solutions for a wide variety of mold design complex problems.

Hybrid system is an ES (KBS) which integrates some advanced AI tehniques. Fig. 1 presents a KBE tehnique for the development of hybrid system [1, 33].

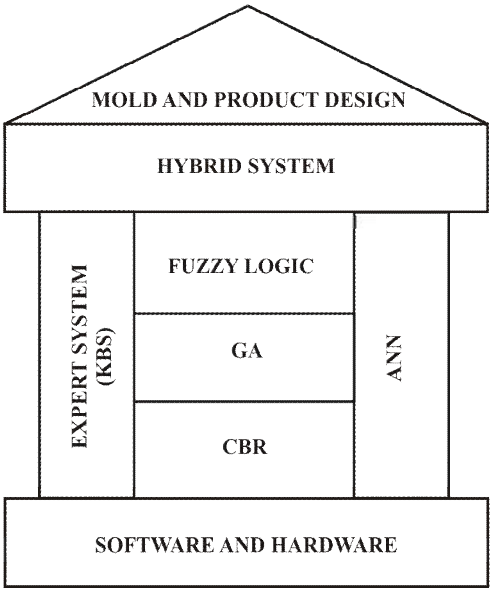

Fig. 1. KBE technique for CAIDMS development

5. COMPARISON OF CAPABILITIES OF VARIOUS COMPUTATIONAL APPROACHES AND TECHNIQUES FOR SUPPORTING MOLD DESIGN

A comparison of capabilities of various computational approaches for supporting automation and optimisation of family mold cavity and runner layout design (FMCRLD) is shown in Table 1.

As is well known, various computational approaches for supporting mold design systems of various authors use design automation techniques such as KBE (RBR, CBR, PDT) or design optimisation techniques such as traditional (NLP, LP, BB, GBA, IR, HR) or metaheuristic search such as (TS, SA, GA) and other special techniques such as (SPA, AR, ED). Market gaps found in the field of mold layout design are shown in Table 2.

From the above review, it can be seen that the authors used different approaches to solve the problems of mold design by reducing it to mold configurator (selector). They used CAD/CAE integration to create precise rules for mold-base selection. Many authors used CAE system for numerical simulation of injection molding to define parameters of injection molding. Several also developed original CAE modules for mold and injection molding process calculation.

From the above review, it can be seen that most of the previous contributions consider only certain aspects of design, while some of them are too theoretical to be applied in practical mold design, which involves a substantial practical knowledge about functions and structure of a mold, human heuristic and empirical type of knowledge. CAIDMS, especially the KBS, has demonstrated great potential in assisting the designer to interact with a CAD system for conceptual and detailed mold design by using engineering rules of thumb with extensive analytical means.

Table 1. Computational approaches for supporting FMCRLD automation and optimisation

Functional requirements and characteristics	Design automation techniques			Design optimisation techniques									Other special techniques		
	KBE			Traditional						MHS					
	RBR	CBR	PDT	NLP	LP	BB	GBA	IR	HR	TS	SA	GA	SPA	AR	ED
Complex combinatorial layout design optimisation	-	-	-	O	O	O	O	O	O	O	O	Y	-	-	Y
Non-repetitive and generative	X	X	X	-	-	-	-	-	-	-	-	-	O	O	Y
Fast generation of multiple feasible mold layout design	X	X	X	-	-	-	-	-	-	-	-	-	X	X	Y
Rapid visualisation and evalution of FMCRLD	Y	Y	Y	-	-	-	-	-	-	-	-	-	X	O	Y
Design explanation	O	O	O	-	-	-	-	-	-	-	-	-	Y	Y	Y
Knowledge capture captability	O	O	O	-	-	-	-	-	-	-	-	-	X	X	O
Knowledge reuse capability	O	O	O	-	-	-	-	-	-	-	-	-	X	X	O
Learning capability	X	O	X	-	-	-	-	-	-	-	-	-	X	X	O
Legend: "Y"-supported, "X"-not supported, "O"-limited support, "-"-not applicable															

Table 2. Comparison of commercial and patented systems for family mold layout design

Mold layout design	Commercial software systems							Patented technologies				
	MCAD	CAE	Mold costing and quotation					software				hardware
Cost estimation	X	-	X	X	X	O	X	O	X	X	-	-
Parting surface design	O	-	-	O	O	O	O	O	-	-	O	-
Optimum cavity design	X	X	X	X	X	X	X	-	-	X	-	-
Optimum gate system design	O	O	-	O	O	O	X	X	-	X	-	-
Cooling layout design	O	O	-	O	O	O	X	O	-	-	-	-
Ejection design	O	-	-	O	O	O		O	-	-	-	-
Mold base selection	O	-	O	O	O	O	O	-	-	-	-	-
Mold material selection	O	-	O	O	O	O	O	-	-	-	-	-
Fill ballancing	-	-	-	-	-	-	-	-	-	-	-	O
Legend: "Y"-support, "X"-not support, "O"-have limitation depend on experienced mold designers, "-"-not applicable												

6. CONCLUSION

According to the CAIDMS literature, modern CAIDMS need to be: modular, collaborative, parametric, associative, feature and object-oriented, integrated with CAx commercial system and standard mold base(s), built on AI technologies, simple for use, possess module for calculation of injection molding parameters, mold design, and selection of mold elements, possess module(s) for mold and plastic material selection and IMM, easy to use and updating DB and KB, compliant with OSI and OSA layers, and EUROMAP and ISO.
Bearing in mind the CAD evolution with respect to modelling capabilities, the future development of KBSs could be focused on generating a functional model and constraint-based model. Furthermore, based on the advancement of various aspects of knowledge application in CAD systems, future KBSs development could focus on generating a distributed knowledge base.

REFERENCES

[1] BRITTON, G.A., TOR, S.B., ZHANG, W.Y. "Techniques in Knowledge-Based Expert Systems for the Design of Engineering Systems," Intelligent Knowledge-Based Systems, Vol.3, pp.745-796, 2005.
[2] CHAN, W.M.,·PINFOLD, M., KWONG, C.K., SZETO, W.H. "A review of research, commercial software packages and patents on family mold layout design automation and optimization," International Journal of Advanced Manufacturing Technology, Vol.57, No.1-4, pp.23-47, 2011.
[3] CHAN, W.M., YAN, L., XIANG, W., CHEOK, BT. "A 3D CAD knowledge-based assisted injection mould design system," International Journal of Advanced Manufacturing Technology, Vol.22, No.5-6, pp.387-395, 2003.
[4] DENG, Y.M., EDWARDS, K.L. "The role of materials identification and selection in engineering design," Materials and Design Vol.28, No.1, pp.131-139, 2007.
[5] FUH, J.Y.H., ZHANG, Y.F., NEE, A.Y.C., FU, M.W. "Computer-aided injection mold design and manufacture," p.375, New York, USA, 2003. ISBN 0-8247-5314-3.
[6] GODEC, D., ŠERCER, M., OSREČKI, G. "Konstruiranje kalupa za injekcijsko prešanje otpresaka s unutrašnjim navojem,"Tehnički vjesnik," Vol.15, No.1, pp.53-62, 2009, ISSN 1330-3651.
[7] GUO, Y., HU, J., PENG, Y. "A CBR system for injection mould design based on ontology: A case study," Computer Aided Design, Vol.44, No.6, pp.496-508, 2012.
[8] HIROKI H., KATSUYA S., YASUO, S. "3-dimensional Injection Molding Simulation," Software Business Department, Toray Industries Inc., Siga, Japan, 2007.
[9] HODOLIC, J., MATIN, I., STEVIC, M., VUKELIC, DJ. "Development of Integrated CAD/CAE System for Mold Design for Plastic Injection Molding," Materiale Plastice, Vol.46, No.3, pp.236-242, 2009.
[10] PARK, H.S., DANG, X.P. "Structural optimization based on CAD/CAE Integration and metamodeling techniques," Computer Aided Design, Vol.42, No.10, pp.889-902, 2010.
[11] HUANG, J.M., JOU, Y.T., ZHANG. L.C., WANG, SH., HUANG, CH.X. "A web-based model for developing a mold base system," Expert System with Application, Vol.36, pp.8356-8367, 2009.
[12] HUANG, M.SH., HSU, M.K. "Modular design applied to beverage-container injection molds," International Journal of Advanced Manufacturing Technology, Vol.53, No.1-4, pp.1-10, 2011.
[13] JONG, W.R., LI, T.CH., SYU, R.Z. "Algorithm for automatic parting surface extension in the mold design navigating process," International Journal of Advanced Manufacturing Technology, Vol.62, No.5-8, pp.421-441, 2012.
[14] JONG, W.R., WU, CH., LIU, H.H, LI, M.Y "A collaborative navigation system for concurrent mould design," International Journal of Advanced Manufacturing Technology, Vol.40, No.3-4, pp.215-225, 2009.
[15] LEE, K.S., LIN, J.C. "Design of the runner and gating system parameters for a multi-cavity injection mould using FEM and neural network," International Journal of Advanced Manufacturing Technology, Vol.27, No.11-12, pp.1089-1096, 2006.

[16] LEE, S.H. “Feature-based non-manifold modeling system to integrate design and analysis of injection molding products,” Journal of Mechanical Science and Technology, Vol.23, pp.1331-1341, 2009.
[17] LI, C.L. “Part segmentation by superquadric fitting-a new approach towards automatic design of cooling system for plastic injection mould,” International Journal of Advanced Manufacturing Technology, Vol.35, No.1-2, pp.102-114, 2007.
[18] LI, C.L., LI, C.G., MOK, A.C.K. “Automatic layout design of plastic injection mould cooling system,” Computer Aided Design, Vol.37, No.7, pp.645-662, 2005.
[19] LIN, B.T., CHAN, CH.K., WANG, J.CH. “A knowledge-based parametric design system for drawing dies,” International Journal of Advanced Manufacturing Technology, Vol.36, pp.671-680, 2007.
[20] LOU, Z., JIANG, H., RUAN, X. “Development of An Integrated knowledge-based system for mold-base Design,” Journal of Material Processing Technology, Vol.150, pp.194-199, 2004.
[21] LOW, M.L.H., LEE, K.S. “Application of standardization for initial design of plastic injection moulds,” International Journal of Production Research, Vol.41, No.10, pp.2301-2324, 2003.
[22] MA, Y.S., BRITTON, G.A., TOR, S.B., JIN, L.Y. “Associative assembly design features: concept, implementation and application,” International Journal of Advanced Manufacturing Technology, Vol.32, No.5-6, pp.434-444, 2007.
[23] MA, Y.S., CHEN, G., THIMM, G. “Paradigm shift: unified and associative feature-based concurrent and collaborative engineering,” Journal of Intelligent Manufacturing, Vol.19, No.6, pp.645-641, 2008.
[24] MA, Y.S., TANG, S.H., CHEN, G. “A Fine-grain and Feature-oriented Product Database for Collaborative Engineering. Collaborative Product Design and Manufacturing Methodologies and Applications, pp.110-136, 2007., ISBN 978-1-84628-801-2.
[25] MATIN, I., HADZISTEVIC, M., HODOLIC, J., VUKELIC, DJ., LUKIC, D. “A CAD/CAE-integrated injection mold design system for plastic products,” International Journal of Advanced Manufacturing Technology, Vol.63, No.5-8, pp.595-607, 2012.
[26] MATIN, I., HADZISTEVIC, M., HODOLIC, J., VUKELIC, DJ. “An interactive CAD/CAE system for mold design,” in Proc. of 34th International conference on production engineering, University of Nis, Faculty of Mechanical Engineering, Nis, 2011.
[27] MOK, C.K., CHIN, K.S., LAN, H. “An internet-based intelligent design system for injection moulds,” Robotics and Computer Integrated Manufacturing, Vol.24, No.1, pp.1-15, 2008.
[28] MOK, H.S., KIM, CH.K., KIM, CH.B. “Automation of Mold designs with the reuse of standard parts,” Expert Systems with Applications, Vol.38, No.10, pp.12537-12547, 2011.
[29] WONG, C.T., SHAMSUDDIN, S., NAPSIAH, I., HAMOUDA, A.M.S. “Design and Simulation of Plastic Injection Moulding Process,“ Pertanika Journal of Science and Technology, Vol.12, No.2, pp.85-99, 2004., ISSN 0128-7680.
[30] BOZDANA, T,A. “Development of an expert system for the determination of injection moulding parameters of thermoplastic materials: EX-PIMM,“ Journal of Materials Processing Technology, Vol.128, No.3, pp.113-122, 2002.
[31] YE, X.G., LEE, K.S., FUH, J.Y.H., ZHANG, Y.F.: Automatic initial design of injection mould,“ International Journal of Material and Product Technology, Vol.15, No.6-7, pp.592-604, 2004.
[32] YIN, C.G., MA, Y.S. “Parametric feature constraint modeling and mapping in product development, “Advanced Engineering Informatics, Vol.26, No.3, pp.539-552, 2012.
[33] ZHA, X.F. “Artificial intelligence and integrated intelligent systems in product design and development,“ Intelligent Knowledge-Based Systems, Vol.6, pp.1067-1123, 2005.
[34] ZHAI, M., SHEN, C. „Algorithm to optimise number of gates and locations in an injection mould,” Plastics Rubber and Composites, Vol.33, No.8, pp.330-334, 2004.
[35] ZHENG, R., TANNER, R., XI-JUN, F. “Injection Molding-Integration of Theory and Modeling Methods,“ p.147 Springer, 2011., ISBN:978-3-642-21262-8.
[36] ZHOU, H., SHI, S., MA, B. “Virtual Injection Molding System Based on Numerical Simulation,“ International Journal of Advanced Manufacturing Technology, Vol.40, No.3-4, pp.297-306, 2009.
[37] ZHOU, J., LI, L., HU, Y., YANG, J., CHENG, K. ”Plastic mold design of top-cover of out-shell of mouse based on CAE,” Procedia Engineering, Vol.15, pp.4441-4445, 2004.
[38] ZHOU, H. “Computer Modeling for Injection Molding: Simulation, Optimization, and Control,“ p.394, Wiley 2013 ISBN 978-0-470-60299-7.

35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
Faculty of Mechanical and Civil Engineering in Kraljevo

MANUFACTURING AND HORIZON 2020
What are important for Serbia ?

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Abstract: Manu*future developed the Vision 2020, the Strategic Research Agenda and Road Maps as basics for the European Research in FP8. The vision was mainly influenced by the challenges toward competition and sustainability by transformation from cost orientation to adding value with technical and organizational innovations.* Manu*future developed a strategic research Agenda "2020-2030" and Roadmaps to support the process of structural changes and orientation to higher efficiency and changeability. Technology development was driven by the activation of technological potentials in the process chains from basic materials to finished products and from customer's orders to the end of life to increase adding value.* Manu*future proposed fields of proactive actions for cooperative research in Europe across the 40 industrial sectors. Core fields of the strategic research agenda are part of the Factory of the Future (FOF) and Digital Manufacturing program and on the way now for implementation. Also in this analysis are include of Serbia industry state and steps for joint actions.*

Keywords: *Manufature Program, Factory of the Future, Digital Manufacturing, Innovations.*

1. INTRODUCTION REMARKS

Manufacturing demonstrates a huge potential to generate wealth and create high quality, value-adding jobs [1]**.** In 2007, the total number of manufacturing enterprises in the EU-27 non-financial business economy was estimated to be 2.3 million, representing a little over one in every ten (11%) enterprises within the EU-27 non-financial business economy. Manufacturing enterprises provided employment for 34.5 million persons. This was equivalent to 26 % of the employment in the EU-27 non-financial business economy. In 2008, manufacturing jobs and jobs directly depending on manufacturing represented 36.7% of the overall employment in Germany.
The EU-27 manufacturing sector generated EUR 7.274 billion of turnover in 2007, of which EUR 1.813 billion was value added. This was equivalent to 29% of the value added in the EU-27 non-financial business economy. On average, EUR 52,551 of value added in manufacturing was generated by each person employed. Total investment by the EU-27 manufacturing sector was valued at EUR 262 billion in 2006, equivalent to almost 14% of the manufacturing sector's value added.
Manufacturing activity is important for SMEs [2]**.** SMEs are the backbone of the manufacturing industry in Europe. Micro, small and medium enterprises provide around 45% of the value added by manufacturing while they provide around 59% of manufacturing employment.
Manufacturing is an R&D&I intensive activity [3]. In 2006, the R&D expenditure just in the Mechanical Engineering sector in EU-10 was $ 8,323 million. In 2007, the 'manufacturing' sector received the greatest share of business enterprise R&D expenditure in most of the EU-27 countries. This was notably the case in Germany, Slovenia and Finland, where 88.7 %, 88.2 % and 80.0 % respectively of R&D expenditure by the BES went on manufacturing. Across all industries R&D intensity (R&D expenditure as % of GDP) was 3.5 % in 2009 worldwide. At the same time, R&D intensity of Mechanical Engineering in Europe was 3.6 whereas in USA and Japan it was 3.2 and 3.0 respectively. This indicates that in the EU, Mechanical Engineering is of higher importance for overall technological performance than in US and Japan where the sectoral figure was below total industries. Also, in the business enterprise sector, manufacturing accounted for the highest shares of researchers in most EU Member States. In 2008, 14.1% of all tertiary students (EU-27) were participating in engineering, manufacturing and construction education. In 2008, 39.8 % of 6 enterprises in the EU-27 were considered innovative in terms of technological innovation. In most countries, the proportion of innovative enterprises was generally higher in manufacturing than in services. In 2009, 2.4 million people were employed in the high-tech manufacturing sector in the EU-27.

2. MANUFACTURING IS A KEY ENABLER FOR EUROPE - A SUSTAINABLE & COMPETITIVE EUROPEAN MANUFACTURING

It is envisaged that the continuation of the joint EC-industry investments on cross-disciplinary manufacturing research would allow the contribution to major social-driven targets for European manufacturing [4]:

 Employment: maintain and create new jobs in manufacturing
 Value added: increase value added by manufacturing
 Environmental impact:
 reduce emissions of green house gases from manufacturing activities
 reduce energy consumption in manufacturing activities
 reduce waste generation by manufacturing activities
 Research & Development: increase business enterprise R&D expenditure in manufacturing
 Innovation: increase the number of manufacturing enterprises engaged in innovation activities
 Education: bring all manufacturing engineering graduates & doctorate holders into manufacturing employment.

2.1 Towards a manufacturing knowledge-value chain

On the basis of previous achievements, a coordination and integration of activities related to [4]:
 research,
 valorization (innovation),
 education & training,
standards, IPRs, infrastructures and international cooperation,
is needed to promote a sustainable & competitive European manufacturing. This is to be supported on the basis of private and national / European funding. A multi-disciplinary approach involving all relevant actors from the public and private sector is required.
Within this context, a number of cross-disciplinary implementation "vehicles" (existing or envisioned) are to be employed, such as.
 Manufacturing research addressing industrial competitiveness - Factories of the Future PPP (H2020 – Pillar II),
 Manufacturing research addressing societal challenges (H2020 Pillar III),
 Manufacturing research at the frontiers of knowledge - ERC (H2020 Pillar I),
 Manufuture Industry Cluster – EUREKA,
 Manufacturing education / research-innovation-education, pilot projects & KIC on manufacturing - Education, EIT,
 New Industry European Innovation Partnership – Innovation,
 Advanced Manufacturing Systems (KET) - Industrial Policy,

In collaboration with all relevant actors, Manufuture ETP, together with its sub-platforms and national / regional platforms, will provide the integration framework catalyzing the synergies among these "vehicles".

2.2 Factories of the Future Roadmap beyond 2013

The manufacturing research and innovation community has been working on a strategic innovation agenda and a roadmap2 for the future, applying in a broad range of manufacturing sectors [5].
In response to the megatrends, following the Europe 2020 strategy and focusing on future market demands, it is foreseen that European Manufacturing sectors will undergo structural transformations towards:
 Factory and Nature -> green / sustainable
 Factory as a good neighbour -> close to the customer
 Factories in the value chain -> collaborative
 Factory and Humans -> human centered

Achieving these transformations requires a coordinated research and innovation effort, where manufacturing challenges and opportunities are addressed by deploying successively a set of technologies and enablers providing the decisive answers to the manufacturing challenges as well.

2.3. Research priorities

The suggested priorities are organized under the following clusters [4,5]:
 Cluster 1: Advanced Manufacturing processes
 Cluster 2: Adaptive and smart manufacturing systems
 Cluster 3: Digital, virtual and resource-efficient factories
 Cluster 4: Manufacturing eco-systems
 Cluster 5: Human-centric manufacturing
 Cluster 6: Customer-focused manufacturing

For the research and innovation actions to have the desired impact, specific consideration is given to the fact that R&D&I (research, development and innovation) need to be associated to dissemination and demonstration activities, addressing market readiness (industrial implementation) at an early stage.

3. MANUFACTURING RESEARCH & INNOVATION IN HORIZON 2020

The manufacturing research and innovation community has been already working on a strategic innovation agenda and roadmap for the future. It also has in place the appropriate instruments, i.e. a Technology Platform – Manufuture and a Research Association – EFFRA. This is a sound basis for having implementation vehicles in the context of Horizon 2020 quickly in place.
With respect to Horizon 2020 structure, manufacturing is clearly an enabling cross pillar activity with major relevance to several research and innovation themes in all three pillars. Thus, on the basis of the successful implementation of the FoF PPP so far, a continuation and expansion of the community's thinking and implementation to all three pillars of Horizon 2020 would bring added value to the Programme [1,6-10].

3.1 Manufacturing in Pillar I - Excellent Science

A1. ERC - *In order to stimulate substantial advances at the frontiers of knowledge, the ERC will support individual teams to carry out research in any field of basic scientific and technological research which falls within the scope of Horizon 2020, including engineering, social sciences and the humanities.* Basic research for manufacturing.

A2. FUTURE & EMERGING TECHNOLOGIES - A2.1. FET Open: fostering novel ideas - *By being explicitly non–topical and non-prescriptive, this activity allows for new ideas, whenever they arise and wherever they come from, within the broadest spectrum of themes and disciplines.* This topic is general and could foster highly innovative ideas for manufacturing.

A3. MARIE CURIE ACTIONS - A3.1. Fostering new skills by means of excellent initial training of researchers - *Typically, successful partnerships will take the form of research training networks or industrial doctorates, while single institutions will usually be involved in innovative doctoral programmes.* Among others, this topic is expected to train researchers in an industrial perspective .

A4. RESEARCH INFRASTRUCTURES - 4.1. Developing the European research infrastructures for 2020 and beyond - Mainly related to subtopic 4.1.3. Development, deployment and operation of ICT-based e-infrastructures - *Grid and cloud infrastructures providing virtually unlimited computational and data processing capacity; an ecosystem of supercomputing facilities, advancing towards exa-scale; a software and service infrastructure, e.g. for simulation and visualisation; real-time collaborative tools; and an interoperable, open and trusted scientific data infrastructure.* Such facilities and infrastructure may also be exploited for manufacturing related research activities.

3.2 Manufacturing in Pillar II - Industrial Leadership

B1. LEADERSHIP IN ENABLING AND INDUSTRIAL TECHNOLOGIES

B1.1. Information and Communication Technologies (ICT) - *A number of activity lines will target ICT industrial and technological leadership challenges and cover generic ICT research and innovation agendas.*
Mainly related to subtopics:
1.1.3. Future Internet: infrastructures, technologies and services
1.1.4 Content technologies and information management: ICT for digital content and creativity
1.1.5. Advanced interfaces and robots: robotics and smart spaces
1.1.6. Micro- and nanoelectronics and photonics.
ICT for Manufacturing is a critical enabler for the future sustainable competitiveness of manufacturing industry. In the context of this theme, a number of key ICT for manufacturing research areas should be addressed, such as agile manufacturing systems & processes, seamless factory life-cycle management, human-centricity in manufacturing, collaborative supply networks, customer-centric design & manufacturing.

B1.2. Nanotechnologies - Mainly related to subtopic **1.2.4.** Efficient synthesis and manufacturing of nanomaterials, components and systems - *Focusing on new flexible, scalable and repeatable unit operations, smart integration of new and existing processes, as well as up-scaling to achieve mass production of products and multi-purpose plants that ensures the efficient transfer of knowledge into industrial innovation.* The achievement of mass production of products is a very interesting and demanding topic for manufacturing.

B1.3. Advanced materials - Mainly related to subtopics:
1.3.4. Materials for a sustainable industry **--** *Developing new products and applications and consumer behaviour that reduce energy demand and facilitate low-carbon production, as well as process intensification, recycling, depollution and high added-value materials from waste and remanufacture.*
1.3.7. Optimisation of the use of materials -- *Research and development to investigate alternatives to the use of materials and innovative business model approaches.*

Topics such as alternative use of materials, use of alternative materials, energy demand, remanufacture and innovative business models will have to be examined in relation to current manufacturing activities.

B1.5. Advanced Manufacturing and Processing - Mainly related to subtopics:
1.5.1. Technologies for Factories of the Future -- *Promoting sustainable, industrial growth by facilitating a strategic shift in Europe from cost-based manufacturing to an approach based on the creation of high added value.*
1.5.4. New, sustainable business models -- *Cross-sectoral cooperation in concepts and methodologies for "knowledge-based", specialised*
production can boost creativity and innovation with a focus on business models in customized approaches that can adapt to the requirements of globalised value chains and networks,
changing markets, and emerging and future industries.
This is the core for cross –sectorial manufacturing research. This is where manufacturing research & innovation activities will be routed

Key Enabling Technologies (KETs) will be also supported within the Pillar II framework. Advanced manufacturing systems and processes are a "sine qua non" for the KETs. They are an indispensable and essential condition without which KETs will never realize their potential. Thus, advanced manufacturing systems and processes are considered as the Grand Key Enabler for the KETs.

3.3 Manufacturing in Pillar III- Societal challenges

C2. FOOD SECURITY, SUSTAINABLE AGRICULTURE, MARINE AND MARITIME RESEARCH AND THE BIO-ECONOMY.

C2.2. Sustainable and competitive agri-food sector - *Mainly related to sub-topic 2.2.3. A sustainable and competitive agri-food industry. The needs for the food and feed industry to cope with social, environmental, climate and economic change from local to global will be addressed at all stages of the food and feed production chain, including food design, processing, packaging, process control, waste reduction.* Manufacturing is important for the entire food sector and there is big potential for advanced manufacturing technology, i.e. food processing and manufacturing, food machinery, etc.

C4. SMART, GREEN AND INTEGRATED TRANSPORT.

C4.1. Resource efficient transport that respects the environment - Mainly related to subtopic 4.1.1. Making aircraft, vehicles and vessels cleaner and quieter will improve environmental performance and reduce perceived noise and vibration - *Reducing the weight of aircraft, vessels and vehicles and lowering their aerodynamic, hydrodynamic or rolling resistance by using lighter materials, leaner structures and innovative design, will contribute to lower fuel consumption.* Advanced materials and consequently new processes will play an important role in accomplishing these objectives.

C5. CLIMATE ACTION, RESOURCE EFFICIENCY AND RAW MATERIALS.
C5.4. Enabling the transition towards a green economy through eco-innovation - *Mainly related to: 5.4.1. Strengthen eco-innovative technologies, processes, services and products and boost their market uptake, and 5.4.4. Foster resource efficiency through digital systems.* Research in manufacturing is needed in order to decrease resource consumption by exploiting eco-innovative processes and processes as well as digital services and modern business models.

4. CONCLUSIONS

In summary, the H2020 can provide added value and foster the manufacturing renaissance of Europe by [6-10] and also in Serbia:
- A systemic vision, connecting the production of goods and services with procurement and supply chain management, and connecting the different levels of responsibility, from private entities and public administration to the individual social and global needs of people involved in such new production approaches;

- New forms of entrepreneurship able to integrate new business models fostering added value in new combinations of goods production, services provision, value chains, procurement and global societal dimensions;

- Entrepreneurship and entrepreneurship education which are able to support the translation of the new business models into socially acceptable and welfare generating solutions.

REFERENCES

[1]. [Eurostat Yearbook 2011], [Statistical Classification of Economic Activities in the European Community (NACE)], [Statistisches Bundesamt, Stand 01/2010].
[2]. [Eurostat, Statistics in Focus, Industry, trade and services, 62/2009].

[3]. [Ifo Institute, Cambridge Econometrics, Danish Technological Institute, Study on the Competitiveness of the EU Mechanical Engineering Industry, 2012] [Science, technology and innovation in Europe, Eurostat Pocketbook, 2011].
[4]. Majumdar, a., Szigeti, H., ICT FOR MANUFACTURING, The ActionPlanT Vision for Manufacturing 2.0, ActionPlanT, Brussels, 2013.
[5]. Manufuture ETP, EFFRA, 2012, "Factories of the Future Roadmap beyond 2013" – Draft Roadmap Document.
[6]. N., N., Additive Manufacturing: Strategic Research Agenda, AM SRA Consultation Document, Brussels, 2013.
[7]. NMP Expert Advisory Group (EAG), Position paper, ON FUTURE RTD ACTIVITIES OF NMP FOR THE PERIOD 2014 – 2020, European Commission, Brussels, 2013.
[8]. N., N., Impact of the Factories of the Future Public-Private Partnership , Final Report on the Workshop held on March 11-12, 2013, Brussels.
[9]. Riemenschneider, R., Perspectives of the Digital Factory in the FoF-ICT Research Programme, DG Information Society & Media European Commission, 2013.
[10]. N., N., Manufuture Vision, 2020, Brussels, 2013.

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"INDUSTRIALIZATION IN SERBIA"
FACTORIES OF THE FUTURE AND FACTORIES WITH A FUTURE

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Abstract: *This paper presents general information about the re-industrailization of Serbian economic system. The paper is focused to technology and engineering aspects, and in particular to the Program of National Technology Platforms of Serbia (NTPS). In its essece the NTPS Program is based on European Technology Platforms. The paper covers general information about NTPS program, its structure, organization and implementation plan, and in particular, development of network of individual platforms designed to optimally support industry recovery process and its future sustainable growth based on technology development and technology transfer.*

Keywords: *Industrialization, European technologoy platforms, National technology platforms.*

1. INTRODUCTION

Creation of an industrial system, which is vital and globally competitive, is, in every economy, a very long process industrijskog sistema, which, besides extensive investments in building of a complex industrial infrastructure, requires long-term systematic planning of technological development and development of appropriate human resources through permanent higher education.

A knowledge-based society is, before all, based on knowledge economy, and knowledge economy in its basis has knowledge-based industry, i.e. industry which creates its competitiveness on technological strength, and its vitality is built on extensive development processes based on constant technological innovations of products, production processes, organizational structure and marketing activities.

Knowledge-based industry dominantly relies on human resources, and not natural ones.

Industrialization of an economic system is not possible without strong technological development and strong engineering. The main generator of human resources is the education system. In practice, the development of an industrial system and the development of an education system are two intertwined processes, with a strong interconnection, great inertia and inherent asynchronism. Industrial and education systems are functionally complementary systems, and their development in a stable social environment is always a coevolutive process.

Fig. 1. First Serbian factory – the Cannon Foundry in Kragujevac erected in 1853.

Industrialization of Serbia began in the middle of the 19th century, at the time when Serbia established its statehood and national cohesion, the period which is, by a lot of characteristics, similar to our time. This year marks the 160th anniversary of the successful start of production in the first Serbian factory in Kragujevac. On 27 October 1853, Serbia succeeded, after a multi-year effort and careful planning, in accomplishing its first successful casting of 6 cannon barrels in the Cannon Foundry in Kragujevac (Figure 1). Although two centuries have passed since then, that event is of high relevance for the time we live in and difficulties we are faced with while solving accummulated economic problems. The preceding activities had lasted for decades, both in building the physical infrastructure for production and in building intellectual potentials for such a job. Not accidentally, in the same year of 1853, the Department of Natural and Technical Sciences for higher education of engineers was established at the Lyceum, the first institution of higher education in Serbia. At that time, Serbia clearly recognized the causality of industrial development, engineering and technology. In parallel, Serbia made great efforts to accomplish technological transfer through the import of, for that period, high technology equipment and bring foreign experts for industrial production to Serbia (reduction of the technological gap through the concept of convergence of technologies). The results were fascinating. In only ten years, complete substitution of import was accomplished (which, in the context of defence technologies, has other implications in addition to economic ones), Serbia started its own development activities on mastering cannon with inside rifling barrel (extremely complex technology for that time), and, almost unbelievably, realized its first export of high technology products by selling 24 6-pound cannons with smooth barrels to the neighbouring Romania. Further industrial development took place by an exponential model, but in waves – in wars our industry was destroyed, and it was renewed in peace.

This paper is focused on the technological and engineering component of the industrialization process, starting from the attitude that technology and engineering are key constituent components of an idustrial system and therefore the key challenge to successfulness and long-time sustainability of this process. The whole theme is organized in three chapters:

1. Industrial system of Serbia – Quantification, problems and implications;
2. Framework for revitalization and recovery – Industrial policies and the strategic framework for fast and sustainable exit from the crisis;
3. New industry of Serbia – Transformation of Serbian industry in the context of European integration processes, future context (factories of the future), challenges and needs.

The appendix contains the references used for elaboration of this material as well as the references in which more detailed explanations of the terms and statements used in the paper can be found.

2. PRESENT SITUATION IN SERBIAN INDUSTRY

Serbian industry has been facing serious problems that have lasted for more than two decades. Stagnation in all sectors has been present since the end of the eighties, and this process has been associated with the aftermath of the disintegration of the former Socialist Federal Republic of Yugoslavia and various related processes that have had a serious impact on the overall economy, especially industry as its driving sector.

The quantification of the stagnation process can be achieved based on three aggregate indicators: 1) the index of industrial production, 2) the number of industrial workers, and 3) the share of industry in GDP. The Index of Production (IoP) measures the volume of production of manufacturing, mining and quarrying, and energy supply industries. The IoP is a major contributor to the National Accounts. GDP measures the sum of the value added created through the production of goods and services within the economy.

Statistical trends of these aggregate indicators are given in Figure 2(a). The trends show the evidence for sudden collapse of industry output, huge loss of human resources (together with explicit/formal and tacit knowledge for technology and industrial production), and marginalization of the role of industry. Figure 2(b) shows the dynamics of accumulation and erosion of human resources. In fact, the crisis from the nineties has triggered the process of intensive deindustrialization of Serbian economy. Over the five decades, it is possible to identify three characteristic periods:

- 1960 – 1990 The context that preceded the crisis - INDUSTRIALIZATION: Serbia as a part of the Socialist Federal Republic of Yugoslavia; stable industrial development; rapid industrial development, average growth rate over 3 decades: 7.8% per year. Data for the year 1990: IoP_1990 = 100, 998,000 workers, 28.6 % GDP;
- 1990 – 2000 Collapse of the former Yugoslavia: Massive disintegration processes and ethnic conflicts; severe economic downturn; enormous inflation and collapse of the national fiscal system; extensive fragmentation of the industrial system; UN economic sanctions, etc; all these created serious consequences and severely damaged the industry. Data for the year 2000: IoP_1990 = 43.3, 643,000 workers, 24.7 % GDP;
- 2000 – 2010 Democratic changes and DEINDUSTRALIZATION: The emerging Republic of Serbia; economic liberalization process/ market economy; extensive privatization process (almost completed); openness for foreign direct investments; global economy crisis in 2008. Data for the year 2010: IoP_1990 = 45.9, 312,000 workers, 15.9 % GDP;

For a more comprehensive insight into the condition the industry is in, it is necessary to introduce another indicator that refers to the quantification of manufacturing industry sectoral technology content, i.e. industry technological profile. Industry technological profile is defined by the sectoral classification of investment intensity in research and development (products, processes and/or business systems), i.e. R&D expenditure. This indicator is not systematically monitored in Serbia, but it can be derived from the industry statistical data that are collected regularly. Figure 2 shows the sectoral technological profile of Serbian industry for 2008 (source: Republic Development Bureau, Republic of Serbia).

For the purpose of comparison, the sectoral technological profiles of two leading world economies, the US and the EU are also given in Figure 2, expressed through R&D investment of industrial companies (the investment funded by the companies themselves and for their own technological development).

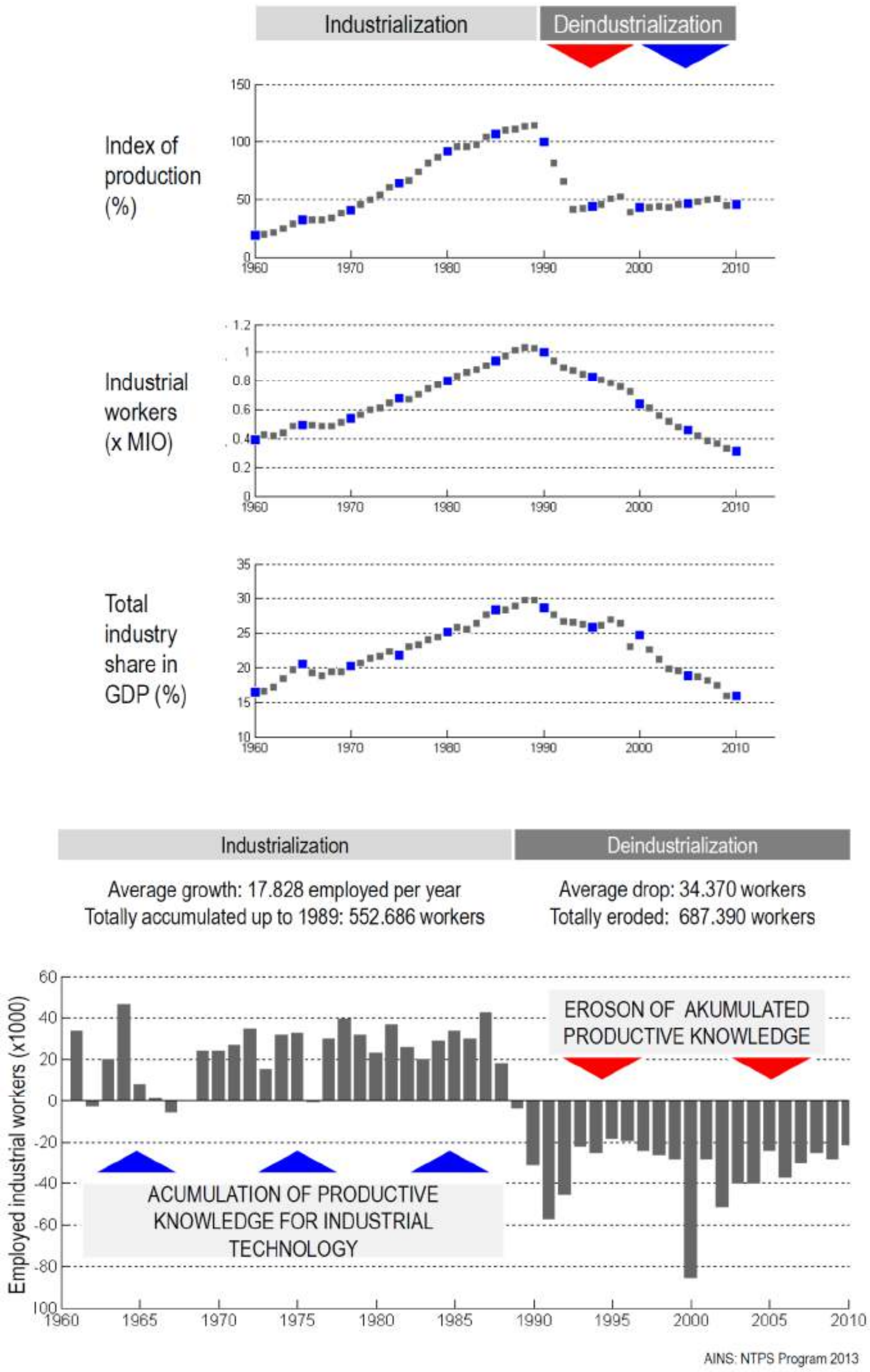
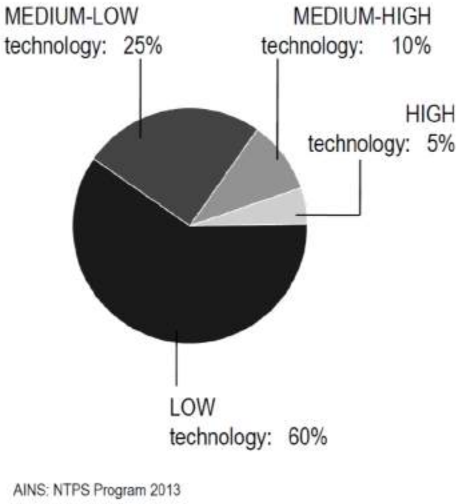


Fig.2. The index of production (indexed to the year 1990), industrial workers, and total industry share in GDP creation within the past five decades. A five-decade process of accumulation and erosion of human resources, i.e, the national intellectual capital for industrial technologies and production (bottom).

The differences are almost dramatic, and clearly show a high degree of technological erosion that had occurred. It is clear that in the past two decades the process of technological development in Serbia has had an inverse character, i.e. a downward direction of development helix that has transformed a former, highly dynamic and technologically intensive industry into a resource-based and low value-adding industry. In this regard, consequences on the overall corpus of engineering, especially in education, as well as R&D activities in the field of industrial technologies, have been very negative (destructive).



High R&D intensity sectors (HT - intensity above 5%) include e.g. Pharmaceuticals & biotechnology; Health care equipment & services; Technology hardware & equipment; Software & computer services.

Medium-high R&D intensity sectors (MHT - between 2% and 5%) include e.g. Electronics & electrical equipment; Automobiles & parts; Aerospace & defence; Industrial engineering & machinery; Chemicals; Personal goods; Household goods; General industrials; Support services.

Medium-low R&D intensity sectors (MLT - between 1% and 2%) include e.g. Food producers; Beverages; Travel & leisure; Media; Oil equipment; Electricity; Fixed line telecommunications.

Low R&D intensity sectors (LT - less than 1%) include e.g. Oil & gas producers; Industrial metals; Construction & materials; Food & drug retailers; Transportation; Mining; Tobacco; Multi-utilities.

Fig. 3. Comparison of the sectoral profile of Serbian industry in accordance with the intensity of technology for 2008 and RTD technology investment profile of industrial companies in the EU and the USA.

3. GENERAL FRAMEWORK FOR REVITALIZATION AND RECOVERY

Industry is an engine of development of every economy, and hence the state of industry has paralizing effect on the overall economic and social development of Serbia. It is almost amazing that even in such a difficult situation, after 25 years of stagnation, Serbian industry (and not agriculture or civil engineering) represents the key component of its economic system, which generates the largest number of jobs in the sectors of material production and has the largest share in creation of new value, which is partly placed for export, in which industrial products have a dominant share (over 80%). It is characteristic that in the structure of industry, which consists of manufacturing industry, mining, energy and water supply, manufacturing industry has a dominant share, far larger than the sum of the other parts. In that context, the prevailing orientation towards strategic directions of development of the sector of material production - almost all of them never mentioning manufacturing industry - looks confusing. Even in comparison with the service sector, which employs twice as many workers as the sector of material production, manufacturing industry is a dominant generator of jobs.

Regardless of the model of economic system, whether “the invisible hand of the market“ is present to a larger or smaller extent, the state has a major role in development of the industrial system. By using appropriate industrial policies, the state strategically directs or coordinates industrial development, before all technological development as the key component for its competitiveness. The role of the state is particularly important at the time of crisis, when the systems of extreme complexity, which certainly refers to industry, require the existence of a hierarchically superior system that will correct anomalies at the subordinate levels by its coordinated actions and thus stabilize the system within the shortest period possible. As an example of this premise, an excerpt from the current industrial policy of the European Union is cited. It is actually a corrected version of the source document adopted by the European Commission for the period 2010-2020 which, in only one year of its implementation, had to pass through essential changes, including the changes of pillars on which the industrial policy stands. This document, which was adopted on 10 October 2012 and publicly presented at the The World Manufacturing Forum, Stuttgart, Germany 2012 (see Figure 4), states as follows:

’’ At a time when financial problems persist, Europe needs its real economy more than ever to underpin the recovery of economic growth and jobs. Our industry is well placed to assume this role: Europe is a world-leader in many strategic

sectors such as automotive, aeronautics, engineering, space, chemicals and pharmaceuticals. Industry still accounts for 4/5 of Europe's exports and 80% of private sector R&D investment comes from manufacturing. ....

...

Industrial activities also have important spillover effects on production and employment in other sectors. For every 100 jobs created in industry, it is estimated that between 60 and 200 new jobs are created in the rest of the economy, depending on the industrial sector.

...

Europe needs to reverse the declining role of industry in Europe for the 21st century. *This is the only way to deliver sustainable growth, create high-value jobs and solve the societal challenges that we face.*

...

This Communication proposes a ***partnership between the EU, its Member States and industry*** *to dramatically step up investment into new technologies and give Europe a competitive lead in the new industrial revolution. After an extensive public consultation, the Commission proposes to jointly focus investment and innovation on* ***six priority action lines****: advanced manufacturing technologies, key enabling technologies, bio-based products, sustainable industrial and construction policy and raw materials, clean vehicles, smart grids.*

...

However, the ***harsh impact of the economic crisis*** *on several Member States, the subsequent economic stagnation in the EU and the deteriorating outlook for the global economy* ***have given a new urgency to this Mid-term Review of the Industrial Policy****.*

...

III. The pillars for a reinforced industrial policy: investment in innovation, better market conditions, access to capital and human capital and skills

The Commission proposes a proactive approach to industrial policy based on the following four main elements.

1. *First, the EU must provide the right framework conditions to* ***stimulate new investments****, speed up the adoption of new technologies and boost resource efficiency. These include technical regulations and Internal Market rules, as well as accompanying measures such as infrastructure and R&D/innovation projects. As a first step,* ***six priority areas*** *for immediate action are proposed in this Communication.*
2. *Secondly, urgent improvements in the functioning of the* ***Internal Market*** *are needed. They are presented here and in the Single Market Act II, and are reflected in the country-specific recommendations issued to Member States in the context of the European Semester. They will contribute to reinvigorate trade in the Internal Market.*
3. *Opening up* ***international markets*** *will also speed up recovery. The fast-growing emerging economies of the world offer new export opportunities for EU firms, especially SMEs. Investment and innovation are not possible without adequate* ***access to finance****. Public resources have already been mobilised to sustain investment in innovation, especially by SMEs. However, only unlocking private funds can ensure the level and sustainability needed to finance investment by EU companies. Improving access to capital markets is therefore another crucial challenge to increase our competitiveness.*
4. *Finally, accompanying measures to increase investment in* ***human capital and skills*** *are key to the success of industrial policy. Policies aimed at job creation and tools to anticipate skills needs are necessary to equip the labour force for industrial transformations.''*

The stated excerpt from the document of the European Commission which relates to industrial policy shows how the strategic documents of this type are actively implemented, how their implementation is actively monitored and actively corrected, if necessary. In contrast to that, Serbia accomplishes its industrial development without a strategy, although it formally exists. The current strategy and policy of Serbian industrial development for the period from 2011 to 2020, which was adopted by the Government of the Republic of Serbia in June 2011, recognizes the difficult state of industry, its outdatedness and implications resulting from such a context and offers concrete measures for exiting the crisis and starting a sustainable spiral of technological development. This document states that the primary strategic development goal of Serbia is sustainable and dynamic development of industry, which can be integrated in the unique market of the European Union and endure the competitive pressure of its members.

The current industrial policy includes definition of the main frameworks for the recovery of industry, which consist of three instruments:

1. Revitalization
   The initial impulse of the process of recovery through consolidation of production resources and bringing them to an operational state, which particularly refers to large companies and industrial systems, as crystallization cores around which clusters of small and medium companies will be formed;

2. Reengineering
   Expansion within the existing framework through technological modernization of the LMT sector and gradual introduction of high technology contents;
3. Development
   Change of the technological profile of industry, through migration of the centre of industrial production from dominantly low technology sectors towards high technology sectors.

In contrast to the existing practice, recovery and development expansion of industry are, within these instruments, connected with technological development and a visible endogenous component, as well as with the active role of the state.

Observed along the time axis, the mentioned strategic program instruments are realized in phases, thus providing convergence, stability and, in the long term, sustainability of the process of recovery and transformation of Serbian industry. Revitalization, reengineering and development expansion are three main elements for stopping the two-decade stagnation and erosion of industrial tissue, and then for starting the process of recovery from the eroded base.

Starting from the previously mentioned, Serbian industry, after revitalization and its bringing into an operational state, has to be transformed so that, through overcoming the two-decade technological gap, it could carry out reengineering of its technological base and thus create real foundations for achieving the necessary competitiveness, if measured globally. The transformation process should be led through an imperative action of two main regulatory instruments: complementarity and compatibility of Serbian industry with the European economic area. Seemingly, these are two antagonistic or conflict instruments, which exclude each other. In reality, these instruments provide precise leading and convergence of transformation processes, whose final outcome is a successful solution, i.e. new, transformed Serbian industry, which has its recognizable, respected and, in the long term, sustainable position in the European economic area.

4. EUROPEAN TECHNOLOGY PLATFORMS

ETPs were first introduced officially in the EC Communication “Industrial Policy in an Enlarged Europe” in December 2002. This document exactly states: “Technological platforms could be considered to foster marketplaces for cooperation among stakeholders and work out a long-term strategic plan for R&D for specific technologies involving major economic or societal challenges, such as the advent of hydrogen as a new source of energy. They would ensure synergy among public authorities, users, regulators, industry, consumers, and poles of excellence viewed as places where basic research and technology transfer are closely linked. There is a need for coherence between research, which can create new opportunities, and the downstream regulatory framework in which these technologies can be developed and marketed.”

The ambition was to bring together R&D-relevant stakeholders with various backgrounds (e.g. regulatory bodies at various geo-political levels, industry, public authorities, research institutes and the academic community, the financial world and civil society) who would develop a long-term R&D strategy in the areas of interest to Europe. The setup of an ETP follows a bottom-up approach in which the stakeholders take the initiative and where the European Commission evaluates and guides the process.

Using the Mirror Groups instrument, the ETP concept has been extended to the national level. The Member States deployed Mirror Groups widely. Mirror Groups are normally composed of experts nominated by the Member States and aim to facilitate coordination and provide an effective two-way interface between ETPs and complementary activities at a national level. Parallel to the Mirror Groups, national platforms started to emerge based on NRTP mechanism, typically focusing on a part of the research agenda of interest to national research players. Currently, national TPs exist in different forms. In most cases they have been set up following a national call for proposals, with varying degrees of involvement of European TPs in the process. Some national TPs operate as national branches of the corresponding ETP, but others are mainly coordinated with their national government. Some countries have a very high number of national TPs because they have decided that the concept serves them well for national policy purposes. Other countries, however, have chosen a limited number of research and social priorities and have promoted the establishment of the corresponding TPs. In this way, public authorities are actively involved in ETPs in their roles as policy-makers and funding agencies, and as promoters and consumers of technologies, focusing on those ETPs which are more relevant for their national industries, research organizations and academia.

Outside the EU community, there are also activities which are related to the process of building up national system of technology platforms, following the core ideas of the ETP concept.

In the year 2011, pursuant to the Resolution of the Governmental Commission for High Technologies and Innovations, the Ministry of Economic Development of the Russian Federation in cooperation with the Ministry of Education and Science of the Russian Federation established 30 Technology Platforms in the priority spheres of developing science and technology seen as a new driver of innovation growth of the Russian economy. In 2012, three more Technology Platforms were submitted for approval. Currently, these self-organizing structures involve hundreds of industrial enterprises, organizations of applied and academic science, higher educational institutions, and initiative groups of developers. The Technology Platforms have achieved significant success in forming and implementing the strategic

research programmes and defining the long-term priorities of the economy with regard to their core business. The Russian Foundation for Technological Development and the Ministry of Economic Development provide financial contribution to the projects developed by the Technology Platform member-organizations. The Foundation organizes and conducts the competitive selection of the innovative projects, included into the Road Maps and Strategic Research Programmes; 10 projects presented by seven Technology Platforms have already been financed to a total amount of 1,134 million rubles (app. 28 million EUR). The Russian technology platform for manufacturing is formally organized under the technology platform named: 'Simulation and operation practice of high-tech systems (industry of the future)'. This platform was established by 21 industrial and scientific organizations in February 2012 (accomplished a precisely formulated procedure and approved by the Decree of the Presidium of the Government Commission for High Technologies and Innovations) and has strong cooperation with the ETP ManuFUTURE platform.
As for Serbia, the particularly important activities are in the Western Balkan region, where the already established national technology platforms are following the model of ETP. The Croatian government has established their national technology platforms program in 2009 under the name: Hrvatske tehnologijske platforme (established Povjerenstvo za tehnološke platforme Republike Hrvatske). The program is developing through the specialized scientific institution: Hrvatski institut za tehnologiju – HIT. The process of establishing and developing the national program of technology platforms in Slovenia was more intensive then in Croatia, mostly due to the role of Janez Potočnik, who was the European Commissioner for Science and Research and who was personally engaged in development and implementation of the ETP program. As an EU member, Slovenia established their own national program of technology platforms in 2005, when the Slovenian government, i.e. their Ministry of Higher Education, Science and Technology, following the ETP model, launched a call for proposals for formation of the national technology platforms, suggesting the model based on cooperation with individual European technology platforms.

5. THE PROGRAM OF NATIOANAL TECHNOLOGY PLATFORMS OF SERBIA

The Program National technology platforms of Serbia, NTPS Program, is based on the concept of European Technology Platforms and in all aspects of its activities is highly focused on establishing and developing various forms of collaboration, especially with individual technology platforms having strategic research agendas complementary with research and development priorities of Serbia.
The Program was formally launched in 2010 and the Academy of Engineering Sciences of Serbia (AINS) is responsible for its development and implementation.
There are four basic objectives that govern the NTPS Program:

- Creating a new formal framework for a smart and systemic transformation of the technological basis of Serbian industry;
- Strengthening science – industry interaction by better focusing of R&D programs and funding on areas of high relevance to Serbian industry and ending the situation in which investment in R&D often produces less than expected;
- Focusing on technology as an important component for the process of European integration;
- Recognizing the challenges of technology which can potentially contribute to the realization of key societal priorities and deliver benefits to Serbian citizens.

Regarding the methodological framework, the NTPS Program draws its foundations from the respective national potential for technology research and development (well-developed educational and R&D infrastructure), the respective industrial tradition that has spread out for nearly two centuries, and also cultural and regional specificities.
The NTPS Program is organized as a structure that is composed of two hierarchical levels: 1) The NTPS Core, which is located within the Serbian Academy of Engineering Sciences and governed by the NTPS Committee, and 2) NTPS Individual Platforms, a set of up to 10 individual platforms that emerge from the NTPS Core as a system of mutually complementary, networked and interacting entities. Figure 3 shows the general structure of the NTPS Program.
Any of the NTPS individual technology platforms should be:

- A Response to a Major National Challenges: The Platforms are mission-oriented and address major national economic – environmental – technical – social challenges. NTPS is not a short-term, problem-solving instrument.
- A Strategic National Initiative: Platforms should be set up only when there is a well-defined, national, strategic need for such an instrument, and national added value can be clearly justified.
- Politically Highly Visible: To affect change across national, industrial, technological boundaries, the NTPS individual platforms must create strong political support and be highly visible at a national, European, and even at a global level.
- Industry Led: To be effective, the NTPS individual platforms must be driven by actors from the applications/ problem end of the innovation process. Individual platforms should not become too academic and the most relevant stakeholders in the sector should be included. The governing bodies of the platforms must be led by a person who comes from the industrial domain.

- Well-planned and executed: There must be a ‘road map’, with a long-term vision, a sound strategy for achieving this vision and a detailed action plan for carrying out the necessary activities. The platform must be big enough to be representative.

The NTPS Program is recognized by the Serbian Ministry of Science and Education as a program of strategic importance for technology development, technology transfer and innovation system development. This program is also incorporated in the ‘Serbian Industrial Policy 2020’, as a strategically important pillar for raising high technology content in Serbian industry.

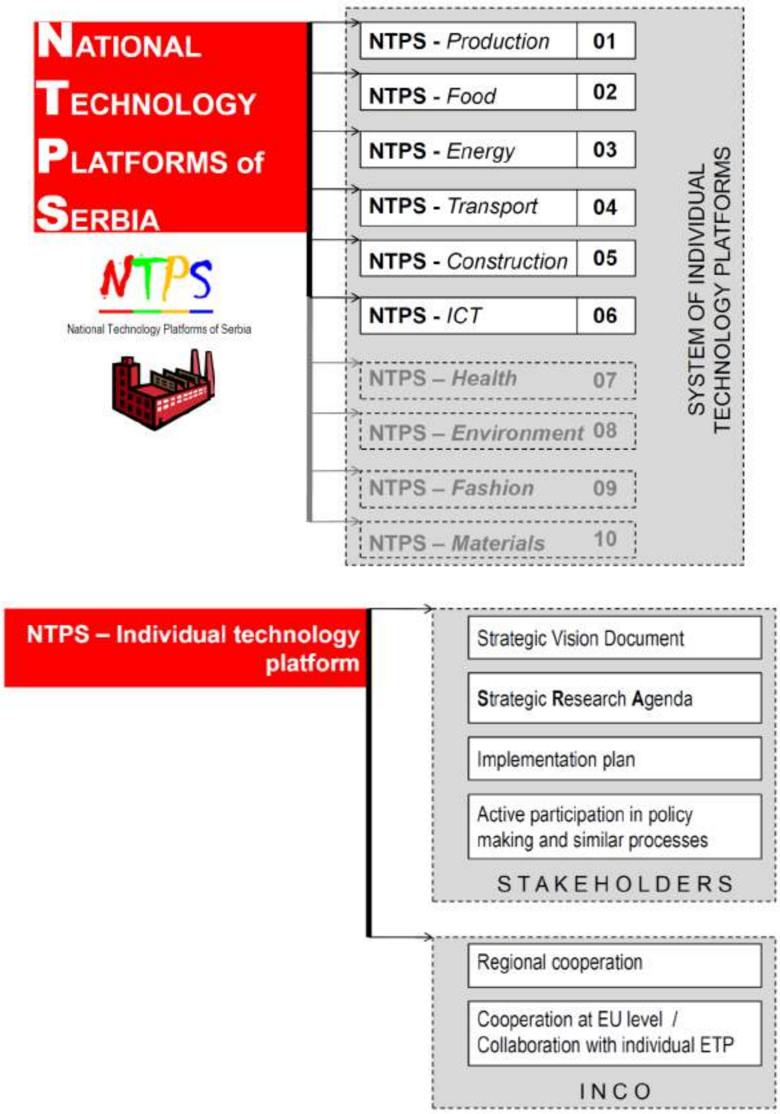


Fig. 4. NTPS structure: Core governing level and up to 10 individual technology platforms, dedicated to one or more societal priorities of Serbia, and key outocomes generated by any of individual technology plaforms (bottom).

NTPS-Production is the first individual platform that has been derived from the NTPS Program and put into operation. It is an industry-led voluntary association of stakeholders in the field of industrial production. This technology platform is closely related to the process of recovery and transformation of the industrial system in Serbia. In this process, NTPS-Production activities are predominantly focused on strengthening the interaction of industry and science, including the educational aspects, with active participation in the following instruments and strategic projects:

- 3R Set of Instruments for the recovery and transformation of industry as defined by the actual Industrial Policy 2020:
    - Revitalization (2011-2015) – The first stage of the recovery process, targeted to big industrial companies and systems;
    - Reengineering (2015-2020) – The second stage of the recovery process, targeted to the modernization of technological basis and organizational structures of big companies and stimulation of mass development of small and medium enterprises in the field of industrial production;

- Expansion and growth (2020-2030) - The third stage of the recovery process that is dedicated to transformation of the technology profile of the industry from dominantly low-tech to high-tech sectors.

- Horizontal transformation programs / FaBS Initiative (the Serbian Factory of the Future - clean, green, lean concept):
    - Ecologically sustainable and compatible industry;
    - Energy and resource efficient industry;
    - Digitalized manufacturing processes and production – ICT agenda for industry: Digital Factory, Smart Factory and Virtual Factory programs.
- TeMaS Project – Technology Maps of Serbia.

For the above listed activities the cooperation with the following individual technology platforms at the EU level is of particular importance: ManuFuture: Future Manufacturing Technologies of Europe, EUROP: European Robotics Platform, MINAM: European Platform on Micro- and Nano-Manufacturing, ARTEMIS: The European Technology Platform for Advanced Research and Technology for Embedded Intelligence and Systems, and EPoSS: European Platform on Smart Systems Integration. This cooperation is considered as a vehicle for fast technology transfer (technology shortcut), as well as for adaptation of Serbian industry to European industry standards and organizational models of industrial companies, especially in the context of new paradigm of customized manufacturing that radically changes the general framework of industrial production. In that sense, of particular importance is the initiative of ManuFuture technology platform named Factories of Future (FoF), which was launched by the European Commission in 2008 within the Economic Recovery Plant, as a Public-Private Partnership (PPP) with an allocated budget of 1.3 billion EUR. The FoF PPP is cross-thematic, encompassing the Information and Communications Technologies (ICT) Theme and Nanosciences, Nanotechnologies, Materials and New Production Technologies (NMP) Theme. FaBS Initiative (Serbian Factory of the Future) is a complementary action at the national level, which is closely related to the FoF PPP, focusing in parallel on the national specificities of Serbian economy, as well as on the European priorities in the field of industrial technologies, covering both the RTD and the educational aspects.

The organizational model of the NTPS-Production platform is shown in Figure 5. This model has four hierarchical strata: Level 1 - Stakeholders / members level, Level 2 - Operational core level, Level 3 - Decision-making level, and Level 4 - Managing level of TP.

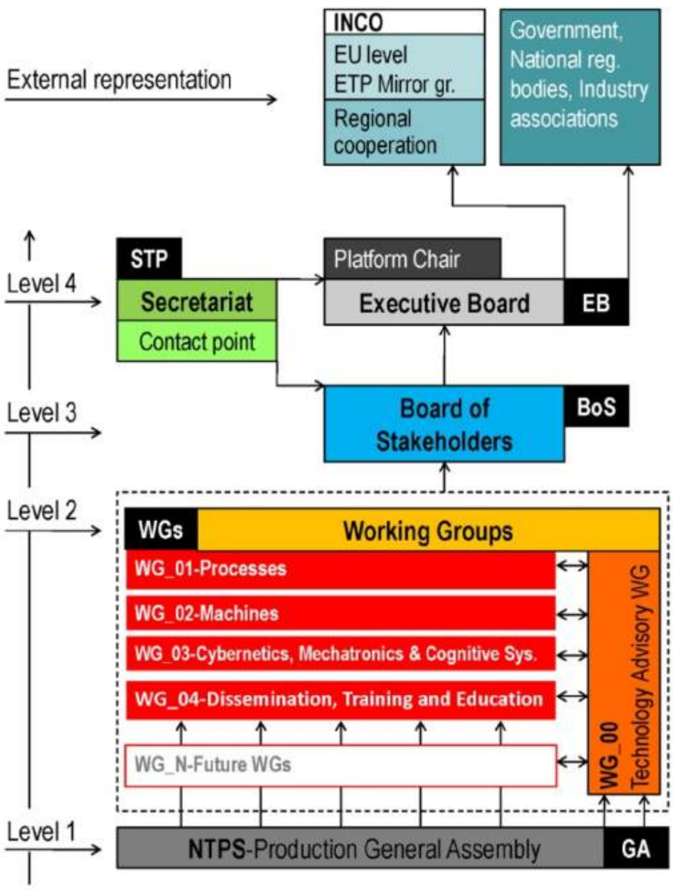


Fig. 5. Organizational structure of NTPS-Production individual technology platform.

Besides the technological aspect, the FaBS initiative is also focused on educational aspects as well as interaction of education system and the labor market. The general model of interaction between the education system and the labor market in sense of the development of 'a common language between education/training and the world of work', adopted from ESCO, is given in Figure 6. It is essential that the occupations and skills/competences generated by the system of higher education in Serbia should be highly responsive to the needs of the reindustrialization process of Serbian economy.

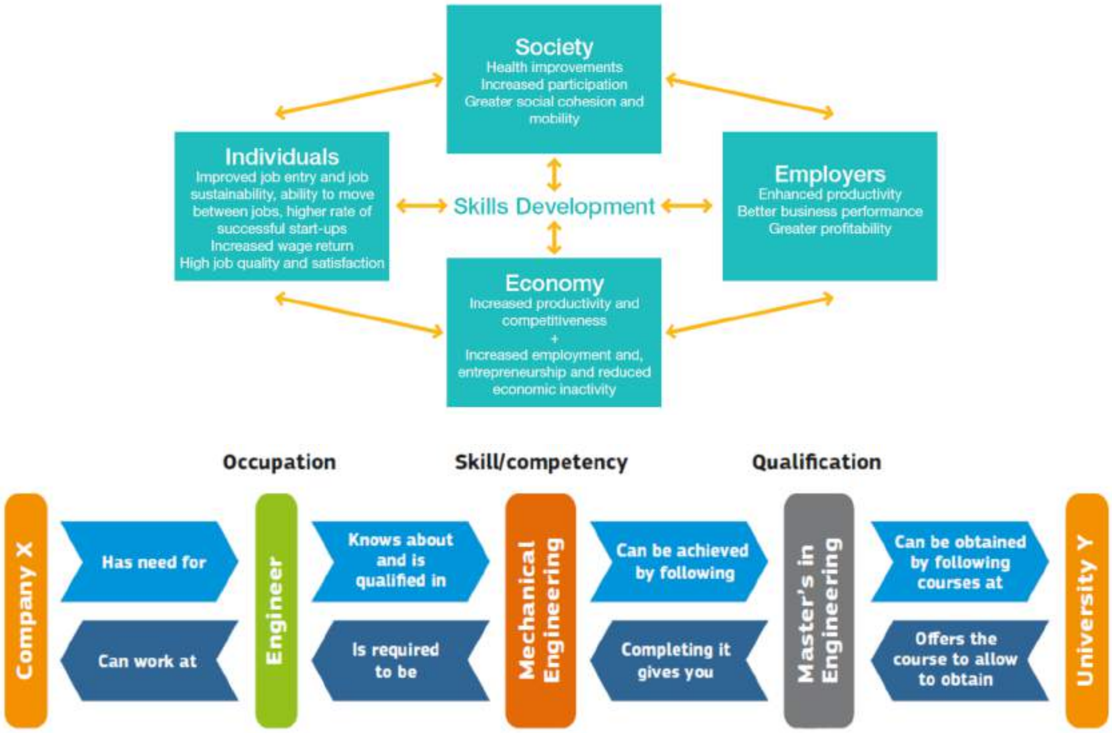


Fig. 6. The general model of the development of a common language between education/training and the world of work, i.e. labor market (adopted from ESCO).

6. CONCLUSION

Serbian economy is faced with a crisis that has lasted for more then two decades. Its excessive length severely destroyed the national economy, especially industry. Industry data show horrifying consequences. Industrial growth and technological development that existed in the period before the crisis were almost completely stopped. The industrial production volume has been reduced to the level of the seventies, the contribution of industry to national GDP was halved, and the number of industrial workers has been reduced to 1/3. The way out of the crisis requires economic growth, but the economic growth is impossible without a strong, productive and competitive industry. The strong industry requires a strong and dynamic technological base. Recognizing these needs, the Academy of Engineering Sciences of Serbia has conceptualized and developed a program of national technology platforms, i.e., NTPS Program. In its basis, NTPS Program is derived from the concept of European technology platforms. Although it is in its beginning, significance of the NTPS Program was recognized by the relevant public authorities and embedded in the industrial policy 2020 as one of strategic pillars, dedicated for recovering of technological basis of Serbian industry and for rising high technology content in all industrial activities. The NTPS Program was started its implementation stage by launching the first individual technology platform NTPS-Production as a pilot action, aimed to show practical value of the NTPS concept and to prove potential of the NTPS Program in whole under the real industrial scenario.

Acknowldgement: This research is carried out the Cyber-Manufacturing Laboratory - CMSysLab, Faculty of Mechanical Engineering, within the project: Smart Robotics for Customized Manufacturing, grant No.: TR35007, supported by the Serbian Ministry for education, science and technology development.

REFERENCES

[1] STRATEGY AND POLICY OF INDUSTRIAL DEVELOPMNET 2011-2020, Ministry of Economy and Regional Development of Republic of Serbia, Belgrade, 2011, (in Serbian).

[2] SERBIA 2020 – A Strategy for Development and Growth of Republic of Serbia, Prepared by ad-hoc working group appointed by President of Republic of Serbia, Belgrade, 2010, (in Serbian).

[3] Commission of the European communities: INDUSTRIAL POLICY IN AN ENLARGED EUROPE - Communication from the commission to the council, the European parliament, the economic and social committee and the committee of the regions, Brussels, 12.2002, com (2002) 714 final.

[4] European commission, TECHNOLOGY PLATFORMS - From Definition to Implementation of a Common Research Agenda, Report compiled by a Commission Inter-Service Group on Technology Platforms, Directorate-General for Research, Directorate B - Structuring the European Research Area, 2004, EUR 21265.

[5] Commission of the European communities, REPORT ON EUROPEAN TECHNOLOGY PLATFORMS AND JOINT TECHNOLOGY INITIATIVES - Fostering Public-Private R&D Partnerships to Boost Europe's Industrial Competitiveness, Brussels, 10.6.2005,SEC(2005) 800.

[6] European Commission Inter-Service Group on European Technology Platforms, SECOND STATUS REPORT ON EUROPEAN TECHNOLOGY PLATFORMS - Moving to Implementation, Directorate-General for Research, Directorate B – Structuring the European Research Area, 2006, ISBN 92-79-01019-0.

[7] European Commission, THIRD STATUS REPORT ON EUROPEAN TECHNOLOGY PLATFORMS - At the Launch of FP7, Directorate-General for Research, Directorate C – European Research Area: Knowledge-based economy, Unit C1 – European Research Area Policy, 2007, EUR 22706 EN

[8] European Commission, FOURTH STATUS REPORT OND EUROPEAN TECHNOLOGY PLATFORMS - Harvesting the Potential, Directorate-General for Research, 2009, EUR 23729 EN

[9] European commission, Directorate-General for Research, European Research Area Knowledge-based economy, STRENGTHENING THE ROLE OF EUROPEAN TECHNOLOGY PLATFORMS IN ADDRESSING EUROPE'S GRAND SOCIETAL CHALLENGES - Report of the ETP Expert Group, October 2009, EUR 24196 EN.

[10] European commission, EUROPEAN TECHNOLOGY PLATFORMS – Ensuring Openness and Transparency, 2006, ISBN: 92-79-02486-8

[11] Commission of the European Communities, DEVELOPMENT OF TECHNOLOGY PLATFORMS - Status report, 2005, ISBN 92-894-8985-5

[12] Ministry of Economic Development of the Russian Federation, RUSSIAN TECHNOLOGY PLATFORMS, Moscow International Forum for Innovative Development Open Innovations, Moscow, CEC «Expocenter» October 31 — November 03, 2012.

[13] Russian Foundation for Technological Development, Technology Platform, Simulation and operation practice of high-tech systems (Industry of the future), Information booklet, Moscow, 2012.

[14] Roadmap: Factories of the future beyond 2013 - Consultation document, EFFRA - European factories of the future research association, Brussels Belgium, Jun 2011.

[15] European commission, Directorate-general for research, Directorate G – Industrial technologies, FACTORIES OF THE FUTURE - PPP Strategic Multi-annual Roadmap, 2010, ISBN 978-92-79-15227-6.

[16] Jovane, F., Westkämper, E., and Williams, D., THE MANUFUTURE ROAD - Towards Competitive and Sustainable High-Adding-Value Manufacturing, 2009, Springer-Verlag Berlin Heidelberg, ISBN 978-3-540-77011-4.

[17] Jovane, F., Koren, Y., and Boer, C.R., Present and Future of Flexible Automation: Towards New Paradigms, CIRP Annals - Manufacturing TechnologyVolume 52, Issue 2, 2003, pp 543-560.

[18] Westkämper, E., TOWARDS THE RE-INDUSTRIALIZATION OF EUROPE - A Concept for Manufacturing for 2030, Springer-Verlag Berlin Heidelberg 2014, ISBN 978-3-642-38501-8, DOI 10.1007/978-3-642-38502-5.

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MODEL FOR OPTIMIZATION OF PHASE PROCESSES BY THE LINEAR PROGRAMMING METHOD

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Abstract: *The problem of optimization of a multiphase production process by the linear programming method is very frequent in manufacturing practice. Instead of a classical solution to the problem, i.e. creation of constraint equations per production phase, the paper proposes the methodology of forming of a unique (summary) table which can be used for creation of a complex mathematical model of the problem in a matrix form.*
The method is illustrated on the example of an optimization process of manufacturing and mounting of a hydraulic valve for regulation of pressure and flow, which is foreseen for installation on hydraulic bar feeders for CNC machines.

***Key words**: Phase process, linear programming, optimization*

1. INTRODUCTION

Production processes can be single phase and multiphase processes. Single phase ones are those in which final products are directly made of raw material. Unlike single phase processes, a multiphase process can be divided into several phases in which the results of previous phases can have effects on later ones. To be more precise, a multiphase process can be divided into several single phase processes which are interconnected and conditioned by the given constraints.
Programming of a multiphase process is commonly reduced to the problem of process realization by individual phases for the purpose of achieving an optimum production result. The number of levels of division of a multiphase process is conditioned by objective circumstances, such as the technological process of manufacturing and mounting of the product, although division can sometimes be a consequence of subjective decisions, too [2].
The paper deals with the programming of multiphase processes which can be mathematically solved by linear programming methods. The procedure of creation of the mathematical model of multiphase process optimization is presented on the example of manufacturing and mounting of a hydraulic valve for regulation of pressure and flow, which is foreseen for installation of hydraulic bar feeders for CNC machines.
The look and mounting structure of the hydraulic valve with its accompanying parts is shown in Figure 1. The product is formed in four phases: in the first phase the parts (D1, D2, ... D8) are manufactured from semi-finished products, in the second phase the parts and standard parts (GR1, GR2, ... GR8) are used for making subassemblies (PS1, PS2 and PS3), in the third phase the main assembly (GS) is made, and the product (P) is formed in the fourth phase.
The task is as follows: It is necessary to program a multiphase production process so that the optimum quantity of regulating valves could be manufactured from the available quantities of semi-finished products and standard parts and thus acquire a maximum profit from the sale of those valves. There are no market constraints with respect to the quantity of products for sale.

Table 1. Specification of necessary semi-finished products for manufacturing valve parts

Designation	Name of part	Unit	Qty/product	Semi-finished product				Mass of finished component [kg]
				Material	Dimensions [mm]	Mass of work piece [kg]	Designation	
D_1	Control block	Pc.	1	S355JR	≠ 60×80×130	4.888	S_1	3.360
D_2	Block	Pc.	1	S355JR	≠ 60×80×92	3.459		2.046
D_3	Flow regulating spindle	Pc.	1	C45E	Ø32×100	0.646	S_2	0.243
D_4	Pressure regulating spindle	Pc.	1	C45E	Ø18h9×107	0.219	S_3	0.176
D_5	Screw 005	Pc.	1	C45E	Ø16×60	0.097	S_4	0.057
D_6	Piston	Pc.	1	C45E	Ø46×40	0.534	S_5	0.105
D_7	Ring	Pc.	1	C45E	Ø55×10	0.191	S_6	0.078
D_8	Bushing	Pc.	1	C45E	Ø30h9×35	0.199	S_7	0.073

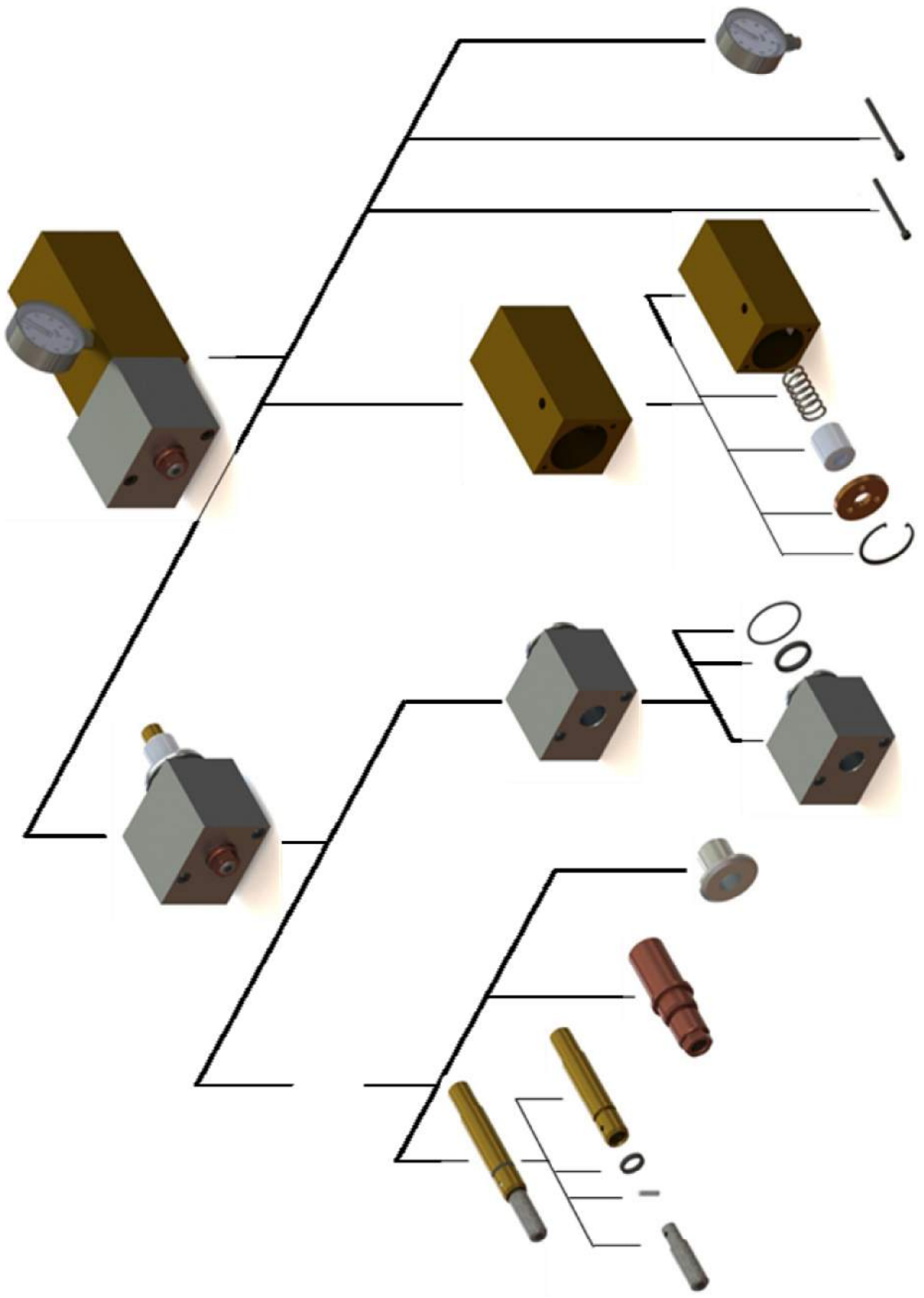

Fig. 1. Assembly structure of the product

Parts D1 through D8 are manufactured from semi-finished products by cutting operation. The necessary dimensions and quantities of semi-finished products for parts manufacturing are shown in Table 1.

The available quantities of semi-finished products in the company are shown in Table 2.

Table 2. Available quantities of semi-finished products used for manufacturing valve parts

Semi-finished products						
Designation	**Name**	**Unit**	**Avail. Qty**	**Material**	**Dimensions [mm]**	**Mass*[kg]**
S_1	Steel plate	Pc.	4	S355JR	2000×2000×80	2506.560
S_2	Cold drawn steel bars	Pc.	3	C45E	Ø32×2000	12.911
S_3	Cold drawn steel bars	Pc.	3	C45E	Ø18×2000	4.085
S_4	Cold drawn steel bars	Pc.	2	C45E	Ø16×2000	3.228
S_5	Cold drawn steel bars	Pc.	2	C45E	Ø46×2000	26.680
S_6	Cold drawn steel bars	Pc.	1	C45E	Ø55×2000	38.142
S_7	Cold drawn steel bars	Pc.	2	C45E	Ø30×2000	11.348
* The mass of semi-finished products refers to the unit of measurement (one steel plate, bar, etc.......)						

Table 3. Specification of standard parts and available quantity

Designation	**Name**	**Standard/ Manufacturer**	**Unit**	**Avail. Qty**
GR_1	Sealing	RubeliGuiquoz	Pc.	500
GR_2	O-ring	RubeliGuiquoz	Pc.	600
GR_3	Seeger ring	DIN472	Pc.	500
GR_4	Spring	DIN 2098	Pc.	700
GR_5	Elastic pin	DIN 1481	Pc.	500
GR_6	Sealing	RubeliGuiquoz	Pc.	600
GR_7	Screw M6x80	DIN 912	Pc.	1000
GR_8	Manometer	WIKA 0-10 bar	Pc.	700

The available quantities of standard parts which are purchased on the market and which are necessary for completion of the valves are shown in Table 3.

2. PRODUCTION PHASES AND CONSTRAINT EQUATIONS

The process of manufacturing and mounting parts, subassemblies and assemblies takes place in phases presented in the following tables. In the first phase semi-finished products S1, S2, . . . S7 are cut for the purpose of making parts D1, D2, . . . D8 in quantities x1, x2, . . . , x8. The necessary and available quantities of semi-finished products are shown in Table 4.

Table 4. Phase 1

			Products of Phase 1								**Available quantities**
			D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	
Phase 1	**Semi-fin. products**	S_1	4.888	3.459							10026.24
		S_2			0.646						38.733
		S_3				0.219					12.255
		S_4					0.097				6.456
		S_5						0.534			53.36
		S_6							0.191		38.142
		S_7								0.199	22.696
	Quantity		x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	

For the first phase of production it is necessary to determine the variables $x_1, x_2, \ldots, x_8$ which satisfy the non-negativity conditions

$$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8 \geq 0 \quad (1)$$

and constraints with respect to the available quantities:

$$4.888 \cdot x_1 + 3.459 \cdot x_2 \leq 10026.24 \quad (2)$$

$$0.646 \cdot x_3 \leq 38.733 \quad (3)$$

$$0.219 \cdot x_4 \leq 12.255 \quad (4)$$

$$0.097 \cdot x_5 \leq 6.456 \quad (5)$$

$$0.534 \cdot x_6 \leq 53.36 \quad (6)$$

$$0.191 \cdot x_7 \leq 38.142 \quad (7)$$

$$0.199 \cdot x_8 \leq 22.696 \quad (8)$$

After the completion of Phase 1, the remaining quantities of semi-finished products are

$a = 10026.24 – 4.888 \cdot x_1 – 3.459 \cdot x_2$ semi-fin. product S_1

$b = 38.733 – 0.646 \cdot x_3$ semi-fin. product S_2

$c = 12.255 – 0.219 \cdot x_4$ semi-fin. product S_3

$d = 6.456 – 0.097 \cdot x_5$ semi-fin. product S_4

$e = 53.36 – 0.534 \cdot x_6$ semi-fin. product S_5

$f = 38.142 – 0.191 \cdot x_7$ semi-fin. product S_6

$g = 22.696 – 0.199 \cdot x_8$ semi-fin. product S_7

and the available quantities of parts $D_1, D_2, \ldots D_8$ cy $x_1, x_2, \ldots, x_8$.

It may happen in Phase 1 that a new part is obtained by additional treatment of a standard part. In that case, Table 4 can be extended by the category of standard parts (Table 4a) on the basis of which new constraints with respect to available quantities of standard parts can be written. There is not such a case in the given example so that these equations are not written.

Table 4a. Phase 1

			Products of Phase 1								Available quantities
			D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	
Phase 1	**Semi-fin. products**	S_1	4.888	3.459							10026.24
		S_2			0.646						38.733
		S_3				0.219					12.255
		S_4					0.097				6.456
		S_5						0.534			53.36
		S_6							0.191		38.142
		S_7								0.199	22.696
	Standard parts	GR_1									500
		GR_2									600
		GR_3									500
		GR_4									700
		GR_5									500
		GR_6									600
		GR_7									1000
		GR_8									700
	Quantity		x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	

In the second phase, the remaining quantity of semi-finished products, parts manufactured in the first phase and standard parts are used to form subassemblies *PS1*, *PS2* and *PS3* in quantities x_9, x_{10} and x_{11} (Table 5).

Table 5. Phase 2

			Products of Phase 2			Available quantities
			PS1	*PS2*	*PS3*	
Phase 2	**Semi-fin. products**	S_1				a = 10026.24–4.888·x_1–3.459·x_2
		S_2				b = 38.733–0.646·x_3
		S_3				c = 12.255–0.219·x_4
		S_4				d = 6.456–0.097·x_5
		S_5				e = 53.36–0.534·x_6
		S_6				f = 38.142–0.191·x_7
		S_7				g = 22.696–0.199·x_8
	Standard parts	GR_1		1		500
		GR_2		1		600
		GR_3			1	500
		GR_4			1	700
		GR_5	1			500
		GR_6	1			600
		GR_7				1000
		GR_8				700
	Products of Phase 1	D_1			1	x_1
		D_2		1		x_2
		D_3	1			x_3
		D_4	1			x_4
		D_5	1			x_5
		D_6	1			x_6
		D_7			1	x_7
		D_8			1	x_8
	Qty		x_9	x_{10}	x_{11}	

The constraint equations for Phase 2 are:
non-negativity conditions

$$x_9, x_{10}, x_{11} \geq 0 \quad (9)$$

and the constraints with respect to available quantities are:

$$x_9 \leq 500 \quad (10)$$
$$x_9 \leq 600 \quad (11)$$
$$x_{10} \leq 500 \quad (12)$$
$$x_{10} \leq 600 \quad (13)$$
$$x_{11} \leq 500 \quad (14)$$
$$x_{11} \leq 700 \quad (15)$$
$$x_{11} \leq x_1 \quad (16)$$
$$x_{10} \leq x_2 \quad (17)$$
$$x_9 \leq x_3 \quad (18)$$
$$x_9 \leq x_4 \quad (19)$$
$$x_9 \leq x_5 \quad (20)$$
$$x_9 \leq x_6 \quad (21)$$
$$x_{11} \leq x_7 \quad (22)$$
$$x_{11} \leq x_8 \quad (23)$$

As the constraints (10), (12) and (14) exclude constraints (11), (13) and (15), Equations (11), (13) and (15) can be excluded from further consideration. However, for the purpose of understanding the methodology which is proposed in the continuation, these constraints will be kept, and in the inequalities (16) through (23) the variables are moved to their left sides so that they now read:

$$-x_1 + x_{11} \leq 0 \quad (16')$$
$$-x_2 + x_{10} \leq 0 \quad (17')$$
$$-x_3 + x_9 \leq 0 \quad (18')$$
$$-x_4 + x_9 \leq 0 \quad (19')$$
$$-x_5 + x_9 \leq 0 \quad (20')$$
$$-x_6 + x_9 \leq 0 \quad (21')$$
$$-x_7 + x_{11} \leq 0 \quad (22')$$
$$-x_8 + x_{11} \leq 0 \quad (23')$$

After Phase 2, the remaining quantities of standard parts are:

$m = 500 – x_{10}$
$n = 600 – x_{10}$
$p = 500 – x_{11}$

q = 700–x_{11}

r = 500–x_9

s = 600–x_9

t = 1000

u = 700

In Phase 3, the remaining quantity of semi-finished products, standard parts, parts manufactured in Phase 1 and subassemblies manufactured in Phase 2 are used to form the main assembly *GS* in the quantity x_{12} (Table 6).

Table 6. Phase 3

			Products of Phase 3 *GS*	Available quantities
Phase 3	Semi-fin. products	S_1		a = 10026.24–4.888·x_1–3,459·x_2
		S_2		b = 38.733–0.646·x_3
		S_3		c = 12.255–0.219·x_4
		S_4		d = 6.456–0.097·x_5
		S_5		e = 53.36–0.534·x_6
		S_6		f = 38.142–0.191·x_7
		S_7		g = 22.696–0.199·x_8
	Standard parts	GR_1		m=500–x_{10}
		GR_2		n=600–x_{10}
		GR_3		p=500–x_{11}
		GR_4		q=700–x_{11}
		GR_5		r=500–x_9
		GR_6		s=600–x_9
		GR_7		t=1000
		GR_8		u=700
	Products of Phase 1	D_1		x_1- x_{11}
		D_2		x_2- x_{10}
		D_3		x_3- x_9
		D_4		x_4- x_9
		D_5		x_5- x_9
		D_6		x_6- x_9
		D_7		x_7- x_{11}
		D_8		x_8- x_{11}
	Products of Phase 2	PS_1	1	x_9
		PS_2	1	x_{10}
		PS_3		x_{11}
	Qty		x_{12}	

The constraint equations for Phase 3 are:

non-negativity conditions

$x_{12} \geq 0$ (24)

and the constraints with respect to available quantities are:

$x_{12} \leq x_9$ (25)

$x_{12} \leq x_{10}$ (26)

It is more suitable to write the inequalities (25) and (26) in the form:

$-x_9+x_{12} \leq 0$ (25')

$-x_{10}+x_{12} \leq 0$ (26')

In the last phase, i.e. Phase 4, the remaining quantity of semi-finished products, standard parts, parts manufactured in Phase 1, subassemblies manufactured in Phase 2 and the main assembly formed in Phase 3 are used to form the product *P* in the quantity X_{13} (Table 7).

Table 7. Phase 4

			Products of Phase 4 *P*	Available quantities
Phase 4	Semi-fin. products	S_1		a = 10026.24–4.888·x_1–3.459·x_2
		S_2		b = 38.733–0.646·x_3
		S_3		c = 12.255–0.219·x_4
		S_4		d = 6.456–0.097·x_5
		S_5		e = 53.36–0.534·x_6
		S_6		f = 38.142–0.191·x_7
		S_7		g = 22.696–0.199·x_8
	Standard parts	GR_1		m=500–x_{10}
		GR_2		n=600–x_{10}
		GR_3		p=500–x_{11}
		GR_4		q=700–x_{11}
		GR_5		r=500–x_9
		GR_6		s=600–x_9
		GR_7	2	t=1000
		GR_8	1	u=700
	Products of Phase 1	D_1		x_1–x_{11}
		D_2		x_2–x_{10}
		D_3		x_3–x_9
		D_4		x_4–x_9
		D_5		x_5–x_9
		D_6		x_6–x_9
		D_7		x_7–x_{11}
		D_8		x_8–x_{11}
	Prod. of Phase 2	PS_1		x_9–x_{12}
		PS_2		x_{10}–x_{12}
		PS_3	1	x_{11}
	Prod. of Phase 3	GS	1	x_{12}
	Quantities		x_{13}	

The constraint equations for Phase 4 are:

non-negativity conditions

$x_{13} \geq 0$ (27)

and the constraints with respect to available quantities are:

$2x_{13} \leq 1000$ (28)

$x_{13} \leq 700$ (29)

$x_{13} \leq x_{11}$ (30)

$x_{13} \leq x_{12}$ (31)

It is more suitable to write the inequalities (30) and (31) in the following form:

$-x_{11}+x_{13} \leq 0$ (30')

$-x_{12}+x_{13} \leq 0$ (31')

The constraints (1) - (31) are summed in Table 8, which can be the basis for creation of the matrix for solving the given problem of a multiphase process by linear programming.

Table 8. Summary table of constraints

Phase	1								2			3	4	Available quantities
	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	PS_1	PS_2	PS_3	GS	P	**B**
S_1	4.888	3.459												10026.24
S_2			0.646											38.733
S_3				0.219										12.255
S_4					0.097									6.456
S_5						0.534								53.36
S_6							0.191							38.142
S_7								0.199						22.696
GR_1										1				500
GR_2										1				600
GR_3											1			500
GR_4											1			700
GR_5									1					500
GR_6									1					600
GR_7													2	1000
GR_8													1	700
D_1	-1										1			0
D_2		-1								1				0
D_3			-1						1					0
D_4				-1					1					0
D_5					-1				1					0
D_6						-1			1					0
D_7							-1				1			0
D_8								-1			1			0
PS_1									-1			1		0
PS_2										-1		1		0
PS_3											-1		1	0
GS												-1	1	0
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	

Instead of Tables 4, 5, 6 and 7, which can serve as the basis for forming the constraint equations, it is possible to initially form only one summary table for all production phases. In table 8 the phases are shown in different colours. In order to keep the available quantities of semi-finished products from Table 2 and available quantities of standard parts from Table 3 (column B- available quantities), it is necessary, in the part of the matrix which refers to the same category (e.g. parts-parts), to add the number -1 on the diagonal (parts of the table that are grey shaded).

The procedure of writing the constraint equations in the mathematical model is thus shortened and it is possible to write the equations in their matrix form directly from the summary table 8.

3. MATHEMATICAL MODEL

3.1. Objective function

If the maximum profit from the sale of product is desired, the objective function can be written in the form:

$$\max f(x_{13}) = d \cdot x_{13} \tag{32}$$

where: d – *the profit gained by the sale of 1 piece of product*

x_{13} – *the optimim quantity of products which should be manufactured*

If it is assumed that the profit per product piece is d=100*нj*, the objective function reads:

$$\max f(x_{13}) = 100 \cdot x_{13} \tag{33}$$

3.2. Constraints

The constraints (1) - (31) hold for all phases and include the non-negativity conditions of the variables:

$$x_1, x_2, x_3, \ldots, x_{13} \geq 0$$

The mathematical model in its matrix form reads:

It is necessary to maximize the objective function:

$$\mathbf{\max F(X) = d\, X} \tag{34}$$

with satisfying the constraints with respect to available quantities:

$$\mathbf{M\, X \leq B} \tag{35}$$

and the non-negativity condition:

$$\mathbf{X \geq 0} \tag{36}$$

For the given example, the matrices **M** , **X** and **B** read:

$$
\mathbf{M} = \left[\begin{array}{cccccccc|ccc|c|c}
4.888 & 3.459 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0.646 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0.219 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0.097 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0.534 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0.191 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.199 & 0 & 0 & 0 & 0 & 0 \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
\hline
-1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 1 & 0 & 0 \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1
\end{array}\right]
$$

$$
X = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \\ x_8 \\ x_9 \\ x_{10} \\ x_{11} \\ x_{12} \\ x_{13} \end{bmatrix}
\qquad
B = \begin{bmatrix} 10026.24 \\ 38.733 \\ 12.255 \\ 6.456 \\ 53.36 \\ 38.142 \\ 22.694 \\ 500 \\ 600 \\ 500 \\ 700 \\ 500 \\ 600 \\ 1000 \\ 700 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}
$$

4. CONCLUSION

Due to the limited space, the paper has analyzed the phase production problem reduced only to the constraints of available semi-finished products and standard parts. Real problems are much more complex in practice because products are more complex, they require a larger number of production phases and the mathematical model can include some other constraints, such as: labour constraints, available capacities of machines, market constraints, available funds, etc.

In addition, phase processes are not always linear or single criterion processes so the mathematical models which describe this problem are much more complex.

The advantages of the presented methodology for solving problems of a multiphase process by linear programming are as follows:

- Instead of forming several tables which are the basis for defining the mathematical model of a phase process by linear programming, it is possible to shorten the procedure by forming only one summary table,
- In contrast to the classical way of forming a mathematical model in which constraints equations are defined for each phase, the mentioned methodology uses the summary table, which defines forming products per phase, in order to directly define the matrices **X**, **M** and **B**.

- The possibility of occurrence of errors in the process of forming the mathematical model of the problem is considerably reduced.

Acknowledgement: The authors would like to express their gratitude to the Ministry of Education and Science of the Republic of Serbia for their support to this research through the project TR37020.

REFERENCES

[1.] Rajović M., *Linearna algebra – teorija matrica i linearnih operatora*, Akademska misao, Beograd, 2007.

[2.] Vadnal A., *Primjena matematičkih metoda u ekonomiji*, Informator, Zagreb, 1980.

[3.] Mamuzić Z., *Determinante, matrice, vektori, analitička geometrija*, Građevinska knjiga, Beograd, 1974.

35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
Faculty of Mechanical and Civil Engineering in Kraljevo

APPLICATION OF THE TRIANGULAR COORDINATE SYSTEM FOR CREATION OF PLANE AND SPATIAL TERNARY GRAPHS

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Abstract: *In the process of investigation of electrical and mechanical properties of alloys, three-component systems play a very important role. Regression analysis provides a possibility to use experimental results in order to obtain the theoretical dependence of these values on the molar ratio of certain components of the mixture. As this refers to multidimensional problems, it is of great importance to present this correlation, in addition to analytical dependencies, by graphical representations. For these needs Draper and Lawrence introduced a new reference system whose base is a concentration triangle (X1, X2, X3) in which the molar ratios of components are drawn on the sides of the equilateral triangle.*
The paper shows the process of transformation of values from the triangular system into the Cartesian coordinate system and the executable code for presentation of plane (2D) and spatial (3D) ternary graphs in Matlab.

Key words: *mixture design, ternary graph, triangular coordinate system*

1. INTRODUCTION

Three-component systems can be graphically represented in 2-D and 3-D space by applying ternary graphs. The main conditions for application of ternary graphs are:

$$0 \le X_i \le 1; \qquad \sum_{i=1}^{3} X_i = 1 . \qquad (1)$$

X_i – the relative proportion of a component in the mixture.
From the previously mentioned conditions it is obvious that the proportion of each component in the mixture depends on the proportion of the remaining two components.

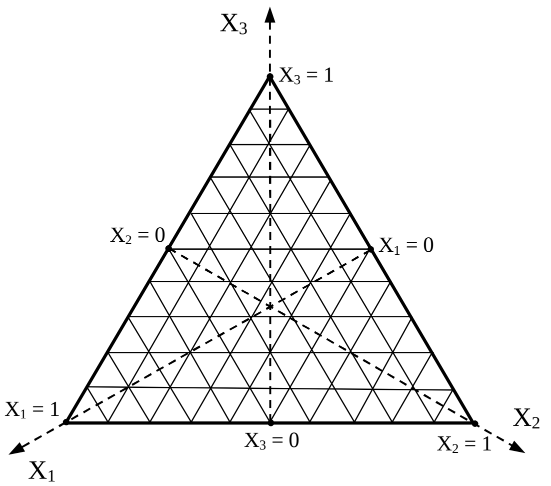

Fig. 1. Vertical sections and directions of increase in the proportion of individual components in the ternary graph

Each point inside the triangle represents a corresponding composition of the three-component system. The vertices of the triangle represent pure substances, while the points on the sides of the triangle represent two-component systems. For a point inside the triangle, the proportion of each component is read by drawing lines through the given point in such a way that they are parallel to the sides of the triangle up to the remaining two sides of the triangle.

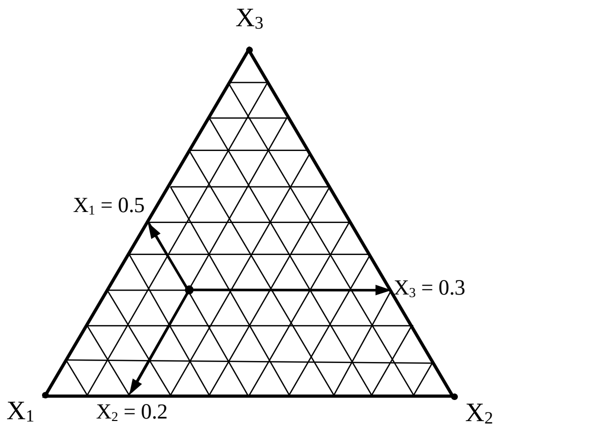

Fig. 2. Determination of the composition of an alloy in the ternary system

2. REGRESSION ANALYSIS

In the process of investigation of electrical and mechanical properties of alloys, three-component systems play a very important role. Regression analysis provides a possibility to use experimental results in order to obtain the theoretical dependence of these values on the molar ratio of certain components in the mixture. For the three-component system, in a general case, regression models can be set up in the form of low-degree polynomials (commonly first, second and third), which are most frequently defined by the following canonical forms [1] [2]:

- Linear regression model

$$y = b_1X_1 + b_2X_2 + b_3X_3 \tag{2}$$

- Quadratic regression model

$$y = b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 \tag{3}$$

- Special cubic regression model

$$y = b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{123}X_1X_2X_3 \tag{4}$$

- Full cubic regression model

$$y = b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{123}X_1X_2X_3 + \delta_{12}X_1X_2(X_1 - X_2) + \delta_{13}X_1X_3(X_1 - X_3) + \delta_{23}X_2X_3(X_2 - X_3) \tag{5}$$

In order to carry out the procedure of regression analysis of the three-component system and make a selection of an adequate regression model, it is necessary to have the following phases [3]:

- Selection of possible forms of regression models
- Calculation of regression coefficients
- Checking the adequacy of mathematical models
- Selection of the regression model
- Evaluation of the significance of regression coefficients of the selected model
- Calculation of confidence limits of regression coefficients of the selected model
- Graphical interpretation of the mathematical model

3. CREATION OF A TERNARY GRAPH

As these problems are multidimensional, it is of great importance to present this correlation, in addition to analytical dependencies, by graphical representations. For these needs, Draper and Lawrence[2] introduced a new reference system whose base is a concentration triangle (X_1, X_2, X_3) in which the molar ratios of components are drawn on the sides of the equilateral triangle.
There is a multitude of software for drawing graphs in the triangular system. However, for the needs of its own research, the Faculty of Mechanical and Civil Engineering in Kraljevo has developed software for regression analysis of three-component systems RA-TeS v1.1 (**R**egression **A**nalysis in **Te**rnary **S**ystem). Besides, the program package Matlab has been used to develop the procedure of obtaining a 3D surface graph and a 2D contour graph in the triangular coordinate system. The possibility of obtaining such a graphical representation gives a clear picture and enables easy interpretation of dependence of the observed characteristic on dependent variables in the ternary system.
The continuation of the paper presents the procedure of conversion of values from the triangular into the Cartesian coordinate system and the executable code for presenting planar (2D) and spatial (3D) ternary graphs in Matlab.
The function Z depends on the variables X_1, X_2, X_3. In order to draw its values into the ternary graph, the program should convert the values X_1, X_2, X_3 from the triangular system into the Cartesian coordinates X and Y. Draper and Lawrence[2] placed the Cartesian coordinate XYZ system into the centre of the equilateral triangle (X_1, X_2, X_3), which is in the plane XY. The relation between the coordinates is expressed by the following dependencies:

$$\left.\begin{aligned} X &= \frac{1}{2}\left(-X_1 + X_2\right) \\ Y &= \frac{\sqrt{3}}{6}\left(-X_1 - X_2 + X_3\right) \end{aligned}\right\} \tag{6}$$

$$\left.\begin{aligned} X_1 &= \frac{1}{3}\left(-3X - Y\sqrt{3}\right) \\ X_2 &= \frac{1}{3}\left(3X - Y\sqrt{3}\right) \\ X_1 &= \frac{1}{3}\left(2Y\sqrt{3}\right) \end{aligned}\right\} \tag{7}$$

For the needs of this paper, the X-axis of the Cartesian coordinate system is perpendicular to the axis X_1 and coincides with the base of the triangle which passes through the vertices X_2 and X_3. The coordinate beginning is placed at the vertex of the triangle X_2 (Figure 3).

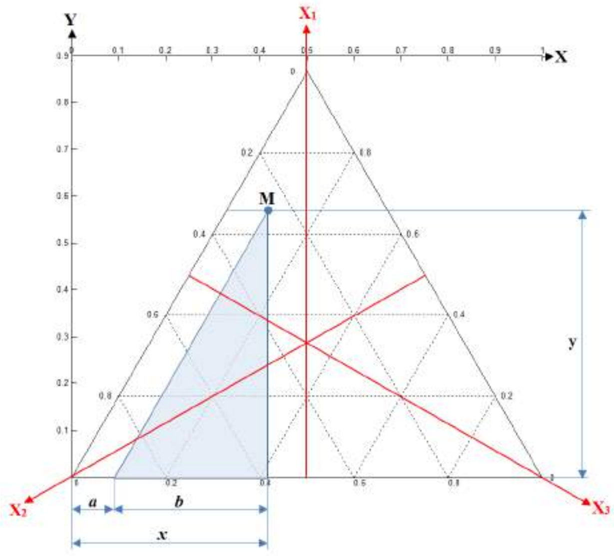

Fig. 3. Correlation between Cartesian coordinates and coordinates in the concentration triangle

The relation between the Cartesian coordinates XY and the coordinates X_1, X_2, X_3 is expressed by the dependencies:

$$\left.\begin{aligned} Y &= \frac{\sqrt{3}}{2} X_1 \\ X &= X_3 + \frac{1}{2} X_1 \end{aligned}\right\} \quad (8)$$

Although the axes X_1 and Y are parallel, for correct conversion it is necessary to multiply the values X_1 by $\frac{\sqrt{3}}{2}$. The relation between the X coordinate and the coordinates of the triangle X_1, X_2, X_3 can be found from Figure 3, i.e.

$$\begin{aligned} a &= X_3 \\ b &= \frac{y}{\sqrt{3}} \\ X &= a + b = X_3 + \frac{1}{2} X_1 \end{aligned} \quad (9)$$

Based on the dependency (8), it is possible to write a code in Matlab for drawing a ternary contour graph in the plane or a ternary surface graph in space. The input data for the values X1, X2, X3 and the values of the function Z are entered in the form of row matrix, and the executable code of the program for drawing graphs reads:

```
%input data
L=[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
x1=[0.00 0.10 0.20 0.30 0.40 0.50 0.60
0.70 0.80 0.90 1.00 0.50 0.45 0.40
0.35 0.30 0.25 0.20 0.15 0.10 0.05
0.00 0.50 0.45 0.40 0.35 0.30 0.25
0.20 0.15 0.10 0.05 0.00]
x2=[0.50 0.45 0.40 0.35 0.30 0.25 0.20
0.15 0.10 0.05 0.00 0.00 0.10 0.20
0.30 0.40 0.50 0.60 0.70 0.80 0.90
1.00 0.50 0.45 0.40 0.35 0.30 0.25
0.20 0.15 0.10 0.05 0.00]
x3=[0.50 0.45 0.40 0.35 0.30 0.25 0.20
0.15 0.10 0.05 0.00 0.50 0.45 0.40
0.35 0.30 0.25 0.20 0.15 0.10 0.05
0.00 0.00 0.10 0.20 0.30 0.40 0.50
0.60 0.70 0.80 0.90 1.00]
Z=[132 46 52 87 45.9 45 51.5 56.1 49.7
52 412 32 25.3 42 46 79.6 83 77.3 87
85.7 48.6 294 82 56.4 32.1 30.6 49.7
53.2 67.2 74.8 89.7 88.2 94.2 ]
Z=Z./100

%vertices of triangle in Cartesian
system
xb=[0 0.5 1 0]
yb=[0 sqrt(3)/2 0 0]
zb=[0 0 0 0]

%conversion of values from triangular
into Cartesian coordinate system
X=x3+1/2*x1
Y=x1*sqrt(3)/2

%drawing points in the plane
figure
ternplot(x1, x2, x3, 'k.');
ternlabel('X1', 'X2', 'X3');

%drawing contour graph
figure
terncontour(x1, x2, Z1);
ternlabel('X1', 'X2', 'X3');
h_ob=findobj(gcf,'Type','hggroup');
set(h_ob,'LevelStep',0.2);
set(h_ob,'ShowText','On');
set(h_ob,'LineWidth',2)
set(h_ob,'LevelList',[0.2 0.4 0.6 0.8
1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6]);

%drawing spatial graph
figure
hold on
plot3(xb,yb,zb,'k-')
plot3(X,Y,L,'k.')
plot3(X,Y,Z,'k.')
ternsurf(x1, x2, Z1); ternlabel('X1',
'X2', 'X3');
terncontour(x1, x2, Z1)
h_ob=findobj(gcf,'Type','hggroup');
set(h_ob,'LevelStep',0.2);
set(h_ob,'ShowText','On');
set(h_ob,'LineWidth',2)
set(h_ob,'LevelList',[0.2 0.4 0.6 0.8
1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6]);
hold off
colormap gray
```

The contour and spatial ternary graphs obtained by the above described procedure are shown in Figures 4 and 5.

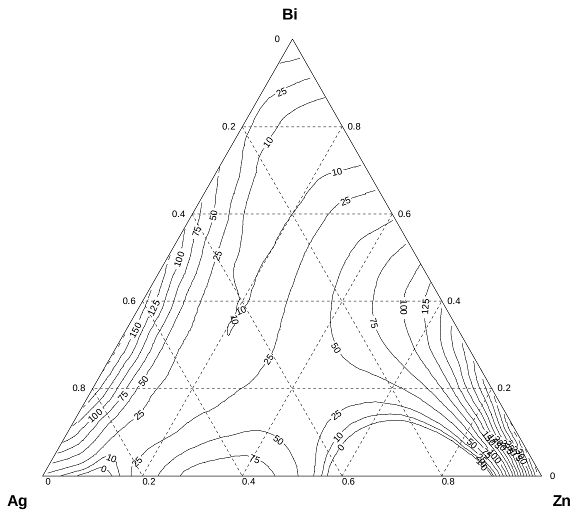

Fig. 4. Ternary contour graph

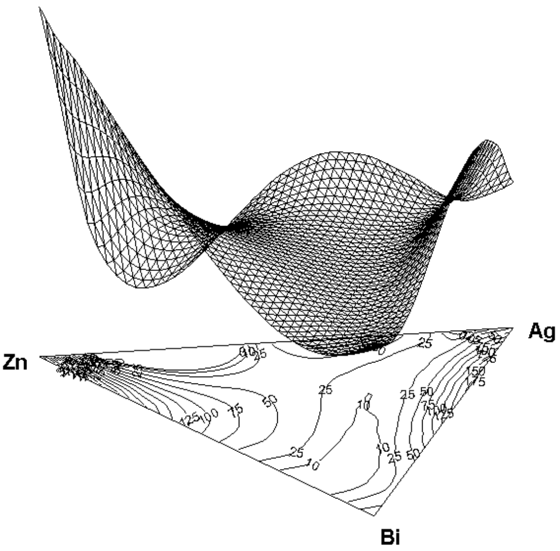

Fig. 5. Ternary spatial graph

The relation and position of the triangular coordinate system in the Cartesian coordinate system can be seen in Figures 6 and 7.

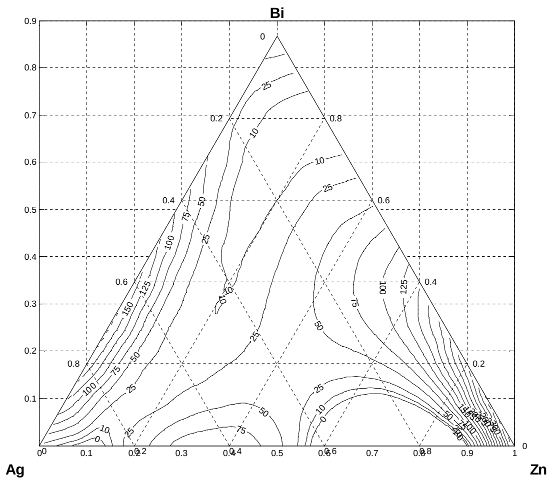

Fig. 6. Position of the contour graph in the Cartesian system

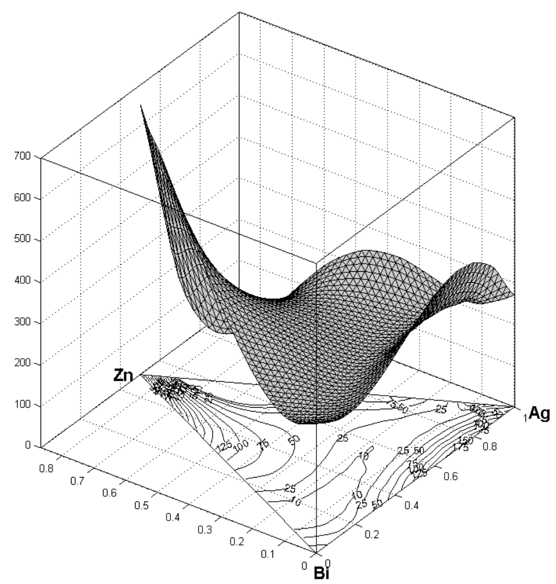

Fig. 7. Position of the spatial ternary graph in relation to the Cartesian system

4. CONCLUSION

The theoretical dependence of the observed characteristic of the three-component alloy on the molar ratio of individual components in the mixture, which is obtained by regression analysis after experimental investigation, is more complete when it is possible to have graphical representation of this dependence. These graphs give a clear visual representation and provide easy interpretation of dependencies of the observed characteristic on dependent variables in the three-component system. Ternary graphs are more convenient than contour and spatial graphs because contour and spatial graphs can be used for presentation and analysis of four-dimensional problems, and categorized ternary graphs can be used even for five-dimensional problems.

There is a multitude of software for drawing graphs in the triangular system. However, most of them have limited capabilities for presentation of the obtained graphs. The advantages of developing ternary graphs in Matlab are: it is possible to adjust the look of the graph, the thickness and shape of the lines, select the combination of colours for presentation of lines and surfaces, the manner of writing data on the graph as well as the type and position of the legend, rotate the graph in space for the purpose of selecting the best view, change the mesh density for presentation of isolines or isosurfaces, etc.

These possibilities offered by Matlab are of great importance because, in addition to the obtained mathematical dependencies of the observed characteristics of three-component alloys, they provide such a method of presentation that can be used by scientific institutions for the purpose of easier interpretation of certain phenomena.

Acknowledgement: The authors would like to express their gratitude to the Ministry of Education and Science of the Republic of Serbia for their support to this research through the project TR37020.

REFERENCES

[1.] Cornell, *Experiments with Mixtures*,2nd ed., John Wiley&Sons, Inc, New York, 1990

[2.] Lazić Ž. *Design of Experiments in Chemical Engineering*, Wilez-VCH Verlag GmbH&Co.KGaA, Weiheim, 2004

[3.] M. Kolarević, M. Vukićević, B. Radičević, M. Bjelić, V. Grković: *A Methodology For Forming The Regression Model Of Ternary System*, The Seventh Triennial International Conference Heavy Machinery HM 2011, Faculty of Mechanical Engineering, Proceedings, Vrnjačka Banja, pp. E 1-6, 29 June-2 July 2011

[4.] Kolarević M, Rajović.M, Bjelić M. *Ternary graph i njegova primena u regresionoj analizi*, IMK-14 Istraživanje i razvoj, časopis instituta IMK "14 OKTOBAR" - Kruševac, Godina XI, broj (22-23) 3-4, Kruševac 2005, str. 113-122.

Product development – product design

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DYNAMIC BEHAVIOUR OF C CONCEPT PLANETARY REDUCER

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Abstract: *Appearance of vibrations has a negative influence on planetary reducer operation. Vibrations which appear at the start have the worst effect. Determination of the mechanism of vibration and their reduction to an acceptable level, are issues for a lot of modern research related to planetary reducers.*
Presented in this paper is a new design solution of a planetary C concept reducer. According to known dynamic models, for this particular reducer, an original dynamic model is developed. The original dynamic model describes dynamic parameters of the presented reducer. At the end of the paper, a discussion is given, and guidelines for further research possibilities.

Key words: *planetary gearbox, dynamic model, dynamic behaviour*

1. INTRODUCTION

Planetary gearboxes with their compact design are largely represented in operating systems of mobile machinery. Operating conditions for transmissions in mobile machinery vary within a wide range. Research of the gearbox dynamics in this case is of great importance. Examining the dynamics of planetary gearboxes leads to conclusions that could greatly assist the development of planetary reducers with regard to: improving their compact design, increasing reliability, increasing the lifetime of the drive, reducing vibration and reducing noise in working conditions, etc.
Due to the aforementioned reasons, a lot of research is done in the field of gearbox dynamics. Analysis of the dynamic behavior of planetary reducers is possible with various computer software, which perform simulations [1], [2], [3]. Computer simulation could be verified by experimental methods [4], [5]. An even greater impact on planetary drive research is given by the possibility of performing physical experiments to verify the computer simulated dynamic analyses.
In this paper a new concept of planetary drive has been developed. Its dynamic model has been made, which has been solved in *MATLAB - SIMULINK*, [6]. The results of the simulation are also presented in the paper. The paper also presents the conclusions drawn from the simulation, and possible directions for future research.

2. DYNAMIC MODEL OF NEW CONCEPT PLANETARY GEARBOX

Planetary gearbox of C conception has been developed in this paper. It consists of a pinion carrier (h), a stationary central ring gear (e), dual pinion (f - g) and the movable central ring gears (b), (Figure 1).The planetary gearbox in Figure 1 is designed for the parameters given in Table 1.

Table 1. Parameters for the design of planetary gearbox

Power	P_{in}	5 [kW]
Input rot. per min.	n_{in}	1200 [min^{-1}]
Transmission ratio	i_R	1:20

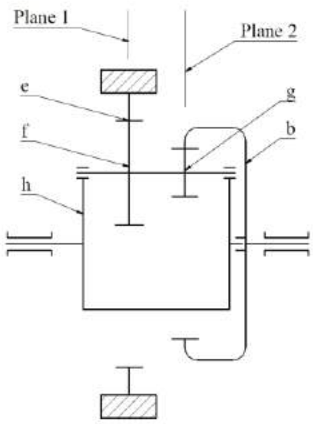
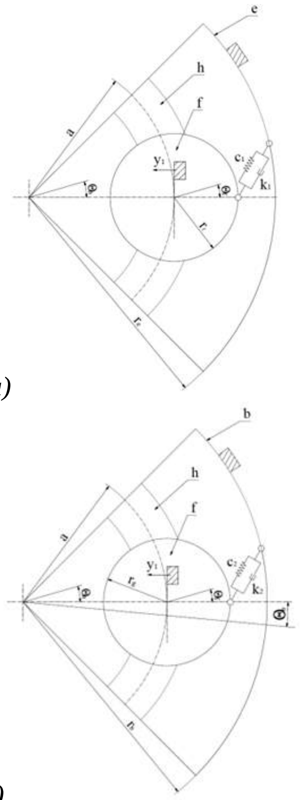


Fig. 1. Schematics of the developed planetary gearbox

2.1 Dynamic model setup

The dynamic model of the planetary reducer is set in such a way as to present the planetary reducer in two planes (Figure 1). Common elements to both planes are the pinion carrier (h), dual pinion (f - g) and the shaft that connects the dual pinion to the pinion carrier. The dynamic model has four degrees of freedom which defines the dynamic system of the planetary reducer: y_1 radial movement, the movement of the pinion carrier (h) around its axis Θ_h, moving dual pinion around its own axis Θ_f (it is equivalent to Θ_g, since it is a dual pinion setup) and moving of the portable central ring gear (b) around its axis Θ_b. The choice of the number of degrees of freedom best describes the operation of this planetary reducer. Contacts between gears which are coupled are modeled as springs and dampers. Contact between the gear (e) and gear (f) is modeled as spring with stiffness c_1 and dumper with damping coefficient k_1, while the contact between the gear g and gear b is modeled as a spring with stiffness c_2, dumper with damping coefficient k_2. The dynamic model does not take into consideration the reduced mass of the system elements, however, in favor of more accurate calculations; the total mass of the system elements has been used here. The values of mass and moments of inertia were obtained from the CAD model of the design of planetary gearbox. The dynamic model of the planetary gearbox is shown in Figure 2.



a)

b)

Fig. 2. The dynamic model of the planetary gearbox a) plane 1; b) plane 2

Degrees of freedom, accordin to which the dynamic model has ben made, are shown at Figure 3. Degrees of freedom are marked at three-dimensional figure of planetary reducer.

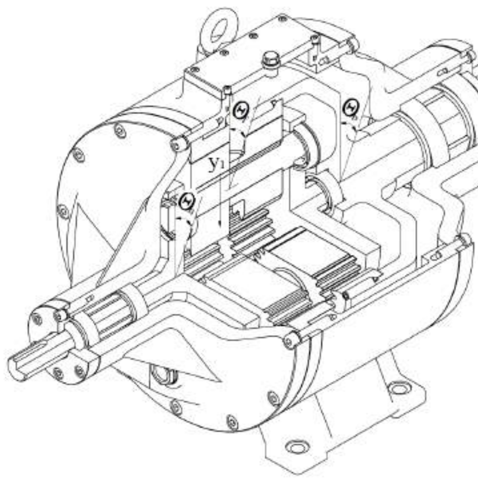


Fig. 3. Degrees of fredoom on planetary reducer

2.2 Dynamic model definition

Defining the dynamic equations of planetary gearboxes is performed using Lagrange equations of the second kind. It has been adopted, because given the choice between it and Dalamber's principle or even Hamilton's principle, Lagrange equations give the best depiction of a dynamic system. When setting up the dynamic equations via Lagrange equations of the second kind, the kinetic energy of the system is first calculated:

$$E_k = \frac{1}{2}\left[m_h\left(\dot{y}_1^2 + a^2\dot{\theta}_h^2\right) + J_{ch}\dot{\theta}_h^2\right] + \frac{1}{2}\left[m_f\left(\dot{y}_1^2 + a^2\dot{\theta}_h^2\right) + J_{cf}\left(\dot{\theta}_h + \dot{\theta}_f\right)^2\right] + \frac{1}{2}\left[m_g\left(\dot{y}_1^2 + a^2\dot{\theta}_h^2\right) + J_{cg}\left(\dot{\theta}_h + \dot{\theta}_f\right)^2\right] + \frac{1}{2}J_{cf}\dot{\theta}_b^2 \quad (1)$$

Following the kinetic energy, the potential energy of the system is calculated:

$$E_p = \frac{1}{2}c_1\left\{y_1^2 + \left[r_f\left(\theta_h + \theta_f\right) + a\theta_h\right]^2\right\} - c_1 y_1\left[r_f\left(\theta_h + \theta_f\right) + a\theta_h\right] + \frac{1}{2}c_2\left\{y_1^2 + \left[r_g\left(\theta_h + \theta_f\right) + a\theta_h - r_b\theta_b\right]^2\right\} - c_2 y_1\left[r_g\left(\theta_h + \theta_f\right) + a\theta_h - r_b\theta_b\right] \quad (2)$$

Finally, the function of system dissipation is calculated:

$$\phi = \frac{1}{2}k_1\left\{\dot{y}_1^2 + \left[r_f\left(\dot{\theta}_h + \dot{\theta}_f\right) + a\dot{\theta}_h\right]^2\right\} - k_1\dot{y}_1\left[r_f\left(\dot{\theta}_h + \dot{\theta}_f\right) + a\dot{\theta}_h\right] + \frac{1}{2}k_2\left\{\dot{y}_1^2 + \left[r_g\left(\dot{\theta}_h + \dot{\theta}_f\right) + a\dot{\theta}_h - r_b\dot{\theta}_b\right]^2\right\} - k_2\dot{y}_1\left[r_g\left(\dot{\theta}_h + \dot{\theta}_f\right) + a\dot{\theta}_h - r_b\dot{\theta}_b\right] \quad (3)$$

After calculating these functions the next step is the Lagrange equations of the second kind for the dynamic system according to the formula:

$$\frac{d}{dt}\frac{\partial E_k}{\partial \dot{q}_i} - \frac{\partial E_k}{\partial q_i} = -\frac{\partial E_p}{\partial q_i} - \frac{\partial \phi}{\partial \dot{q}_i} + Q_i \quad (4)$$

Writing the dynamic equations presents the final step before its putting in matrix form. System of dynamic equations has been putted in matrix form because of its easier solving:

$$\mathbf{M}\{\ddot{q}\} + \mathbf{B}\{\dot{q}\} + \mathbf{C}\{q\} = \{D\} \quad (5)$$

First member in expresion (5) is mass and moment of inertia matrix:

$$\mathbf{M}\{\ddot{q}\} = \begin{bmatrix} m_h + m_f + m_g & 0 & 0 & 0 \\ 0 & m_h a^2 + J_{ch} + m_f a^2 + J_{cf} + m_g a^2 + J_{cg} & J_{cf} + J_{cg} & 0 \\ 0 & J_{cf} + J_{cg} & J_{cf} + J_{cg} & 0 \\ 0 & 0 & 0 & J_{cb} \end{bmatrix} \quad (6)$$

Second member in expresion (5), is dumping matrix:

$$\mathbf{B}\{\dot{q}\} = \begin{bmatrix} k_1 + k_2 & 0 & 0 & 0 \\ 0 & k_1(r_f + a)^2 + k_2(r_g + a)^2 & k_1 r_f (r_f + a) + k_2 r_g (r_g + a) & -k_2 r_b (r_g + a) \\ 0 & k_1 r_f (r_f + a) + k_2 r_g (r_g + a) & k_1 r_f^2 + k_2 r_g^2 & -k_2 r_b r_g \\ 0 & -k_2 r_b (r_g + a) & -k_2 r_b r_g & k_2 r_b^2 \end{bmatrix} \quad (7)$$

Third member in expresion (5) is stiffneess matrix:

$$\mathbf{C}\{q\} = \begin{bmatrix} c_1 + c_2 & 0 & 0 & 0 \\ 0 & c_1(r_f + a)^2 + c_2(r_g + a)^2 & c_1 r_f (r_f + a) + c_2 r_g (r_g + a) & -c_2 r_b (r_g + a) \\ 0 & c_1 r_f (r_f + a) + c_2 r_g (r_g + a) & c_1 r_f^2 + k_2 r_g^2 & -c_2 r_b r_g \\ 0 & -c_2 r_b (r_g + a) & -c_2 r_b r_g & c_2 r_b^2 \end{bmatrix} \quad (8)$$

Last matrix in expresion (5), is impulse matrix:

$$\{D\} = \begin{Bmatrix} 0 \\ M_h \\ 0 \\ 0 \end{Bmatrix} \quad (9)$$

By defining all of matrixes and equations it can be procedeed to solving dynamic system.

2.3 Dynamic model solving

Solving equation systems of the dynamic model, is performed with a simulation in *MATLAB-SIMULINK*. In order to solve the system of equations a solving scheme has been made (Figure 4), in the *SIMULINK* environment. Before solving the system dynamic equations, parameters of the system must be taken from CAD model (Table 2):

Table 2. Dynamic model parameters

Parameter name	Sn.	Value
Sattelite carrier h mass	m_h	11,152[kg]
Gear f mass	m_f	3,376[kg]
Gear g mass	m_g	8,536[kg]
Moment of inertia of sattelite carrier h	J_{ch}	116x10-3[kgm2]
Moment of inertia of gear f	J_{cf}	3x10-3[kgm2]
Moment of inertia of gear g	J_{cg}	17x10-3[kgm2]
Moment of inertia of gear b	J_{cb}	306x10-3[kgm2]
Axes distance	a	69x10-3[m]
Gear f radius	r_f	52,5x10-3[m]
Gear g radius	r_g	48x10-3[m]
Gear b radius	r_b	117x10-3[m]
Pair f – e stiffness	c_1	1,67x1010[N/m]
Pair g – b stiffness	c_2	1,56x1010[N/m]
Pair f – e dumping	k_1	3200[Ns/m]
Pair g – b dumping	k_2	2400[Ns/m]

Dumping and stiffness coefficient values has been taken from literature, [3], [8].

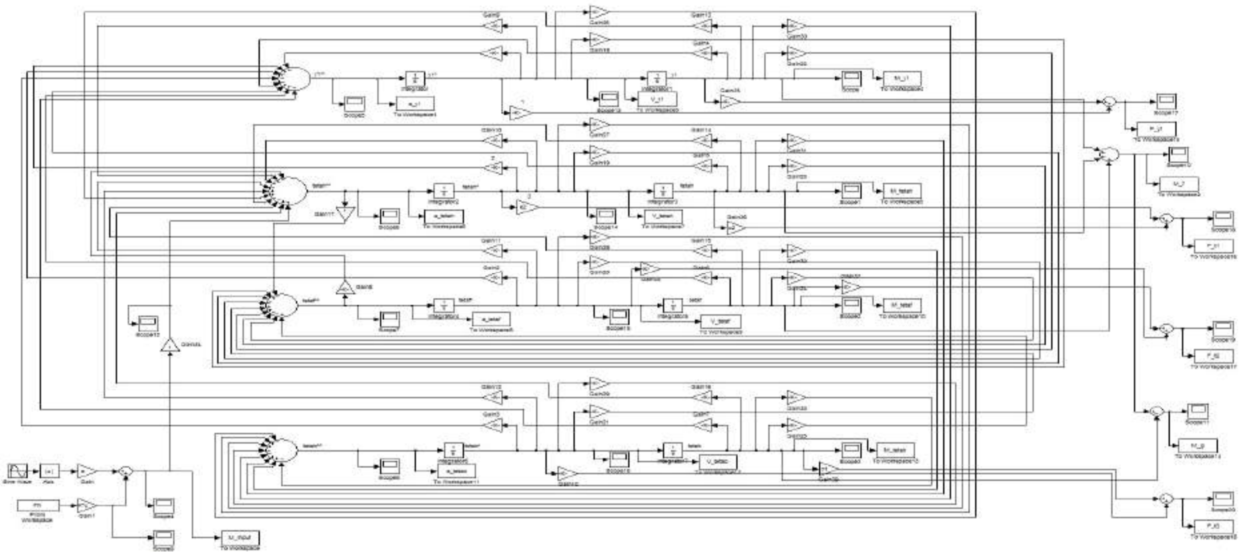


Fig.4. Schematics of dynamic system solver in SIMULINK

3. RESULTS OF SIMULINK DYNAMIC SIMULATION

Simulation of the dynamic model has been performed in two periods of oscillation of the dynamic system. Impulse of the oscillating dynamic system was performed with the moment M_h, as an input impulse parameter. Moment M_h was developed as an absolute sine function (Figure 5), [7].

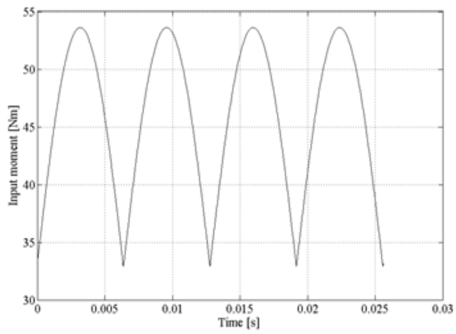


Fig. 5. Impulse moment, M_h

With the introduction of an impulse moment the simulation is started (Figure 5), which simulates the dynamic oscillation of the planetary gearbox system. As the output of diagrams are obtained: acceleration, velocity (Figure 6), displacement (Figure 7) and total displacement of all four degrees of freedom in the dynamic system. Acceleration along the directions of degrees of freedom, at the beginning of the first period of oscillation, is with large variations, while at the end of the second period of the oscillations is in calm variations. Final product of *MATLAB-SIMULINK* simulation are the dynamic forces (Figure8).

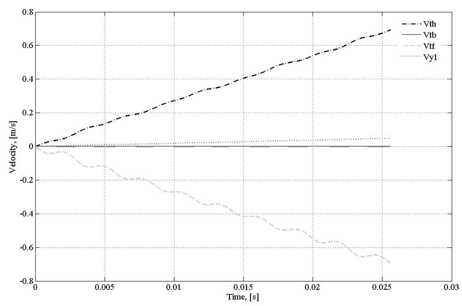


Fig. 6. Velocities of reducer elements at c_1=1,67x1010[N/m]; c_2=1,56x1010[N/m]; k_1=3200[Ns/m]; k_2 =2400[Ns/m]

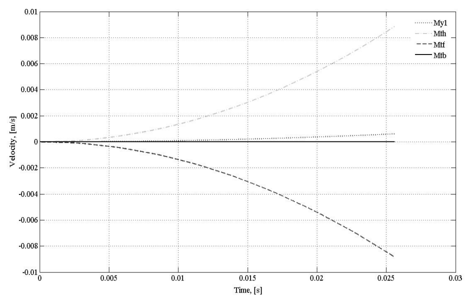
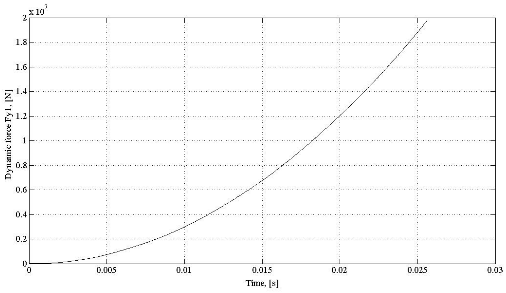


Fig. 7. Movements of reducer elements at c_1=1,67x1010[N/m]; c_2=1,56x1010[N/m]; k_1=3200[Ns/m]; k_2 =2400[Ns/m]

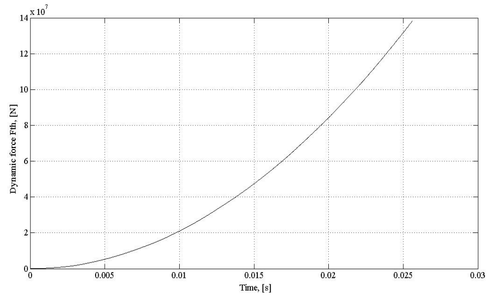
Calculation of dynamic forces has been performed according to formula:

$$F_{dyn} = c \cdot q + k \cdot \dot{q} \tag{10}$$

Dynamic force, which is calculated according to formula (9), presents complete dynamic force which is acting at particular moment at element of reducer. From figure 8 it can be seen that oscillations of dynamic force its far less than oscilations on velocities.



a)



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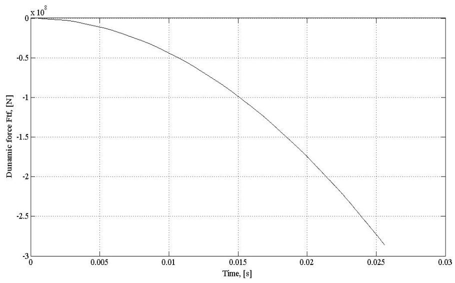

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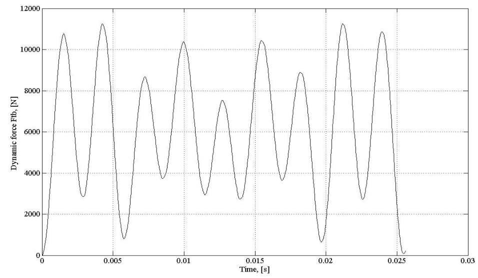

d)

Fig. 8. Dynamic forces of reducer elements at c_1=1,67x1010[N/m]; c_2=1,56x1010[N/m]; k_1=3200[Ns/m]; k_2=2400[Ns/m], a) shaft of double satellite f-g; b) satelite carrier h; c) double satellite f-g and d) mov. central gear b

From figure 8 it can be seen that the bigest dynamic force acts at double satellite f-g. Double satellite only has the negative dynamic, because the direction of force depends of the direction of movement and velocity. The smallest dynamic force acts on movable centra gear b, but that dynamic force has the greatest oscillations (Figure 8d).

4. CONCLUSION

When the simulation has been completed, it can be concluded that the most critical is the first period of oscillation. After the first period of oscillation, the dynamic oscillations of the dynamical system are calming. This rule applies to the dynamic force, and acceleration, and velocity, and displacement. Research of the dynamics of planetary gear from this point of view can greatly help to reduce vibration at startup of planetary reducer. Further research on this issue are available on a theoretical and analytical and experimental design. At the level of theoretical screening can be done at: improving the model, the dynamic force that involves measuring of the dynamic force in real planetary gear unit, the determination of stiffness through simulation and many other parameters and their causes. On the experimental design can be made and measured values in order of confirmation of results obtained by simulation.

REFERENCES

[1] C. YUKSEL, A. KAHRAMAN, (2004) *Dynamic tooth loads of planetary gear sets having tooth profile wear*, Mechanism and Machine Theory, Vol. 39, p. 695-715

[2] H. DING, A. KAHRAMAN, (2007) *Interactions between nonlinear spur gear dynamicsand surface wear*, Journal of Sound and Vibration, Vol. 307, p. 662–679

[3] BATINIĆ, V., S. MUDŽEKA, (2002) *Dynamic loads of mechanical gearboxes*, IRMES 2002 Conference Proceedings, p. 703-708

[4] V. Batinić, (2000) *Internal dynamic loads of planetary gear trains,* Master thesis, Faculty of mechanical engineering, University of Belgrade

[5] V. BATINIĆ (2005) *Internal dynamic loads of planetary gear trains*, Doctor of philosophy dissertation", Faculty of mechanical engineering, University of Belgrade

[6] M. BLAGOJEVIĆ, V. NIKOLIĆ, N. MARJANOVIĆ, Lj. VELJOVIĆ (2009) *Analysis of cycloid drive dynamic behavior*, Scientific Technical Review, Vol. LIX, No. 1, 2009, pp. 52-56

[7] M. MATEJIĆ, Lj. VELJOVIĆ, V. MARJANOVIĆ, M. BLAGOJEVIĆ, N. MARJANOVIĆ, (2013) *DYNAMIC BEHAVIOR OF PLANETARY GEARBOX NEW CONCEPT*, DEMI 2013 Conference Proceedings, pp. 321-328,

[8] V. BATINIĆ, (1998) *Dynamic stability of planetary gearboxes*", IRMES 1998 Conference Proceedings, p. 539-544,

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35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
Faculty of Mechanical and Civil Engineering in Kraljevo

DESIGN OF A DELTA WOUND CORE TRANSFORMER WITH NOISE REDUCTION

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Abstract: *Distributive transformers with traditional E-magnetic core are important sources of noise in urban substations and urban areas. Noise reduction is achieved by reducing magnetic induction, which also leads to dimension increase of magnetic core, and thus to an increase in material and price of transformers. This paper presents a method for calculation and design of new generation distributive transformers with delta wound core with improved functional characteristics, reduced losses and lower noise level than conventional distributive transformers. It also presents original production technology of delta wound core on the modified machine with special tools that enables the same machine to perform operations winding process.*
In addition to lower noise level, transformers with delta wound core have more advantages over other types of transformers and higher economical production that can be organized in small enterprises.

Key words*: Drsign, transformer, delta core, noise reduction*

1. INTRODUCTION

Transformers fall under the group of the most important and most efficient electrical machines in the transmission of alternating current to great distances. Tesla's genius discoveries of the magnetic field and the asynchronous motor in 1888, together with the construction of the first hydro power plant in Niagara in 1895 according to Tesla's ideas, where alternating current was transmitted with the help of a transformer to the city of Buffalo distanced at 40km with insignificant losses in transmission, led to the second industrial revolution. Thanks to the transmission of n-phase AC over great distances, factories started being constructed where the crudes, transportation routes and workforce were, as opposed to adjacent to power plants as was the case when machines were driven by direct current machines.
Power transformers as fundamental systems for transformation of electricity from one voltage level to another, in the phase of transmission or electricity generation they have several sources of noise, of which the most important are:

1. Magnetic core – where vibrations occur due to the effect of magnetic forces (magnetostriction)
2. Windings – where vibrations of the conductors occur due to electrodynamics magnetic forces and
3. Aerodynamic and hydraulic noise of the cooler – which is generated by the operation of pump units for water cooling or fans for air cooling.

Magnetostriction is a phenomenon that results in a change of dimensions of material being in the magnetic field, and in the case of transformers it results in changes of dimensions of transformer's sheet of magnetic core. The changes are in few μm/m for typical transformer's sheet. The value of magnetostriction depends on magnetic induction type of transformer's sheet and mechanical strains that arise due to the effect of electromagnetic forces. Magnetic forces are generated within the joints of pillars and yokes of magnetic core.
Although the construction of power transformers in its basis hasn't been changed notably since 1885 until today, some of the significant development results have been achieved in recent decades in the area of application of new materials, reduction of losses, increment of power and voltage levels, regulation, production technology, testing and maintenance of transformers.
Transformer's noise is very important exploitation characteristic of power transformers, which is measured in any final test with methods prescribed by the standards IEC 60076-10 (2001) and IEEE Std C57.12.90 (2006), and at the same time the recommended values of the permitted noise levels by NEMA - National Electrical Manufacturers Association Standards TR1 (1998) must be met. Recommended values of the permitted noise levels of power transformers are defined depending on the power of the particular transformer, test voltage and cooling method.

2. CONSTRUCTION OF A DELTA WOUND CORE TRANSFORMER

In contemporary three phase transformer manufacturing, the E-core is the most common type of magnetic core which is constructed by stacking numerous specially cut parts of electrical steel boards. The structure of an "E" core is most often comprised of an upper part– a trapeze-shaped yoke with angles of 45° and a "V" cutout of 90° in the middle, the outside limbs that are also trapezoidal with 45° angles, and a central limb shaped like a double arrow with a vertex of 90°. The more advanced method of assembling the "E" core of a transformer is a so called "step lap" method, which in relation to the classical construction requires two holes per board, enabling a proper magnetic core stacking. With the "E" core, the three phases of the transformer are joined in the same line which causes difference in interphase relations and that will introduce asymmetry of electrical values in power transmission system. Magnetic circuit of such transformer consists of a few thousand parts, and cutting waste is above 5%. Once, the stacking of such magnetic circuit is finished the core is still in loose state and has to be extra fastened by additional means in order to become compact and to reduce noise during transformer operation.

To eliminate the shortcomings of the transformer with an "E" core, producers performed various researches in order to out with more favorable geometry and structure of the magnetic core of three-phase transformers. One of the better solutions were so called "delta" transformer cores, with symmetrical shape and optimal phase core distribution in the vertices of the equilateral triangle and its yoke cross-section area is only half of the cross-section area of the limb. All three yokes are of the same length, and its total mass is a 2/3 mass of yokes for an equivalent E-type magnetic core. The magnetizing currents in a "delta" core are symmetrical, equal in all phases and they are third harmonic free (Fig.1).

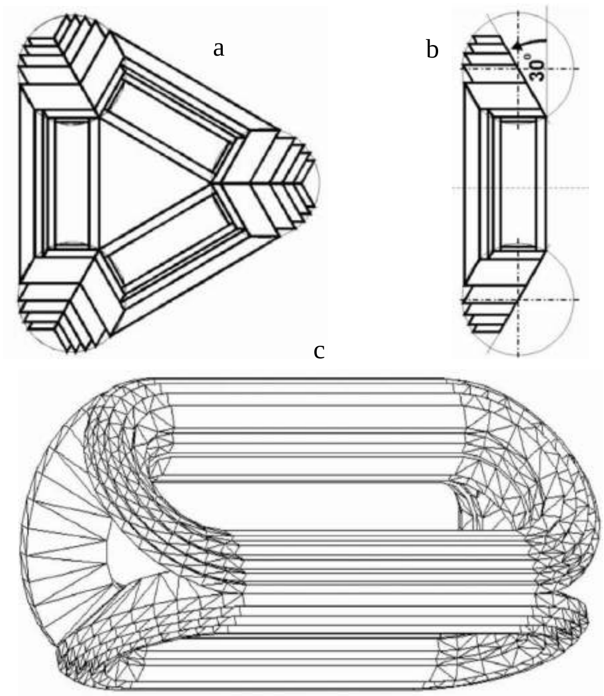

Fig.1. Construction of a delta wound magnetic core

a) Cross section of a magnetic core

b) Cross section of the rectangular spools

c) Wound delta magnetic core

The technology behind the construction of a delta core isn't based on the technique of stacking the cut electrical steel boards, but in the winding technique of the board strips (Fig.2) which has significant advantages. Winding them eliminates cutting scrap and thus significantly reduces material costs. Wound "delta" cores are of simple construction, have a fast and cheap building process, small magnetizing currents, provide reduced noise and vibration level during operation and enable core torrefying which result in a reversion to the original properties of the electrical sheet, which inevitably deteriorate after every treatment.

Fig.2. Technology of making the active part of a delta wound core transformer

The best known solution of the magnetic "delta" core for a three phase transformer was up till now realized by small Swedish company Hexaformer. Their solution has a major flaw with the construction not being technologically competitive but also very complicated to make. The Hexaformer delta-wound magnetic core has a hexagonal cross section shape of the core, but with insufficient fulfilling of an ideal circle, about 82.5%.

This construction solution is also based on the wound delta core, but with significantly better characteristics in relation to Hexaformer. The magnetic core is made simpler with standard technological equipment by using special tools. Forming the structure of a three-phase wound delta magnetic core is done by making three identical rectangular spools with rounded short sides. Rectangular spools are wound from electrical steel strips of different widths and a corresponding displacement, which achieves a total connection angle of under 30°. The three rectangular spools are on connecting sides of the limbs wound into a delta core and with metal clamps or poly glass strips are joined into a unique construction.

The advantage of this construction solution's in relation to all current solutions is very significant. It is specially perceived in the greater degree electrical steel utilization, because strips with a maximum width of 0.577 of the value of the diameter of the circumcircle of the magnetic core limb can be used to wound the core. The optimization of filling the cross section of the magnetic core limb mainly achieves a construction with seven steps that can be realized with five different strip widths and achieved a degree of geometrical filling to an ideal circle above 90%.

The wound delta core of a three-phase transformer, makes three rectangular spools, connected by their longer sides into a triangle. Each rectangular spool is wound by moving the strips while winding them by an angle of 30°, so the step lap winding is designated by the following criteria: their vertices are on the semi-circle of the magnetic core limb's cross-section, and their bases are on a line passing through the center of the circle at an angle of 30° against the axial line of the rectangular spools or against the winding plane of the rectangular spools.

3. CALCULATION OF GEOMETRICAL PARAMETERS OF THE MAGNETIC CORE

To produce three identical rectangular spools from which the delta core is formed, the width of the strip needs to be designated (a_i) and the width of the wound layer (b_i) for every segment of the rectangular spools. Besides, the as well as pattern by which the rectangular spools will be woundeds needs to be dimensioned. For every voltage level, power and other transformer characteristics, through the design phase are designated the basic construction parameters (Fig.3 and Fig.4):

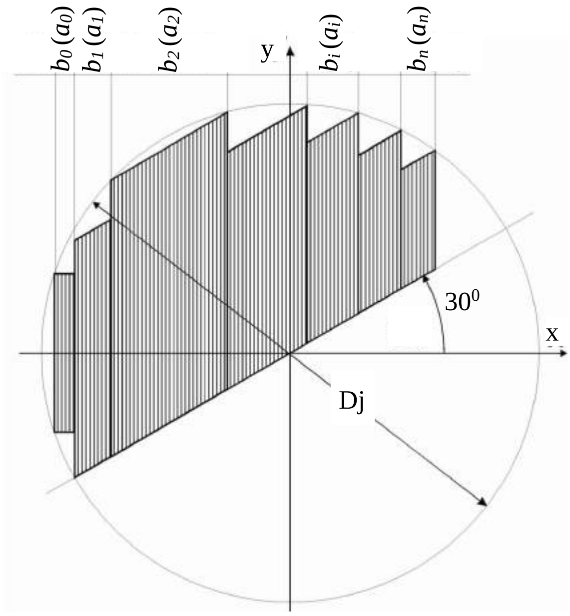

Fig.3. Cross section of the magnetic core limb

- Dj – diameter of the circumcircle of the magnetic core,
- Bj – distance between the limbs of the magnetic core,
- Hj – length of the magnetic core limbs,
- Rj – internal radius of the curve of the rectangular spools, because the reduced dimensions of the active part of the transformer can make the yokes into shorter sides of a rectangle, and not in a semi-circular shape
- 30° – the displacement when winding the rectangular spools.

The zero rectangular spool b_0 (a_0) is wound horizontally (without a 30°displacement angle) so strip width a_0 ($a_0 < Dj/2$) and width of the wound layer b_0 can be determined graphically. The width of the wound layer b_0 can be determined analytically too:

$$b_0 = \sqrt{D_j^{\,2} - a_0^{\,2}} \qquad (1)$$

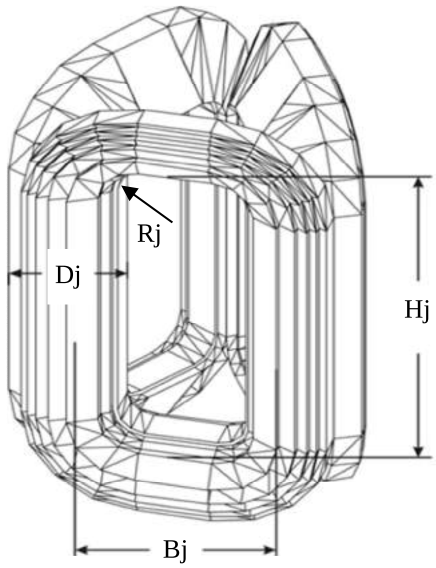

Fig.4. Geometrical measures of the magnetic core

The first and the other rectangular spools b_1 (a_1) are wound at a 30° displacement angle, so the width of strip a_1 ($a_0 < a_1 \le Dj/2$) and the width of the wound layer b_1, which is supposed to contact the circumcircle of the magnetic core limb cross section, can be determined graphically. Furthermore, the width of the wound layer b_1 can be calculated analytically too:

$$b_1 = \frac{-2a_2 tg30^0}{2(1+tg^2 30^0)} - \frac{\sqrt{4a_2^{\,2} tg^2 30^0 - 4(1+tg^2 30^0)(a_2^{\,2} - 0.25D_j^{\,2})}}{2(1+tg^2 30^0)} - 0.5D_j \cos 30^0 \qquad (2)$$

Where a_2 is the width of the second layer of the rectangular spools ($a_1 < a_2 \le 0.577 \cdot Dj$). The width of the rest of the wound layers of the rectangular spools b_i (a_i), $2 \le i \le n$ is determined depending on the solution to the quadratic equation:

$$X_{i1/2} = \frac{-2a_i tg30^0}{2(1+tg^2 30^0)} \pm \frac{\sqrt{4a_i^{\,2} tg^2 30^0 - 4(1+tg^2 30^0)(a_i^{\,2} - 0.25D_j^{\,2})}}{2(1+tg^2 30^0)} \qquad (3)$$

which can be either both negative or have one positive solution. If both solutions are negative, the width of the wound layer of the rectangular spools is $b_i = |X_{i1} - X_{i2}|$, but if one solution is positive (X_{i1}) then the width of the wound layer is $b_i = X_{i1} - X_{(i-1)1}$.

Determining the internal width and length of the rectangular spools at the same time represents the dimensioning of the pattern around which the winding of the magnetic core is performed. The shorter end of pattern B of the rectangular spools is determined according to the formula

$$B = B_j - (D_j \cos 30^0 + 2b_0), \qquad (4)$$

while the longer end of the pattern A is determined acording to the formula

$$A = H_j + 2R_j. \quad (5)$$

Winding the rectangular spools is performed on a modified machine for winding windings with a computer, controlling the axial displacement, by using a system for the control of the clamping force of the electrical steel strip.

4. CHARACTERISTICS OF DELTA WOUND MAGNETIC CORE

The advantages of the “Shingle Core” transformer against classical “E” core construction solutions are multiple (Fig.5). Only the most important are listed:

- Reduced noise and transformer vibrations by 9%,
- Smaller size and mass of the transformer by 20%,
- Smaller energy losses in the exploitation of transformers by 20%,
- A smaller magnetizing current by eight times (cca 0.1%),
- No-load: cos φ = 0.995 (cca 1.00),
- Third harmonic free in the magnetizing current,
- An ideal symmetry of all phases,
- A simple and efficient installation of the transformer and perennial exploitation without maintenance.

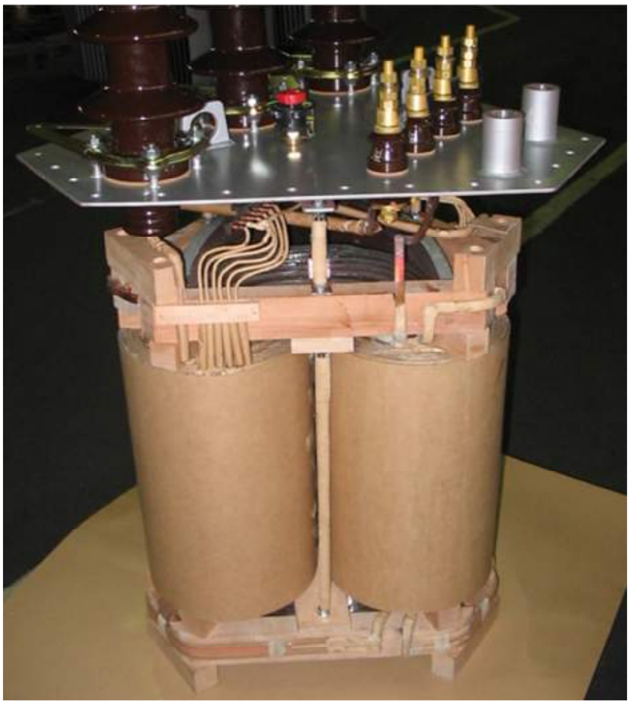

Fig.5. Active part of delta wound magnetic core transformer

The entire laboratory testing has been performed for all the 16 types of delta wound magnetic core transformers produced by company Minel Trafo in Mladenovac and attests have been awarded according to the requirements of several national standards as well as IEC and GOST.

5. CONCLUSION

So far, the patent has been applied in the production of distribution transformers rated up to 2500 kVA, but projects have been done for high power transformers rated 110 kV. Company Minel Trafo has won the production of delta wound magnetic core transformers at a volume of up to 50 transformers a month with modified classical machines for winding cores and windings. Our plan is to invest into the production line with special automatic machines valued at EUR 1.2mn, which would introduce a serial production of transformers with wound delta cores at Minel Trafo in Mladenovac. In this way, contemporary construction transformers from Serbia, with lowered losses, would find their application in the power distribution systems of numerous countries around the world.

REFERENCES

[1] HEXAFORMER (2004) *Transformer Core*, United States Patent Nº US 6.683.524 B1

[2] LUKIC, Lj., PEJCIC, N. (2011) *A New Generation of Transformers with Wound Core Patented by ABS Minel Trafo Serbia*, Paper on call, Proc. 7th International Symposium Nikola Tesla, November 2011, Belgrade, pp. 51-56, 23

[3] HOHN, B. (2002) *Modern Gear Calculation*, Proceedings of the International Conference on Gears, Munich, VDI-Berichte, pp 23-43

[4] LUKIC, LJ., DJAPIC, M., LUKIC,D., PETROVIC, A. (2012) *Aspects of Design of Power Transformers for Noise Reduction*, Proc. 4th International Conference Noise and Vibration, Niš, 17-18. October 2012, Niš, pp. 255-262.

[5] PETROVIC, A., LUKIĆ, LJ., KOLAREVIĆ, M., LUKIC,D. (2012) *Noise measurements of the Power Transformers*, Proc. 4th International Conference Noise and Vibration, 17-18. October 2012, Niš, pp. 263-267.

[6] LUKIC, LJ., DJAPIC, M. (2012) *Railway Transport of 725 MVA Power Transformer*, Proc. XV International Scientific-Expert Conference on Railways RAILCON'12, October 04-05, 2012, Niš, pp.253-256

[7] LUKIC, D., CIRIC, D., LUKIĆ, LJ. (2012) *Transformer's Noise Measurements Using Sound Pressure Method*, Proc. 20th Telecomunications forum (TELFOR), Beograd, pp. 736-739

Acknowledgement: The results presented in this paper are part of research activities within roject TR37020 – „The development of methodologies and means for noise protection of urban areas“, which is funded by Ministry of Education and Science, Government of the Republic of Serbia. The authors wish to express their gratitude to Serbian Ministry of Education and Science for support through out the project TR37020.

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GEOMETRY ANALYSIS OF STRAIGHT FLUTED TAPS

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Abstract: *The paper presents cutting tools geometry analysis of the active part of straight fluted taps. In addition to setting the analytical models, the taps are modeled in Autodesk Inventor CAD package with main parameters from external database. The geometry of the cutting tool is defined in detail in the geometry system, which includes a set of geometric parameters that determine the absolute and relative positions of all elements in machining system. This system includes all the parameters that determine the geometric accuracy of machines, tools and fixtures, as well as initial indicators of quality. Surfaces, cutting edges and tool angles, as a set of geometric elements with certain relations, define the geometry of the cutting tool. To derive the relation between the angles that define the geometry of the tools, the transformation matrix for coordinate systems of taps is defined, using the conventions for their description and representation which are used in problems of the solid modeling, i.e. computer graphics. In this way we can detect the influence of geometry on the main process factors: friction and wear between the tool and the chip, tool and part, tool life, the dynamic stability of a machining system, temperature and heat balance in the cutting zone, chip shape, surface finish, and others.*

Keywords: tap, cutting tools geometry, tool angles, CAD

1. INTRODUCTION

Metal cutting is one of the most important methods of removing material in the production of mechanical components. This treatment identifies the major problem areas and relates observed performance to fundamentals of physics, chemistry, materials behavior, and the engineering sciences of heat transfer, solid mechanics, and tribology [1, 4].

Cutting processes are extremely complex largely due to the fact that two basic operations occur simultaneously in close proximity with strong interaction: large strain plastic deformation in a zone of concentrated shear, material transport along a heavily loaded region of relative motion between chip and tool [1].

All cutting operations share the same principles of mechanics of cutting, but their geometry and kinematics are different. The first step in prediction of forces acting on a cutting tool is to consider a relatively simple orthogonal cutting process in which the cutting edge is perpendicular to the cutting speed and the deformation occurring in the plane, in order to continue to use the results of this analysis as a base for the development of a much more general case of oblique cutting where edge is angled to the cutting speed [4].

Tapping is a common operation used to produce internal screw threads in the predrilled hole with special tool, named tap. This is one of the more demanding machining processes.

Figure 1 shows the layout of machine taps M10 and M8.

Fig. 1. Machine taps (HSS-E, EMo5Co5)

2. STRAIGHT FLUTED TAPS GEOMETRY

The tool-in-hand and the tool-in-use reference system of planes can be defined for any tool. Tool-in-hand geometry includes a set of geometric elements, which are defined through the tool drawing, used in manufacturing, sharpening or measurement the tool. Tool-in-use geometry works with real or effective geometric elements of cutting tools, which appear in the cutting operations [2].

The figure 2 shows the tool-in-hand and the tool-in-use geometry of cutting tool part of machine tap with three straight flute, with nominal diameter $\boldsymbol{D}$, tool back rake $\boldsymbol{\gamma_p}$ and tool cutting edge angle $\boldsymbol{\kappa_r}$, at selected point **0** on major cutting edge.

Projection of major cutting edge is shown in the plane P_r which is normal to cutting speed v at selected point.

Assumed working plane P_f contains cutting speed and feed speed. The cutting edge is approximately a straight line due to the small length of cut and rake angle. The cutting edge is inclined at approximately the chamfer angle κ_r, to the plane P_f as shown in the plane P_r.

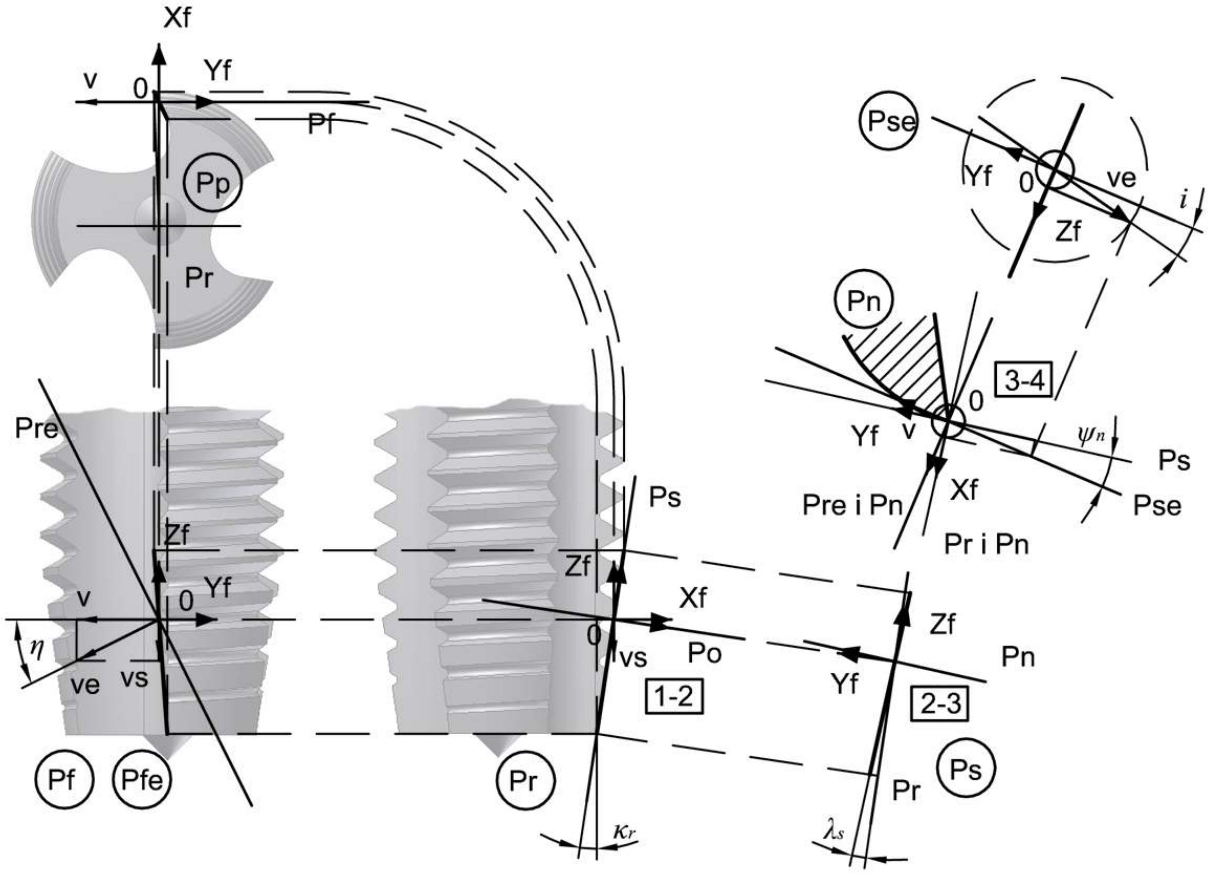


Fig. 2. Tool-in-hand and the tool-in-use geometry of machine tap.

Conventions for the description and presentation of the coordinate system and the indexing system of the transformations are from theory of computer graphics and modeling systems of solids, and are also used in robot manipulation problems.

An arbitrary point in the space P, can be presented with the position vectors with respect to a variety of coordinate systems, so for coordinate systems in which the origin coincides:

$$^{1}\mathbf{p}={}^{1}_{2}R\cdot{}^{2}\mathbf{p}\text{ , then }{}^{2}\mathbf{p}={}^{1}_{2}R^{-1}\cdot{}^{1}\mathbf{p}={}^{1}_{2}R^{T}\cdot{}^{1}\mathbf{p}\text{ ,}$$

because the inverse of a rotation matrix, R, is the same as its transposed matrix.

Based on figure 2, switch from the tool-in-hand coordinate system "f" defined with the basic planes P_r, P_f and P_p, labeled as "1", into the tool-in-use system "4" defined with planes P_n, P_{se} and their normal plane that contains intersection $P_{re} \cap P_n$, requires three rotation matrix.

$$^{1}_{2}R = R_{y,\kappa_r} = \begin{bmatrix} \cos\kappa_r & 0 & \sin\kappa_r \\ 0 & 1 & 0 \\ -\sin\kappa_r & 0 & \cos\kappa_r \end{bmatrix},$$

$$^{2}_{3}R = R_{x,\lambda_s} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\lambda_s & -\sin\lambda_s \\ 0 & \sin\lambda_s & \cos\lambda_s \end{bmatrix},$$

$$^{3}_{4}R = R_{z,\psi_n} = \begin{bmatrix} \cos\psi_n & -\sin\psi_n & 0 \\ \sin\psi_n & \cos\psi_n & 0 \\ 0 & 0 & 1 \end{bmatrix},$$

where κ_r denotes the chamfer angle, λ_s is the angle of inclination and ψ_n is the angle between the cutting edge planes in tool-in-hand (P_s) and tool-in-use (P_{se}) geometry, measured in the normal plane P_n.

Coordinates of the end point of the resultant cutting velocity vector v_e in the first (plane P_f) and last coordinate system (plane P_{se}) according to figure 2, are known:

$$^{1}\mathbf{p} = -v_e\begin{bmatrix}0 & \cos\eta & \sin\eta\end{bmatrix}^{\mathrm{T}}$$
$$^{4}\mathbf{p} = -v_e\begin{bmatrix}0 & \cos i & -\sin i\end{bmatrix}^{\mathrm{T}},$$

where η represents the resultant cutting speed angle and i is the oblique angle. From the expression:

$$^{1}\mathbf{p}={}^{1}_{2}R\cdot{}^{2}_{3}R\cdot{}^{3}_{4}R\cdot{}^{4}\mathbf{p}$$

we obtain the unknown angles:

$$tg\psi_n = \frac{tg\eta\sin\kappa_r}{\cos\lambda_s + tg\eta\cos\kappa_r\sin\lambda_s}$$

Rake angle, γ_{n0}, in the normal plane P_n, at selected point 0 on major edge is defined according to the figure 2, from the expression:

$$tg\gamma_{n0} = tg\gamma_{p0} \frac{\cos\lambda_s}{\cos\kappa_r} - tg\kappa_r \sin\lambda_s \,.$$

Accordingly, tool-in-use rake angle, γ_{ne0}, in the normal plane P_n, at selected point 0 on major edge is:

$$\gamma_{ne0} = \gamma_{n0} + \psi_n \,.$$

The angle η is defined in the tool-in-use coordinate system as the feed speed over tangential cutting speed:

$$tg\eta = \frac{v_s}{v} = \frac{P}{\pi d_0} \,.$$

Relation between angles of tool-in-hand geometry is:

$$tg\lambda_{s0} = tg\gamma_{p0} \sin\kappa_{r0} \,,$$

and angle γ_{p0} as a function of γ_p:

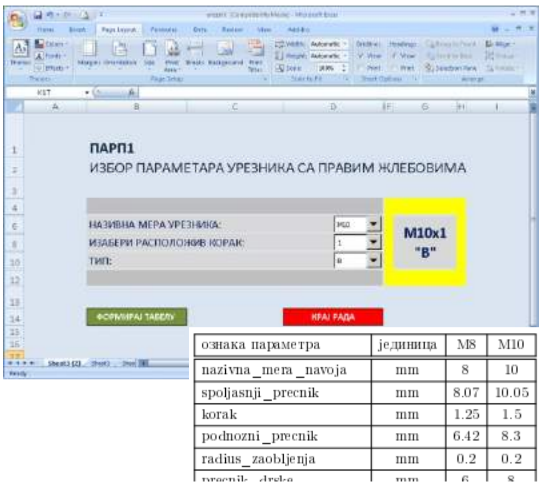
$$\gamma_{p0} = \arcsin(\frac{D}{d_0} \sin\gamma_p) \,,$$

where D, d_0 represent tool diameters.
Angle of inclination i in tool-in-use cutting edge plane P_{se} at selected point 0 on major edge is defined as follows:

$$tg\, i = \frac{\sin\eta\cos\kappa_r\cos\lambda_s - \cos\eta\sin\lambda_s}{\sin\eta\sin\kappa_r} \sin\psi_n$$

2. MACHINE TAPS MODELING

Class of taps is modeled in the CAD programming environment of application *Autodesk Inventor 2011*, using the technique of parametric modeling. In this way, the input into the CAD software is a set of parameters that describe specific dimensions of the taps. One CAD model is created based on tap technology, and works with a number of different sets.
Parameters can be saved in `.xml` format or spreadsheet software program format. This model uses `.xls` format, *Microsoft Excel* spreadsheet format, which can be defined in a similar open-source programs (eg, *Apache OpenOffice*).
Figure 3 shows the basic screen layout of the program for the preparation of a table with the parameters based on nominal diameter, tap pitch, and tap type as inputs.



ознака параметра	јединица	M8	M10
nazivna_mera_navoja	mm	8	10
spoljasnji_precnik	mm	8.07	10.05
korak	mm	1.25	1.5
podnozni_precnik	mm	6.42	8.3
radius_zaobljenja	mm	0.2	0.2
precnik_drske	mm	6	8

Fig. 3. Inputs of the program for the formation of a table with the parameters.

Figure 4 shows the image of cutting edges of machine tap M10 magnified 35 times, and simultaneously display image of M10 tap model obtained by the CAD software using set of parameters.

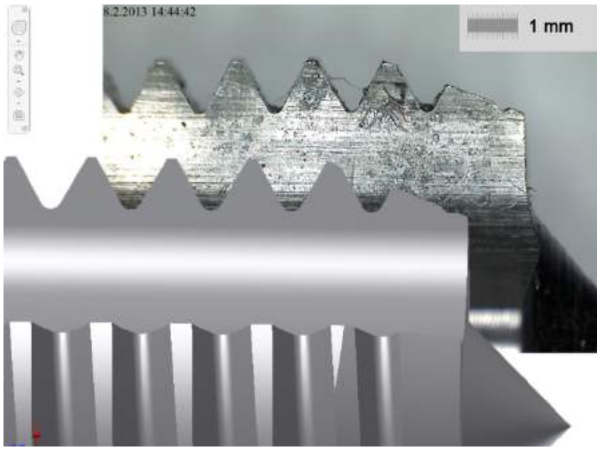


Fig. 4. The cutting edges of the tap in one flute of tap M10 (×35 magnification) and the CAD model

3. FORCE PREDICTION

Many studies [3-6] have shown that the influence of the uncut chip thickness **h** and chip width **b** on cutting force is more significant then depth of cut $\mathbf{a_p}$ and feed **f**. For example, in turning, the cross-section of cutting, with the same depth of cut and the feed has a different form, depending on the value of the tool cutting edge angle.
It is convenient to express the cutting forces in the following form [3, 4]:

$$^4F_1 = K_{tc}bh + K_{te}b,$$
$$^4F_2 = K_{rc}bh + K_{re}b,$$
$$^4F_3 = K_{fc}bh + K_{fe}b,$$

where F_1 is cutting force or main force acting in the direction of the cutting velocity, F_2 thrust force in the direction perpendicular to the produced surface and F_3 feed force in the direction of the tool travel.
The corresponding cutting constants are

$$K_{tc} = \tau_s / C_1 \cdot (\cos(\rho - \gamma_n) + tgi\ tg\nu \sin\rho),$$
$$K_{rc} = \tau_s / C_1 \cdot (\cos(\rho - \gamma_n) tgi - tg\nu \sin\rho),$$
$$K_{fc} = \tau_s / C_1 \cos i \cdot (\sin(\rho - \gamma_n))$$

where

$$C_1 = \sin\phi_n \sqrt{\cos^2(\phi_n + \rho - \gamma_n) + tg^2\nu \sin^2\rho} \,,$$

ρ represent the *average friction angle, ν is chip flow angle, and* K_{ie} are edge coefficients.

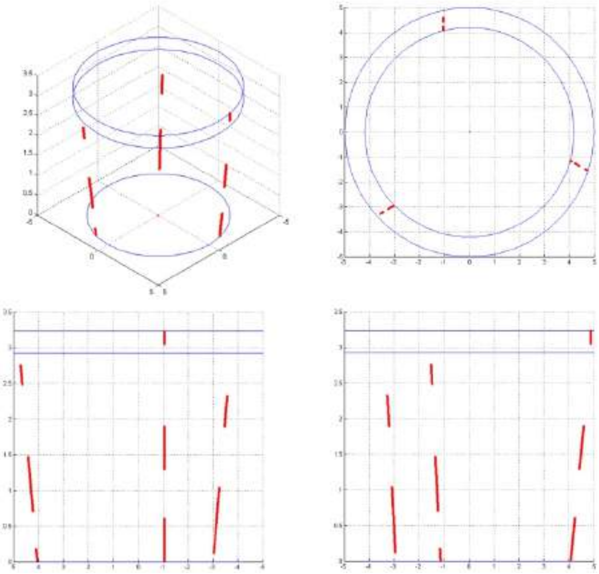


Fig. 5. Major cutting edges of tap

Oblique cutting performs major edge inclined at an angle κ_r, and two minor edges inclined at an angles α and 180^o-α, where α is standard thread angle. The major cutting edges lie on the conical chamfer surface, while the minor edges lie on the flanks of the threads. Figure 5 shows major cutting edges on the conical chamfer surface obtained from CAD model of machine tap to determine the length and position of cutting edges. Now, with

$$^1\mathrm{F} = {}^1_2R \cdot {}^2_3R \cdot {}^3_4R \cdot {}^4\mathrm{F}\,,$$

the cutting force and torque can be evaluated from:

$$\mathrm{F}_z = \sum_i {}^1\mathrm{F}_{3i}\,, \quad \mathrm{M} = \sum_i {}^1\mathrm{F}_{1i} \cdot r_0 .$$

4. CONCLUSION

The force and torque acting on a cutting tool during the process are of the fundamental importance in the design of cutting tools. The prediction of cutting forces acting on the workpiece at the shear zone is essential for solving several important issues: to estimate the power of a machine tool; to estimate the straining actions that must be resisted by the machine tool components, jigs and fixtures; to evaluate the significance of various parameters of cutting forces; to evaluate the performance of new workpiece materials, tool materials, etc. with respect to machinability.

REFERENCES

[1] Shaw, M.C., Metal Cutting Principles, Oxford University Press, 2nd ed., 2005

[2] Kalajdžić, M., Tehnologija mašinogradnje, Univerzitet u Beogradu, Mašinski fakultet, Beograd, 2002

[3] Armarego, E.J.A., "A Generic Mechanics of Cutting Approach to Predictive Technological Performance Modeling of the Wide Spectrum of Machining Operations", Machining Science and Technology, vol. 2, no. 2, pp. 191-211, 1998

[4] Altintas, Y., Manufacturing Automation, Cambridge University Press, UK, 2012

[5] Chen, N.M., Smith, A.J.R., "Modelling of Machine Tapping with Straight Flute Taps", Proceedings of the 36th International MATADOR Conference, pp. 189-192, 2010

[6] Tsai C.L., Liao, Y.S., "Prediction of cutting forces in ball-end milling by means of geometric analysis", Journal of materials processing technology, 205, pp.24–33, 2008

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ON PRODUCTION ENGINEERING

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Kraljevo - Kopaonik
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EXPERIMENTAL DETERMINATION OF BONE MATERIAL PROPERTIES

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Abstract: *Despite of wide application of finite element analysis (FEA) in stress analysis of human osteoarticular system, description of mechanical properties of bone for use in FEA steel represents a notable problem. On one hand, accurate evaluation of subject specific properties of bone is hard to perform in vivo. On the other, bone material is very specific and its mechanical properties vary from subject to subject and from one bone segment to other. Also, it is difficult to describe mechanical behavior of bone material on macro-scale only. Two approaches have mostly been used to achieve this goal: averaging of material properties over typical bone segments and local mapping of material properties based on CT (computed tomography) numbers. Both approaches require previous determination of material properties in laboratory, using small sized samples extracted from a representative number of cadaveric bones. In addition, mechanical testing of whole bones is performed, in order to compare experimental results to results of numerical ones and verify the chosen approach. This paper aims at describing a typical procedure for bone material testing, with purpose of material modeling for use in FEA and verification of numerical results. It also tends to outline the most important aspects and differences of mentioned procedure, compared to determination of mechanical properties of standard engineering materials.*

Key words*: Mechanical properties of bone, mechanical testing, material modeling, protocols for bone material testing*

1. INTRODUCTION

The determination of the mechanical stresses in human bones, which are induced by physical activities, is of great importance in clinical practice. However, mechanical stress in bones cannot be measured in living subjects without the use of an invasive surgical procedure. The only way to estimate bone stresses non-invasively in vivo is finite element analysis [1].

Today, finite element analysis (FEA) is broadly accepted in biomechanics as a tool for prediction and evaluation of stress state in human bones and implants, with the purpose of surgery planning or bone tissue strength evaluation [2, 3]. Finite element models have proved to be a significant tool for investigating a wide range of biological problems, such as designing better artificial hip and knee joints, optimizing shape of implants to compensate for absent part of the bones and better fitting of osteo-fixation device in the sceleto-muscular system. It is especially useful in non-standard cases of bone fractures or tissue degradation.

One of the main issues that arise during finite element (FE) model preparation is the accuracy of material characterization. A number of approaches is used for description of material properties in FE bone models. The prevailing ones are segmentation of the model to typical zones, attributed by averaged material properties, and local material mapping based on correlation between CT (computed tomography) numbers, bone density and mechanical properties of bone tissue. Those are described in detail in [4], together with extensive discussion of their features and a suggested modified approach. In all cases, the accuracy of analysis results directly depends on the accuracy of material model and its coefficients, which are used to describe the mechanical properties of bone tissue.

Mechanical testing has been a direct way to evaluate the mechanical behavior of bone tissue [5, 6] and surrounding materials tissue [7, 8]. Mechanical tests and density measurements are performed in laboratory using small sized bone samples, extracted from a representative number of cadaveric bones. If verification of FEA results is desired, mechanical testing of whole bones may also be performed.

The methods of mechanical testing of bone tissue are based on fundamental principles of the mechanics of materials. Nevertheless, bone material is very specific and its mechanical properties vary from subject to subject and from one bone segment to another. The knowledge of basic bone structure and its mechanical characteristics is essential for understanding the issues that are the consequence of bone fracture, patients age or bone remodeling [9].

Some of the many factors that influence the outcome of mechanical testing of a bone sample are: geometry, architecture, degree of mineralization, properties of the organic matrix, and hydration [10].

There exist significant uncertainties in the measurements of the mechanical properties of bone, usually due to the small sample sizes and the relatively large length scales of the inhomogeneities. Coefficient of friction between bone samples and clamping tools, which is dependent on sample size and shape, also has significant influence on the accuracy of mechanical testing results. Additional complications that may arise during mechanical testing are the inability to recognize changes in bone structure and the change of equivalent modulus [11].

This paper tends to describe the main stages of a typical procedure for bone material testing with purpose of material modeling for use in FEA. It outlines its most important aspects and differences compared to determination of mechanical properties of standard engineering materials. The use of strict protocols for bone material testing is recommended, in order to properly acquire, extract and store valuable bone material as well as to properly prepare and perform the testing and avoid the possible errors.

2. MECHANICAL PROPERTIES OF BONES

One of the important facts that, to the great extent, influences design, application and durability of the implant and osteofixational material is the knowledge of mechanical characteristics of bones. Mechanical behavior of bones in normal physical conditions is similar to behavior of elastic material without visible changes on the external surfaces [12]. In contrary to the inorganic materials, the bones have adaptive mechanisms that characterize the bone tissue with the ability of regeneration, allowing them to change their mechanical properties and morphology in response to increase or decrease of external load. Mechanical properties of bones directly depend on their structure and function.

Before the start of testing, it has to be clear what kind of bone material will be tested and what mechanical properties are to be determined. The best results can only be obtained if the testing is planned carefully, using a detailed protocol [13]. The protocol should include the description of sources of bone specimens, harvesting procedures, methods of storage, preparation of bone specimens, testing procedures and various factors which may affect the test results.

For determination of bone mechanical properties similar testing methods are used as for standard engineering materials such as metals, wood or polymers. Determination of mechanical properties of bone material is performed by loading of bone tissue specimens extracted from a part of a bone, or by loading of entire bones in tension, pressure, bending, torsion or shearing. Only the methods for static testing will be described in this paper, as the most important and most frequently used ones.

3. PREPARATION OF BONE SAMPLES FOR MECHANICAL TESTING

The main issues related to preparation of bone samples for mechanical testing, may be divided into several groups that outline the important stages of sample preparation protocol:

- The source of samples extraction
- The procedure of samples extraction
- Storage of samples
- Preparation of samples for testing
- Factors which may influence the accuracy of test results

3.1. The source of samples extraction

When sample acquisition is performed, certain ethical rules have to be followed. In this respect it is essential to have the approval of the ethical committee for sample extraction or for performing an experimental procedure on the patient.

There are several major sources of bone material that can be used in mechanical testing. Bone specimens can be obtained from a patient during surgery. A consent form be should be filled out when a bone specimen is taken from or an experimental procedure is performed on a volunteer patient [14]. Bone specimens can also be obtained at necropsy. Necropsy should be done immediately after subject has passed away. If this is not possible, the bone should be put in a refrigerator until the necropsy is performed. If bone specimens are taken within several days (up to 3 to 4 days) of death or euthanasia (for animals), there should be no significant influence on the mechanical properties of the bone tissue [15].

3.2. The procedure of samples extraction

Dissection of soft tissue has to be performed carefully in order to avoid incising of the bone surface, which introduces additional sources of stress concentration. This is especially important if mechanical testing of the entire bone is to be performed later. It is recommended that the bone to be extracted together with the additional quantity of the surrounding tissue, in order to prevent its desiccation and thus the decay of its mechanical characteristics. A good practice dictates the performing of X-ray filming before the storage, as well as sample marking.

3.3. Storage of samples

There exists a number of factors, related to the storage of bone samples, that can significantly alter bone structure and test results. Those factors, that should be addressed when storing bone samples, are: temperature, humidity, sterilization and usage of a solution for sample preservation.

In an ideal situation, the tests should be performed immediately after bone extraction. If it is necessary to postpone the testing for a few days, then the storage of bone samples can be done in a cold chamber of the refrigerator. If bone samples are to be held for a period longer than a few months, it is necessary to freeze them at the temperature of - 20 ˚ C. The freezing should be performed up to one hour after the extraction. If it is feasible, bone samples should be kept at ideal storage temperature of -70 ˚ C.

In order to preserve its mechanical properties, it is recommended that the bone is frozen together with the surrounding tissue with which it was extracted. If the tissue has to be removed, the bone should be wrapped

gauze soaked in saline (min. 9 g of salt per 1l of water) and placed in an appropriate container before freezing.
Before any subsequent testing, bone sample needs to be melted, by keeping it for 3 hours in saline at room temperature.
Nevertheless, some studies have shown that even when the bone is kept frozen as described, it's mechanical properties decrease by 2 - 4% during the three months.

3.4. Preparation of samples for testing

Before the beginning of specimens preparation, it has to be clear what structural level of the bone is going to be tested. Based on the experience of numerous researchers, some recommendations for minimal dimensions of specimen cross section exist [16]. Those dimensions are determined by analysis of the structural levels existing in the composite bone structure. It is recommended that any dimension of a cross section, regardless of its shape, equals no less than 2 mm. If thinner specimens are tested (micromechanical testing), one would expect to get the properties of structural elements of the bone tissue, such as a single osteon, lamellae, or individual trabeculae. Their mechanical behavior, certainly, may not represent that of bone tissue in general, or the behavior of the bone as a whole.
During the process of sample extraction using cutting tools, the bone should be kept wet by periodic soaking in saline. Damaged edges that appear during sample preparation must be removed with sandpaper. Cylindrical samples should be made with diamond "coring" tool, whereby the sample and the tool are fully immersed in saline solution. After the sample is prepared, it should be checked for micro cracks.
Fixation of bone samples to clamping tools is done by immersing in resin, dental cement or bone cement. Before the immersion, bone marrow should be removed from the rest of the bone using water or air jet. Fat should also be removed either chemically or using detergent or alcohol. When implementing this procedure it is necessary to constantly rehydrate the samples in order to avoid the decrease of their mechanical properties.

3.5. Factors which may influence the accuracy of test results

One of the factors that may affect the accuracy of test results is the flexibility of the machine and clamping tools. If the deformation of the clamping equipment or deformation at the contact between clamping equipment and machine is large, it should be taken into consideration when test results are examined. Also, the flexibility of whole machine-clamping tools system should be taken into account if it consists of a large number of elements.

4. MECHANICAL TESTING OF BONE TISSUE

This chapter explains the basic methodology for mechanical testing of bone tissue. There exists a number of methods for mechanical testing of bone. Each method provides the unique information related to the behavior of bone tissue under specific load conditions. Since bone is an anisotropic material, its mechanical properties vary with directions for both cortical [17] and trabecular bones. The type of loading has a great influence on the mechanical behavior of bone at the macroscopic or bulk tissue level. In addition, the mechanical behavior of bone is also load-rate or strain-rate dependent [18, 19].
During mechanical testing it is desirable that temperature and humidity are controlled. If there are no special requirements in this respect or there are no technical conditions for their provision, tests are carried out at room temperature (24 °C) and relative air humidity of 40 to 90%. During the testing, humidity of the samples should be maintained by occasional immersion in saline.
Mechanical tests are performed at a constant low speed, usually up to 1 mm / min. Direct measurement of displacement on the sample may be left out in compression testing if the clamping tools are very stiff and testing is carried out at a constant rate. If tensile testing is performed or the supports are not rigid enough, extensometers or strain gauges should be used, positioned at the medium-fifth of the sample.

4.1 Tensile testing

The most precise method for determination of mechanical properties of the bone is tensile test (Fig. 1.). Tensile test samples must be relatively large and precisely cut (Fig. 2 and 3). This kind of test yields very accurate results if mounting of bone specimen is performed carefully so that the generation of additional stresses, which are the consequence of bending, is avoided.

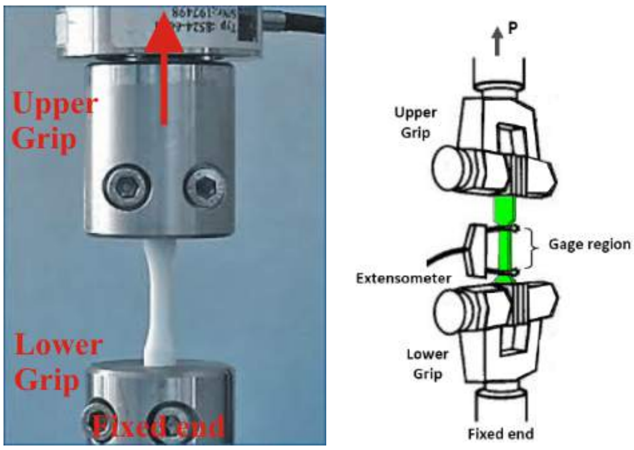

Fig.1. A typical tensile test of bone [17, 21]

Tensile specimens are prepared in rectangular, cylindrical or dumbbell shape. The samples are gripped firmly in the upper and lower clamping tools, to avoid slipping. The ratio of diameters of dumbbell samples (Fig. 2), d / D, should be about 0.5, while the parallel length of the narrow section of the tube should be three times the diameter d. The radius of curvature R should be the size of the parallel length of the narrow part of the tube, in order to avoid stress concentration. The length of the ends of dumbbell specimens, M, equals to ¼ of overall sample length L. To achieve continuous stress state it is necessary to use universal joints or guides. Measurement of the displacement is performed using average displacement value, calculated from values obtained by four sensors positioned around the sample.

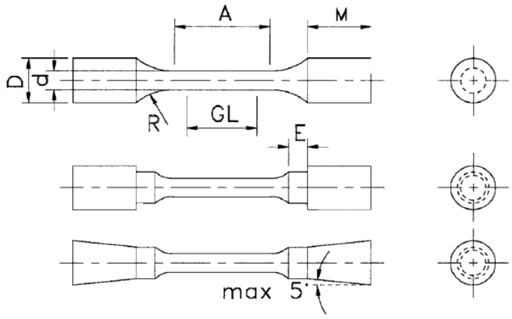

Fig.2. The geometry of dumbbell specimen for tensile testing of cortical bone. The ratio d / D should be close to 1/2, and the parallel length of the narrow part should be at least three times larger than the diameter d [22]

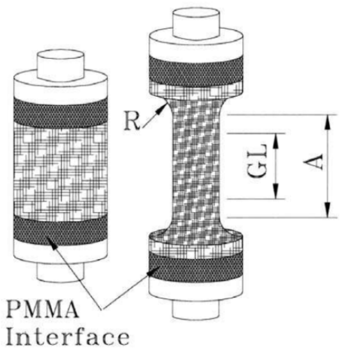

Fig.3. The geometry of the specimens for tensile testing of spongious bone [22]

4.2 Compression testing

Compression testing (Fig. 4) is a popular technique for determination of mechanical properties of bones, as it is easier to perform than tensile testing. The accuracy of compression test results is lower than the accuracy of tensile test results, because of the friction that exists between the sample and clamping tools and also because of sample cracking.

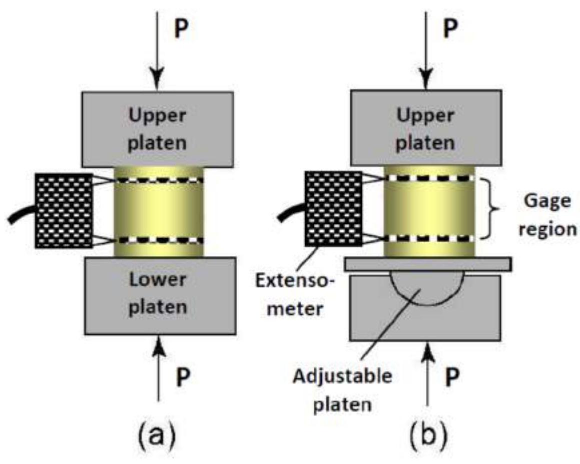

Fig.4. The geometry of cylindrical specimen for compression test: a) clamping tools with fixed plates, b) compression tool with one fixed and one movable plate [17].

Compression test specimens are often of a low height, with cylindrical or square cross-section. To avoid buckling, compression test samples should be prepared in cubic shapes with cube sides of 6 - 8 mm, or cylindrical shape, where L / D = 2 and diameter D = 6 to 8 mm [18, 19, 20]. The sample, which is positioned between compression plates, must be polished in order to remove the non parallelism of specimen surfaces. For the same reason, spherical joints should be used to support compression plates.

5. CONCLUSION

Bone material characterization is a necessary stage in creation of finite element models of bones. It relies heavily on the results of mechanical testing of bone samples. Also, mechanical testing of whole bones may be performed in order to verify numerical results obtained using the mentioned models.

Accurate and repeatable results of mechanical testing of bones may be achieved if testing procedures are executed cautiously and in a correct way. Factors that influence the outcome of mechanical testing of a bone sample are: geometry, architecture, degree of mineralization, properties of the organic matrix, hydration etc. Bone samples must be carefully extracted, in order not to be damaged. It is desirable to carry out an immediate mechanical testing of samples, in order to avoid the decrease of bone material properties. If this is not possible, it is necessary to store the samples according to the procedure described in the paper. During the testing, a special attention should be paid to the stability of the contact between the sample and clamping accessories, as well as the rigidity of the clamping accessories. To minimize the effect of local variations of bone material properties, mechanical properties of the samples (elasticity modulus, yield stress, ultimate tensile/compression stress, etc.) should be determined as the arithmetic mean of the values obtained from several independent tests.

Acknowledgment: The paper is a result of multidisciplinary research in the domain of bioengineering in real medical practice (Virtual Human Osteoarticular System and its Application in Preclinical and Clinical Practice) which is sponsored by the Ministry of Science and Technology of the Republic of Serbia - project id III 41017 for the period of 2011-2014.

REFERENCES

[1] Taddeia F., Cristofolinia L., Martellia S., Gillc H.S. and Vicecontia M. (2006) *Subject-specific finite element models of long bones: An in vitro evaluation of the overall accuracy*, Journal of Biomechanics, Vol. 39, pp 2457 – 2467.

[2] Vicecontia M., Davinellib M., Taddeia F. and Cappello A. (2004) *Automatic generation of accurate subject-specific bone finite element models to be used in clinical studies*, Journal of Biomechanics, Vol. 37, pp 1597 – 1605.

[3] Schileo E., Taddei F., Malandrino A., Cristofolini L. and Viceconti M. (2007) *Subject-specific finite*

element models can accurately predict strain levels in long bones, Journal of Biomechanics, Vol. 40, pp 2982 – 2989.

[4] Korunovic D. N., Trajanovic D. M., Stevanovic M. D., Vitkovic M. N., Stojkovic S. M., Milovanovic R. J. and Ilic S. D. (2013) *Material characterization issues in FEA of long bones*, in Proc. 3rd South-East European Conference on Computational Mechanics an ECCOMAS and IACM Special Interest Conference, Kos Island, Greece.

[5] Anderson M.J., Keyak J.H., and Skinner H.B. (1992) *Compressive mechanical properties of human cancellous bone after gamma irradiation*, Journal of. Bone Joint Surg Am, Vol. 74, pp 747 – 752.

[6] Grimal Q., Haupert S., Mitton D., Vastel L. and Laugier P. (2009) Assessment of cortical bone elasticity and strength: mechanical testing and ultrasound provide complementary data, Medical Engineering & Physics, Vol. 31, pp 1140 – 1147.

[7] Gravius S., Wirtz D.C., Marx R., Maus U., Andereya S., Müller-Rath R. and Mumme T. (2007) *Mechanical in vitro testing of fifteen commercial bone cements based on polymethylmethacrylate*, Z Orthop Unfall, Vol. 145, pp 579 – 585.

[8] Boger A., Wheeler K., Montali A. and Gruskin E. (2009) *NMP-modified PMMA bone cement with adapted mechanical and hardening properties for the use in cancellous bone augmentation*, Journal of Biomedical Materials Research Part B: Applied Biomaterials, Vol. 90, pp 760 – 766.

[9] Spatz H.C., O'Leary E.J. and Vincent J.F.(1996) *Young's moduli and shear moduli in cortical bone*, Proc. Biol. Sci., Vol. 94, pp 263 – 287.

[10] Gallant A. M., Brown M. D., Organ M. J., Allen R. M. and Burr B. D. (2013) *Reference-point indentation correlates with bone toughness assessed using whole-bone traditional mechanical testing*, Bone, Vol. 53, pp 301 – 305.

[11] Ladd J. C. A., Kinney H. J. John, Haupt L. D. and Goldstein A. S. (1998) *Finite-Element Modeling of Trabecular Bone: Comparison with Mechanical Testing and Determination of Tissue Moduli*, Journal of Orthopaedic Research, Vol. 16, pp 622 – 628.

[12] An H. Y., Barfield R. W., and Draughn A. R. (2010) *Basic Concepts of Mechanical Property Measurement and Bone Biomechanics*, Mechanical Testing of Bone and the Bone–Implant Interface, ISBN 1420073567, 9781420073560. Taylor & Francis.

[13] An H. Y. and Bensen V. C. (2010) *General Considerations of Mechanical Testing*, Mechanical Testing of Bone and the Bone–Implant Interface, ISBN 1420073567, 9781420073560. Taylor & Francis.

[14] Mitton D., Rumelhart C., Hans D. and Meunier P.J. (1997) *The effects of density and test conditions on measured compression and shear strength of cancellous bone from the lumbar vertebrae of ewes*, Medical Engineering & Physics, Vol. 19, pp 464 – 474.

[15] Melnis, A. and Knets, I. (1985) *Viscoelastic properties of compact bone tissue*, Modern Problems of Biomechanics, Vol. 2, Knets, I., Ed., Zinatne, Riga.

[16] Linde F. (1994) *Elastic and viscoelastic properties of trabecular bone by a compression testing approach*, Dan Med Bull., Vol. 41, pp 119 – 138.

[17] X.Wang, J.S. Nyman, X. Dong, H. Leng, and M. Reyes. (2010) *Fundamental Biomechanics in Bone Tissue Engineering*, Morgan & Claypool.

[18] Ferreira F. , Vaz M.A. , Simões J.A. (2006) *Mechanical properties of bovine cortical bone at high strain rate*, Materials Characterization, Vol. 57, pp 71 – 79.

[19] Hansen U., Zioupos P., Simpson R., Currey J.D. and Hynd D. (2008) *The effect of strain rate on the mechanical properties of human cortical bone*, Journal of Biomechanics Engineering, Vol. 130, pp 1 - 8.

[20] Vanleene M., Mazeran P.E. and Tho M.C.H.B. (2006) *Influence of strain rate on the mechanical behavior of cortical bone interstitial lamellae at the micrometer scale*, Journal of Materials Research, Vol. 21, pp 2093 – 2097.

[21] *https://encrypted-tbn1.gstatic.com/images?q=tbn:ANd9GcQimRqwjBMaKvxX-RFDyLTMT6m-tAsMpXEsS_Q4_dNHNOMkhoDd*.

[22] *Keller S. T. and Michael A. K.* and *Liebschner* V. C. B. (2010) *General Considerations of Mechanical Testing*, Mechanical Testing of Bone and the Bone–Implant Interface, ISBN 1420073567, 9781420073560. Taylor & Francis.

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DEVELOPMENT OF A MODEL OF THE CHIP TEMPERATURE IN THE CUTTING PROCESS OF WEAR RESISTANT PARTS

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Abstract: *During the treatment by cutting manganese steels with 12% Mn (Hadfield Steel), due to the superficial reinforcement of material and creation of the layers on the chest surface of the blade generates the rise of a high temperature field in the cutting zone. Knowing this temperature field provides possibility of choices of cut elements (tiles) whose technical and technological charactesistics are best suited to the demands of the tecnological process of treatment. This paper presents the modeling of chip temperature in process of treatment on the lathe of the caterpillar pins of the mining machines. A significant number of experiments is conducted with different cutting modes, while the temperature was measured by IC infrared camera. After analyzing the collected data the modeling of chip temperature in the function of cutting mode was performed. Modeling was performed by using RSM method, and four different models were presented. After the modeling the testing of the created models was performed, the most favorable was defined and the validity of its use was established.*

Key words*: turning, manganese steel,chip temperature, RSM*

1. INTRODUCTION

In the process of steel treatment with high content of manganese (12% Mn – Hadfield steel) there is a reinforcement of processed metal surface and prominent creation of the layers on the chest surface of the blade. Manganese steel castings after the technological process of turning off, which have surface layer with remains of sand and cracks are particularly hard to treat. In such cases, there are dynamic loads of tools that affect frying of the cutting edge and appearance of the high temperature in the cutting zone. Improving the workability of these materials is achieved by the process of cutting in the heated condition. However, warming of the metal violates the mechanical characteristics of the metal, such as solidity and hardness. In this paper we analyzed the treatment of caterpillar pins of the bucket wheel excavator. Considering the fact that excavators work in abrasive environments, it is necessary for the caterpillar pins to have high solidity and hardness. In accordance to that, treatment of these elements is not recommended to run in heated condition. During the treatment of the caterpillar pins of the bucket wheel excavator, it is important to make the correct choice of cutting mode. Adequate choice of cutting the mode requires good knowledge of phenomenon that occur during the process of cutting. One of the significant phenomenon is the cutting temperature. High temperature has a negative impact on quality of processed surface, as well as on tool wear. The most important temperature in this process is the maximum heating temperature of the cutting tools. Because of the chip layers on the chest surface of the tool, this temperature can not be measured directly by using infrared camera. By using numerical methods, based on chip temperature (whose measuremet and modeling is presented in this paper), it is possible to get to the temperature of the cutting tools. The literature is rich with research ties between cutting parameters and cutting temperature. Silva and Wallbank (1999) provided an overview of the analytical and experimental methods used to measure cutting temperature [8]. I. Mukherjee and P. K. Ray (2006) provided an overview of the optimization techniques in metal cutting processes[13]. W. Grzesik at al. (2005) showed that modeling of cutting temperature using finite element method[11]. N.A. Abukhshim at al. (2006) analyzed the methods of measurement and measurement results for high temperature cutting [7]. N.R. Dhara and M. Kamruzzaman (2007) presented the thermodynamics of steel processing and cooling effect on the reduction temperature [9]. L. Dharmesh and V. Ajay (2012) developed an analytical model to determine the temperature during cutting [10]. O. Pius at al. (2013) presented an analysis of the effect of temperature distribution in cutting tool life and wear using finite element methods [12]. D. Tanikić and V. Despotović (2012) presented the modeling of cutting temperature using artificial intelligence [6]. The special significance of this research provides material of the workpiece. Manganese steel is one of the materials with difficult workability. The main purpose of this paper is to present the thermodynamic properties and their modeling in cutting process manganese steels.

2. THERMODYNAMICS OF CUTTING

One of the important factors in treatment by cutting is the temperature, which appears as inevitable phenomenon in the process of removing the chip. If we look the balance of energy consumption when cutting, it can be approximately considered (if the cutting is performed without vibrations) that the entire energy used in cutting is converted to heat, if you ignore the increase of surface voltage, deformation of crystals etc., which are negligible for the balans of energy. More than 99,5 % of energy (mechanical work) spent in deforming the work piece material and overcoming the friction force on the contact surface of the cutting wedge of the tool (chest and back) is converted into heat. Analysis of thermal sources shows that the greatest amount of heat is generated in the zone of deformation and in contact of chest surface of the cutting wedge of the tool and the chip. These are precisely the areas which, in analysing problems of cutting process, are given the most attention. Most of the generated heat is being drained by chip. Heat generated in the cutting zone leads to warming of the workpiece, chip and cutting tools and characteristic temperature fields and temperatures *(Figure 1).* In figure 1 it is clear that the different points of chip and chest surface of the cutting wedge of the tool are at different temperatures. In both cases, the maximum temperature is in the middle of the contact. The temperature in any point in the cutting zone depends on the coordinates of that point (x, y, z) and the time (t): $T = f(x,y,z,t)$[1].

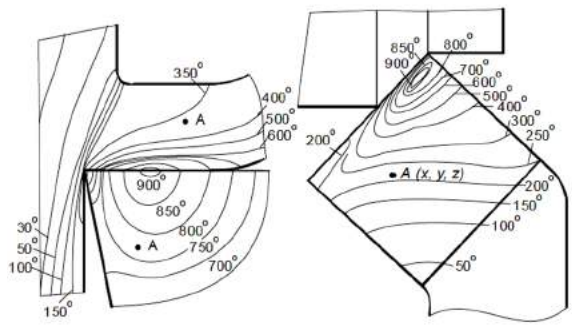


Fig. 1. Temperature fields in steel treatment

Methods of measuring the tools temperature, chip and work piece are divided into two groups, depending on whether the temperature is measured in the cutting zone or in the narrow tool area, chip and work piece, and those methods of measuring are:

- Average cutting temperature
- Narrow area temperature

For measuring the average cutting temperature the most used methods are: calorimetric method, method of changing color of the thin layer of oxides, method of heat-sensitive colors or coating and method of natural thermocouples. For measuring the cutting temperature in narrow area methods applied are: method of artificial thermocouples, method of semi-artificial thermocouples, radiation and the optical method, the method of microscopic analysis, method of electrothermic analogy etc.

3. EXPERIMENTAL SETUP AND METHODOLOGY

The experiment was realized in the company "IKG Guča". For testing and measuring the universal lathe was used. Material being used is manganese steel, marked GX120Mn12, and with hardness of 220HB. Initial dimensions of the workpiece are $\emptyset 75x260\ [mm]$. The treatment is performed without using coolants and lubricants, because of the use of these means would prevent capturing characteristic chip area. Recording was realized by using IC infrared camera IR FLEX CAM T. IR FLEX CAM T is thermal imaging system for wavelengths outside the visible spectrum from 8µm to 12 µm, with the following characteristics:

- Range of temperature measurement 0˚C - 1200˚C.
- Thermal sensitivity 0.09˚C na 30˚C.
- LCD display 5"; picture resolution 320x240; pictire formats: JPEG, BMP, PCX, PNG, PSD.

Figure 2. gives a schematic diagram of the experiment, and Figure 3. presents the thermogram for cutting conditions:$a = 0.5mm, V = 70\,m/min\,, S = 0.08\,mm/o$

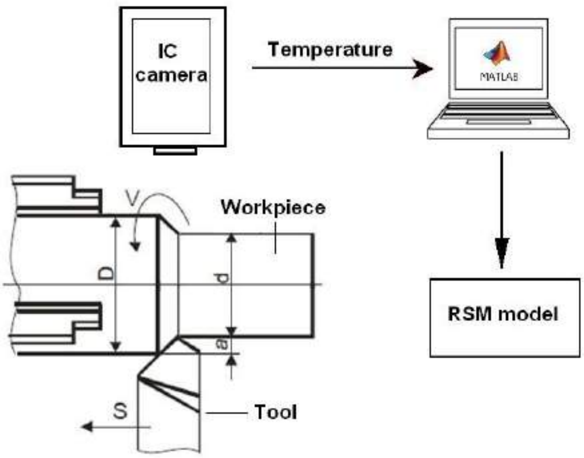


Fig. 2. Schematic diagram of the realization of the experiment and data processing

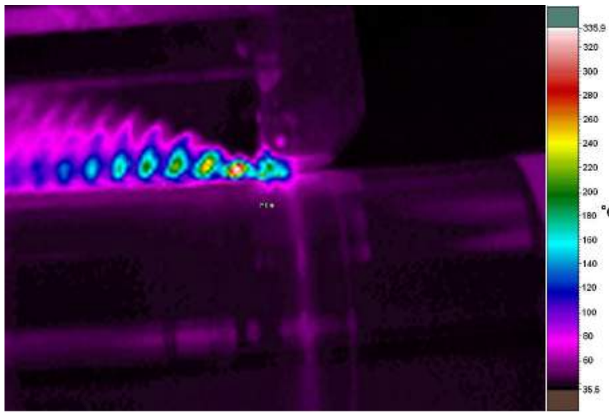
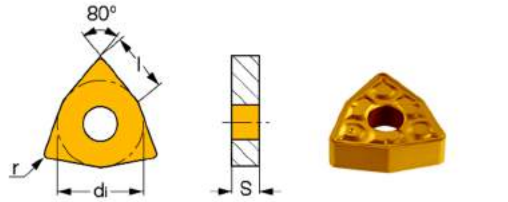


Fig. 3. Displaying thermogram ($a = 0.5\ [mm], V = 70\ [m/min], S = 0.08\ [mm/o]$)

A tool that has been used is ISCAR cutting tool that consists of two parts: the blade holder WNMG080408-TF, combined with the tiles IC907 (ISO M20), TiAlN coating tiles (ISCAR) (Figure 4.).



r=0.4 mm; di=12.70mm; S=4.76 mm; I=8.70mm

Fig.4. ISCAR cutting tool - tiles IC907

During the process of scraping the temperature rises until it reaches appropriate maximum value and it varies further during cutting process. It is very important to perform the measurement after a certain time since the begining of the treatment. Based on previous researches and monitoring of the begining of research, it was concluded that the period from 60 to 80 s has been sufficient to stabililize the cutting temperature. The obtained thermograms are saved on camera memory card, and then processed by a computer to the final output which is an analytic function of the temperature dependence on cutting mode. The temperature was measured for the following cutting parameters (Table 1).

Table 1.

a [mm]	*0.5; 1; 1.5;2.*
V[m/min]	*70;80;90;115;120.*
S[mm/o]	*0.08; 0.160; 0.214; 0.321*

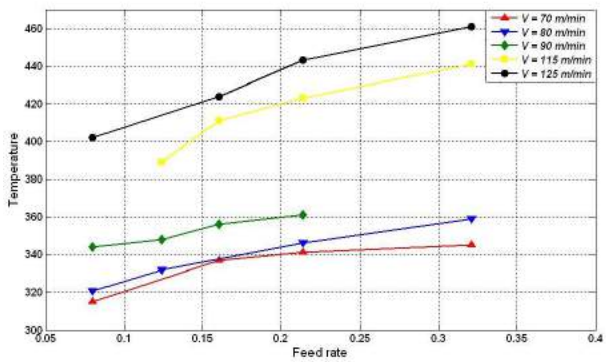


Fig. 5. Chip temperature at cutting depth a=0.5 mm

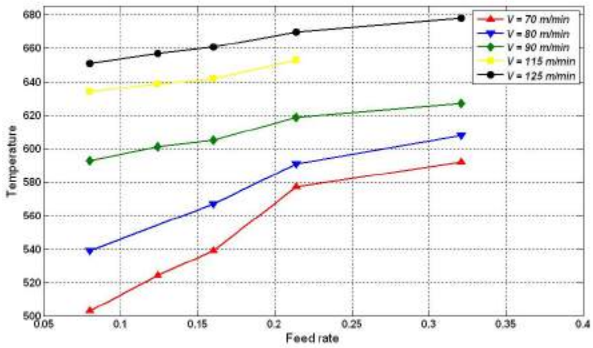


Fig. 6. Chip temperature at cutting depth a=2 mm

Figures 5 and 6 give a graphical representation of the recorded results for the minimum and maximum cutting depth.

4. MODELING OF THE CHIP TEMPERATURE

In this section of the paper, the results of measuring are used for modeling of the temperature. The created models which represent analitical functions to determine temperature in proper cutting conditions, are developed by using RSM method. RSM is the methodology used in research and definition of the relations between several input variables and one output variable. This method was introduced by G. E. P. Box i K. B. Wilson with a basic idea to obtain optimal response based on experimental data [5]. They recommend using polynomials of the second degree, and point out that this method is only an approximation, but it is being used becouse it is applicable even when little is known about the process. RSM model is deffined by polynomial function (1):

$$f = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij} x_i x_j + \cdots + \varepsilon, i < j \qquad (1)$$

Where it: b_0, b_i, b_{ij} – coefficients, n – number of inputs.
Four different models were created from a set of 85 experimental data. The models were developed in program package MATLAB. The first model is linear model and it contains constant and linear parts. Linear model of the chip temperature with corresponding coefficients is presented by the relation (2):

$$T = b_0 + b_1 a + b_2 V + b_3 S$$
$$= 55.854 + 154.87\, a + 2.0117V + 210.9643S \qquad (2)$$

The second model is interaction model and it contains constant parts, linear parts and reciprocal products of inputs. Interaction model of the chip temperature with corresponding coefficients is presented by the relation (3):

$$T = b_0 + b_1 a + b_2 V + b_3 S + b_4 aV + b_5 aS$$
$$+ b_6 VS = 43.75 + 138.81\, a + 2.16\, V$$
$$+ 383.36\, S + 0.148\, aV + 9.30\, aS - 1.93\, VS \qquad (3)$$

The third model is the pure quadratic model, it contains constant, linear and quadratic parts, and it is given by relation (4):

$$T = b_0 + b_1 a + b_2 V + b_3 S + b_4 a^2 + b_5 V^2 + b_6 S^2 =$$
$$= 32.6 + 45.5\, a + 3.44V + 358.97S + 43.46a^2$$
$$-0.0073V^2 - 378.19S^2 \qquad (4)$$

The fourth model is the full quadratic model, it contains constant, linear,interaction and quardatic parts, and it is given by relation (5):

$$T = b_0 + b_1 a + b_2 V + b_3 S + b_4 aV + b_5 aS$$
$$+ b_6 VS + b_7 a^2 + b_8 V^2 + b_9 S^2$$
$$= 23.89 + 27.65\, a + 3.36V + 523.17S + 0.16aV$$
$$+ 14.75aS - 1.86VS$$
$$+ 43.39a^2\ 0.0073V^2\ 391.24S^2 \qquad (5)$$

As a measure of the quality of created models,a set of 15 data is used which are not used in the modeling phase but are solely the set of the test data. Varification results of created models of test data are given in Table (2).

Table 2. Comparison of different RSM models

	Linear model	Intera-ctions model	Pure qua-dratic model	Full qua-dratic model
Maximum error [%]	10.39	9.42	10.68	8.45
Average error [%]	4.46	3.61	3.46	3.41

In Figure 7 we can see the graphical comparison of created models. Based on the represented results of different models, the conclusion is that the best results were given by the model of full quadratic form, and that is why it is taken as adequate in analysis of the phenomenon of the chip temperature in process of proper cutting treatment.

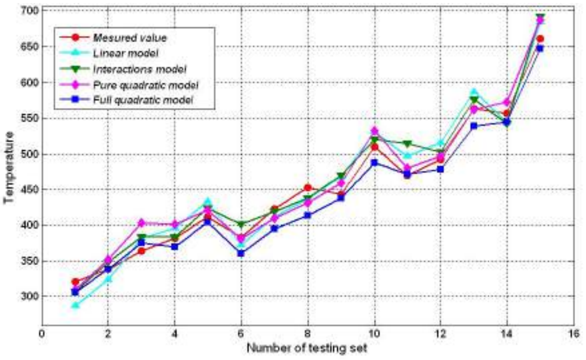


Fig. 7. Comparison of different RSM models with measured values of temperature

5. CONCLUSION

The effect of reinforcement of processed surface of mechanical structures of steel with 12% Mn during the process of cutting in cold condition contributes to extension of their working life in hard operating conditions (abrasive environment with strikes). This paper presents the thermodynamic characteristics and their modeling in cutting process manganese steels. The introductory part of the paper gives the background information of the hard workable material used in the experiment, as well and the basis of thermodynamics of cutting. In the next phase the arrangement of the experiment and graphical representation of the results of measurements are represented. In the final phase of the paper, measured results were used for developing RSM model that best defines correlation between input parametres (the depth of cut, cutting speed and step) and an output parameter (temperature). Model with the lowest average and the lowest maximal error in the phase of testing is represented as adequate model for obtaining the chip temperature in the function of cutting mode. Knowing the chip temperature is an important indicator of the process of treatment by cutting and it can be used in optimal management of thermodynamics of cutting process, by selecting the type and intesity of coolants, cutting geometries, as well as the coating of cutting surfaces. Knowing chip temperature gives the oportunity of further researches in terms of modeling the temperature of the cutting tools by methods of numerical analysis.

REFERENCES

[1] NEDIC, B., LAZIC, M., (2007) *Metal cutting*, Faculty of Mechanical Engineering, Kragujevac.

[2] CHRZANOWSKI, A., (2010) *Testing thermal imagers - Practical guidebook*, Warsaw.

[3] JOVICIC, M. (1992) *Metal cutting*, Faculty of Mechanical Engineering, Belgrade.

[4] STANKOVIC, P. (1974) Machine processing. Faculty of Mechanical Engineering, Belgrade.

[5] KHURI, A., I., MUKHOPADHYAY, S., (2010) *Response surface methodology*, John Wiley & Sons, Inc.

[6] TANIKIC, D., DESPOTOVIC, V., (2012) *Artificial Intelligence Techniques for Modelling of Temperature in the Metal Cutting Process*, Metallurgy – Advances in Materials and Processes, 7, pp. 153-176.

[7] ABUKHASIM, N., A., MATIVENGA, P., T., SHEIKH, M., A., (2006) *Heat generation and temperature prediction in metal cutting: A review and implications for high speed machining*, International Journal of Machine Tools & Manufacture 46, 782–800.

[8] SILVA, M., B., WALLBANK, J., (1999) *Cutting temperature: prediction and measurement methods – a review*, Journal of Materials Processing Technology 88, 195–202.

[9] DHARA, N., R., KAMRUZZAMANB, M., (2007) *Cutting temperature, tool wear, surface roughness and dimensional deviation in turning AISI-4037 steel under cryogenic condition*. International Journal of Machine Tools & Manufacture 47, 754–759.

[10]DHARMESH, L., AJAY, V., (2012) *Modelling Of Temperature Profile In Metal Cutting Process*, International Journal of innovative research & development, ISSN: 2278 – 0211.

[11]GREZESIK, W., BARTOSZUK, M., NIESLONY, P., (2005) *Finite element modelling of temperature distribution in the cutting zone in turning processes with differently coated tools*, 13th International scientific conference on achievements in mechanical and materials engineering. Gliwice - Wisla, Poland.

[12]MUKHERJJE, I., RAY, P.,K., (2006) *A review of optimization techniques in metal cutting processes*. Computers & Industrial Engineering 50, 15–34.

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SOFTWARE STRUCTURE OF THE POSTPROCESSOR GENERATOR OF NC PROGRAMS IN FLEXIBLE MANUFACTURING SYSTEM

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Abstract: *The task of the postprocessor generator of NC programs in flexible manufacturing system is bringing to fulfillment of technological demands through changes of machining regimes in NC programs and through choices of alternative tools. That task is executed through informational component of flexible manufacturing system that consists of three modules: control module, input-output module and variant module. The system configuration, pallet contents, technological database and assigned technological demands are parts of the control module. Reading data from NC programs, transformation data to NC tables and writing the changed data into NC programs are executed in the input-output module. Creation of combinations of tools and machining regimes in accordance to alternative tools and allowed machining regimes as well as calculations are executed in the variant module.*

Key words*: Flexible manufacturing system, Database, NC program.*

1. INTRODUCTION

The task of the postprocessor generator of NC programs in flexible manufacturing system is to bring to fulfillment of technological demands through changes of machining regimes in NC programs and through choices of alternative tools before the execution of NC programs. That informational component of flexible manufacturing system consists of three modules: control module, input-output module and variant module (fig.1).

Control module relies on technological database from which it receives data relating to machining centres, tools, materials and machining regimes. Alternative tools and all of alternative machining regimes for corresponding pallet contents are defined for each tool in magazine tools. Technological demands, changes of number of machining centres in use and changes of number of workpieces are entered in control module.

Input-output module takes the necessary data from input NC programs and transforms data into database according to corresponding segments of the control module. Information about number of tools, kinematics of tools, which tool is using in which operation, machining regimes and corresponding pallet contents are obtained from NC programs. Control of fulfillment of assigned technological demands and writing of new machining regimes into output NC programs are executed in this module.

Variant module is executing calculation of parameters required for control of fulfillment of assigned technological demands, which are total machining time or total tool costs required for machining of assigned assortment of workpieces. The large number of database tables are created and changed in this module, and this procedure is repeated due to changes that have been entered in control module until a positive evaluation of technological demands is achieved. The system generates all possible contents of magazine tools of machining centres and all possible machining regimes for corresponding tools. According to magazine tools and machining regimes, the system calculates the number of workpieces to be machined by generated magazine tools, machining time and tool costs for each magazine tool. Further, the system calculates the number of required magazine tools, total machining time and total tool costs in accordance to assigned number of workpieces and time limit. According to defined general criterions where all of tools in one magazine tool are changing in one time, the system calculates the level of blunting of each tool in possible magazine tool for corresponding machining regime. Finally, the system calculates general coefficient of blunting for magazine tools. This coefficient of blunting is one of criterions for choice of tools and machining regimes.

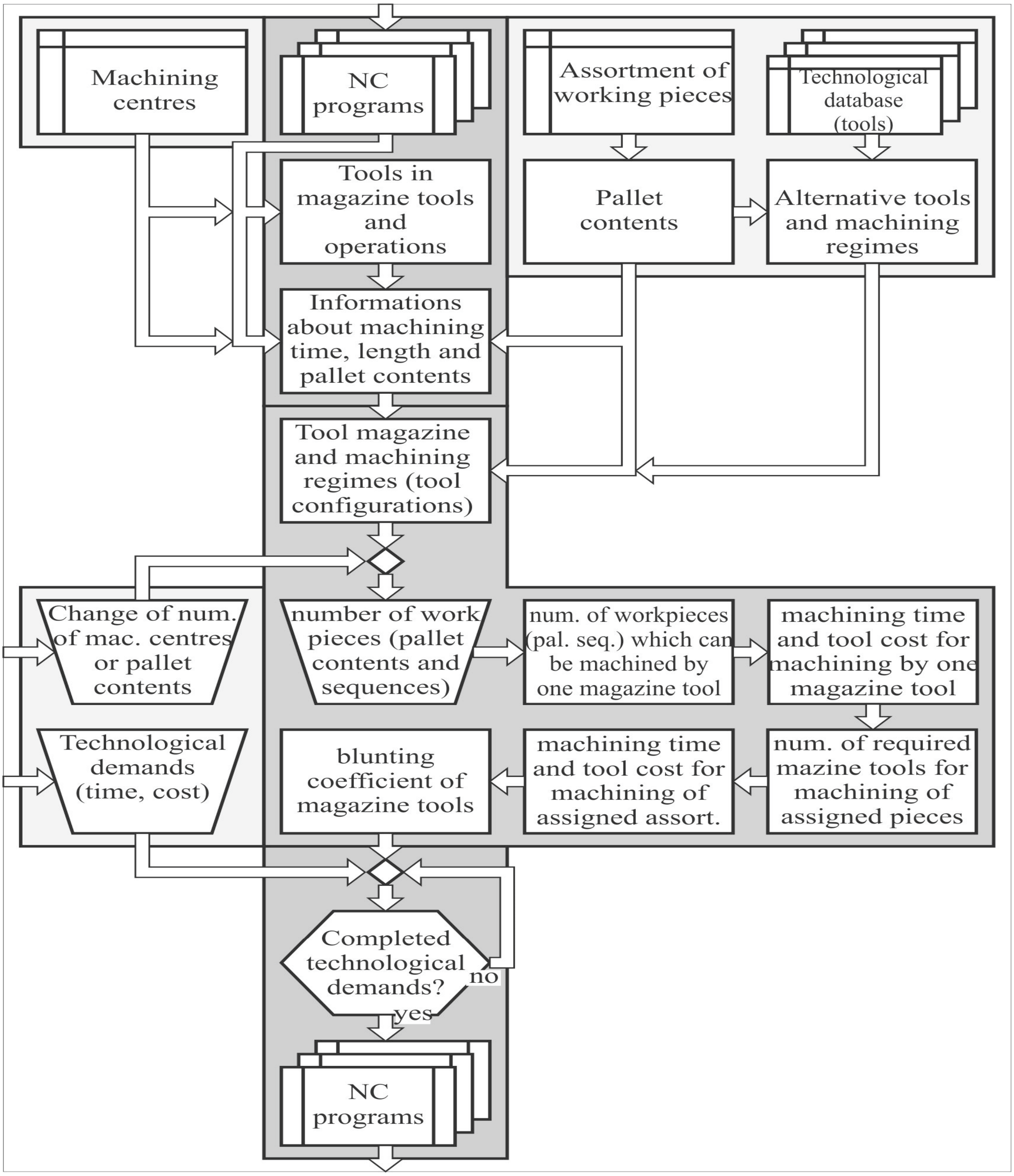

Fig.1. Modules of the postprocessor generator of NC programs in FMS

2. SOFTWARE STRUCTURE

The structure of program (fig.2) which represents postprocessor generator of NC programs in flexible manufacturing system is based on described modules of informational component of FMS (fig.1).

Due to changes of input parameters, functional and procedural machining conditions in flexible manufacturing system there are large problems in completing of technological demands during production process. Changes of machining regimes and/or tools in NC programs are leading up to changes of machining times and production costs, therefore it is necessary to execute an optimization of production process before NC program is executed.

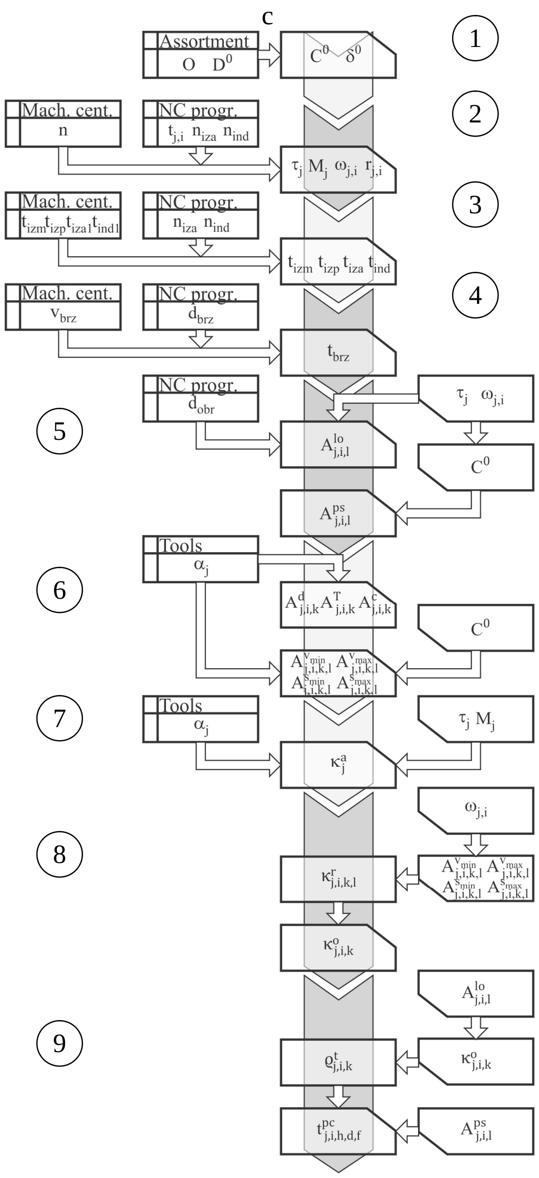

Fig.2. Structure of program

1. Pallet contents
2. Data related to magazine tools and operations
3. Times of magazine tools changing, pallet changing, tools changing, and indexing
4. Times of rapid traverse for operations
5. Cutting feed pathsfor operations related to pallet contents
6. Alternative tools and possible machining regimes for operations related to pallet contents
7. Configurations of tools
8. Variations of machining regimes
9. Machining times for configurations of tools

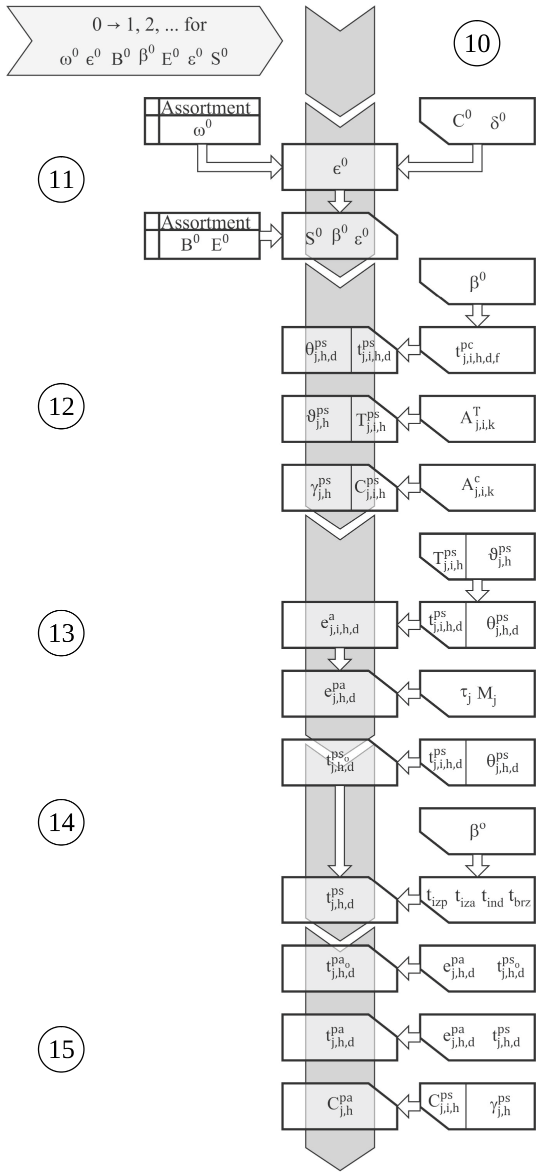

Fig.2. (continued) Structure of program

10. Change of the number of machining centres or change of the number of workpieces
11. The number of pallet contents
    Content and the number of pallet sequences
12. Machining time of pallet sequence for single tool in configuration of tools
    Tool life for single tool in configur. of tools
    Tool cost index for single tool in conf. of tools
13. The number of pallet sequences that can be machined with one tool in configuration of tools
    The number of pallet sequences that can be machined with one configuration of tools

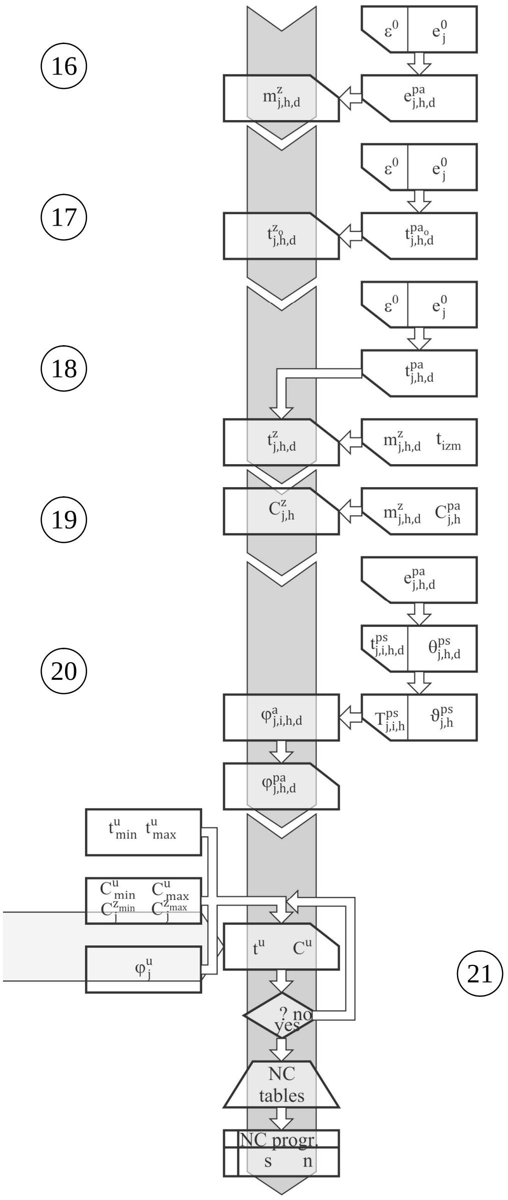

Fig.2. (continued) Structure of program

3. PROGRAM MODULES

3.1.Machining centres

The starting part of the program is the module in which the number and characteristics of machining centres required for work of other parts of program are defined. This program module is the part of control module of informational component of flexible manufacturing system. This program module is used for updating of data relating to operativity of machining centres, the number of places in magazine tools, time of tool changes, etc.

3.2.Using of data from NC programs

This program module is a part of input-output module of postprocessor and NC programs placed in ASCII files are transformed into database tables in this module. First, every NC program block is converted into corresponding record of NC table, then corresponding fields (path, speed, time, ...) are calculated in accordance with fields obtained by transformation of data from NC program block (G, X, Y, Z, ...).

Afterwards, in accordance with records of this table, record of the table that corresponds single NC program is created, but fields that are related to times present added times for whole program. Records of the table that correspond with one tool, one cutting feed and one spindle speed in one NC program are filled in simultaneously.

3.3.Tool system

This program module is a part of control module of postprocessor. In this module, code of alternative tools from technological database are assigned to each place in magazine tool specified in NC program for related machining centre. Each code of alternative tool uniquely determines attributes of tool: diameter, tool life, index of cost etc. This program module automatically generates all uses of tool, i.e. all operations with related code of pallet content and related machining lengths in all NC programs for specified place in magazine tool. Finally, attributes of tool related to operations (the minimum and maximum cutting speed and the minimum and maximum cutting feed) are defined for each operation of each alternative tool.

Limits of cutting feed and cutting speed defined in this module will be later used for generating configurations of tools with variations of machining regimes.

3.4.Tools configuration

This program module is a part of variant module of postprocessor. All possible configurations of tools for all machining centres are generated in this module, afterwards all possible variations of machining regimes are generated for each configuration of tools in accordance to defined limits. Both of these actions are executed by software application of Cartesian product of arrays with unequal number of elements.

According to previously calculated data, total machining times are calculated for each configuration of tools as sum of machining times for all operations for tools from configuration of tools.

3.5. Pallets

Program modules related to the number and type of pallet contents are modules for defining assortments of workpieces, pallet contents and pallet sequences, and these program modules are parts of control module of postprocessor.

Basic attributes of workpieces and array that contain numbers of workpieces in series are defined in the first module, and these data are placed in the table of the database. Array that contains numbers of workpieces stored on pallets is defined in the second module, and array that contains the numbers of pallet contents is calculated in this module. Pallet sequences are defined in the third module as arrays of numbers of pallet contents in pallet sequences and pallet sequences related to machining centres.

3.6. Computing of machining process parameters

This program module is a part of variant module of postprocessor. For machining all of working pieces, times of all operations and feed range times for each tool called from that NC programs are calculated from generated NC programs. According to operational times, pallet change times and magazine tool change times, total time necessary for machining of assigned working pieces on single machining centre is calculated. According to feed range time and tool life, the result is number of working pieces that is possible to machine by that tool, as well as the necessary number of tools in machining centre magazine for machining of assigned working pieces. Calculating total times for machining of assigned working pieces on each machining centre produces the total time for machining of assigned assortment of working pieces in flexible manufacturing system. Adding costs of single tool in machining centre magazine tools produces total tools costs for machining of assigned assortment of working pieces in FMS.

In the case of change of remaining working pieces spectrum for machining on equal or different number of machining centres, optimization process is repeating just in operations over parameters from database and number of working pieces in order to compute machining times and the number of magazine tools for machining centres. In addition to machining times and tools costs the result is wear coefficient of tools in magazine. This coefficient is used as additional criterion for evaluation of the most convenient machining times and tools costs.

3.7. Choice of optimal parameters of manufacturing process

This program module is a part of input-output module of postprocessor. The choice of optimal parameters of manufacturing process represents the choice of optimal configurations of tools (sets of tools and variation of machining regimes) in accordance with three criterions: total time required for machining of assigned assortment of working pieces, total tools costs for machining of assigned assortment of working pieces and blunting coefficient of magazine tools. One of these three criterions is primary, and the rest are secondary criterions. The choice can be executed either in interactive way, i.e. from group of tools configurations meeting assigned technological demands, or automatically through the best marked tools configuration by postprocessor for each machining centre.

3.8. Update of data in NC programs

This program module is a part of input-output module of postprocessor. In this module the selected configurations of tools are used for updating machining regimes in NC programs located in ASCII files.

First, according to machining centre, configuration of tools and variation of machining regimes in database software is searching for corresponding values of generated machining regimes for each tool and operation. Afterwards, according to marks of NC programs and tools in magazine tools of machining centres and corresponding operations in initial NC tables, software is changing values of spindle speed and cutting feed with new values.

Finally, according to number of program rows (blocks), that values are placed into corresponding program words, i.e. into words beginning with letters ”F” or ”S”.

4. CONCLUSIONS

The designed postprocessor generator of NC programs in flexible manufacturing system can be applied on configurations of flexible manufacturing systems with same or different machining centres, with equal or different number of places in magazine tools. Pallet sequences for machining centres need not be equal to each other, and composition of pallet contents is not limited.

Projected and implemented postprocessor generator of NC programs can be applied modularly in manufacturing systems which are not flexible manufacturing systems by definition, but manufacturing systems which are composed of CNC machine tools. Modules of postprocessor for definition of alternative tools, calculation of machining times and tool costs and choice of optimal parameters of technological process can be applied in manufacturing systems which are composed of conventional machine tools.

REFERENCES

[1] Ivanović S., Lukić Lj. “Database design from techonological and kinematic parameters of NC program for production in flexible manufacturing system”, The Sixth TriennialInternational ConferenceHM 2008, Mataruška Banja, 26.-29.06.2008.

[2] Ivanović S., Lukić Lj., Petrović Z. “Database reconfiguring in flexible manufacturing system according to parameters of NC program”,IMK-14 Research and Development, Journal of Institute IMK “14. Oktobar” Kruševac, No (28-29) 1-2/2008.

[3] Ivanović S., Petrović Z., Đapić M., Lukić Lj.“Functional model of postprocessor generator of NC programs in flexible manufacturing system”,IMK-14 Research and Development, Journal of Institute IMK “14. Oktobar” Kruševac, No (30-31) 1-2/2009.

[4] Ivanović S., Petrović Z., Lukić Lj., Đorđević Lj.“Tool system of postprocessor generator of NC programs in flexible manufacturing system”, IMK-14 Research and Development, Journal of Institute IMK “14. Oktobar” Kruševac, No (30-31) 1-2/2009.

[5] Ivanović S., Lukić Lj.“Module for update of technological parameters in postprocessor generator of NC programs in flexible manufacturing system”, The Seventh Triennial International Conference Heavy Machinery HM 2011, Vrnjačka Banja, 29.06.-02.07.2011.

[6] Ivanović S., Lukić Lj., Petrović Z., Radičević B.“System of Pallet Sequencesin the Postprocessor Generator of NC Programs in Flexible Manufacturing System”,IMK-14 Research and Development, Journal of Institute IMK “14. Oktobar” Kruševac,No18(2012)2.

[7] Lukić Lj.,Đapić M.,Ivanović S., PetrovićA.“NC Post-Processor Generator Model for Optimization of FMS Technologies”, Metalurgia International, Vol.17 (2012) No.12, pp 147-152. ISSN 1582-214.

Forming and shaping technologies

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ANALYSIS OF INJECTION MOLDING IN THE DIE CAVITY WITH METAL INSERTS

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Abstract: *Injection molding of polypropylene technology when designing complex products has a broad representation. Inserting different metal elements in the cavity tools get more complex conditions fulfilled and melt flow near the contact surface. Constructive and technological solution tools directly causes variable field temperature and pressure variation within polypropylene continuum that is very difficult to be monitored and controlled. These problems lead to incomplete filling tools, poor quality parts almost as ultimately does not meet the initial requirements. The simulation models of these processes provide answers to many questions that can be solved very quickly on the basis of which the correction or a complete change of tools.*

Key words*: Injection molding, Tool, Temperature filed, Pressure filed.*

1. INTRODUCTION

New constructions of products and their individual constituent elements include a number of different materials and technologies. Often we find a combination of metal and plastic, metal and wood, metal and rubber products and so on. This gives products that meet the demands of the market with prices that are adapted to each customer. On the other hand, the designers and engineers of appropriate tools come in a situation where the combination of materials in the production process leads to various problems which must be solved specific methods that in the design phase. Simulation of flow in the phase polypropylene fill mold cavities with embedded metal elements is a challenge to obtain finished goods of satisfactory quality [1].

2. INJECTION MOLDING OF POLYPROPYLENE

Injection molding is a manufacturing process in which plastic material spews into usable products for the general purposes of the appropriate standard and acceptable performance. Each plastic material, depending on the species and type, can be correctly processed within a certain range of temperatures and pressures, which are key parameters for the processing of plastics. Melt temperature is the temperature at which the material changes from a solid state to a liquid, and then crystalline regions of material softens and begins the process flow. Generally, this occurs at temperatures in the range 120-350oC, the temperature is controlled by cylinder, nozzle temperature, the screw speed, back pressure and residence time [2]. About 70% of the heat needed to melt the plastic material is formed warming, the friction that occurs within the material. Therefore, it is difficult to measure the temperature of the melt and it can not be directly controlled by the thermostat on the control panel. The remaining 30% of the heat is obtained by means of electric heaters, which ensures the required temperature for the flow of plastic material.

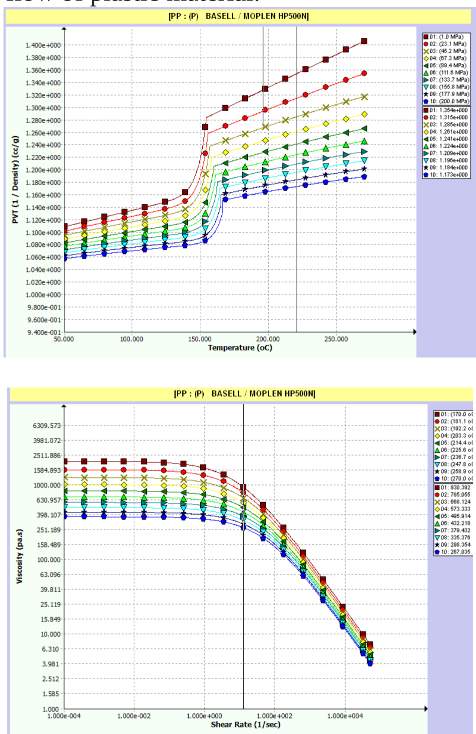

Fig.1. Density dependence of viscosity and temperature of polypropylene

Thermal properties of the material are equally important for its processing and the characteristics of the finished part. Thermal properties of plastic materials are phase and relaxation transitions, thermal stability, heat capacity, and thermal conductivity. For practical application of this material, it is important to know the temperature of the softening temperature limit usability, as well as mechanical properties change depending on the temperature.

Thermodynamic properties of molten plastic material, such as viscosity, enthalpy and specific gravity, changing the temperature of the melt at the same time. It is therefore very important to maintain a constant temperature of the melt in the injection molding process, the melt because the temperature variations that there are some common mistakes at work, such as the short burning of short injections, poor surface appearance of bubbles visible flow lines, and so on. [2, 3].

The mold temperature is the one that is required to maintain the surface of the mold cavity at a temperature at which the cooling of the polymer melt and the transition to the solid state. Die temperature can range from 0 to 150oC and depend on the temperature of the coolant flow, distribution of cooling channels in the tool and the degree of heat plastic material. Heat transfer can be satisfying when it is a new tool, but decreases over time due to the effects of corrosion and the formation of deposits in the channels. The heat transfer from the plastic material varies, depending on the location and thickness of the part and the mold wall temperature is not identical, and thus the degree of cooling is not uniform. These problems can cause a variety of defects in molded parts. In many injection molding machine applies hydraulic pressure to suppress the screw relative to the molten material. The molten material is forced to the nozzle, distribution channels and pouring system fill the mold cavity, where it forms a compression molds. Depending on time, full melt and solidify in the mold cavity, but the pressure is not uniform throughout the molded part.

The highest pressure at the start of pouring system, and the lowest at the farthest point in the mold to be filled last. In order to provide compensation for the collection of materials, apply additional pressure which after filling mold cavity subsequently added material in the mold to fill the space that occurs due to shrinkage caused by cooling pallet material. At the same time, to reduce shrinkage in the mold, the pressure is reduced to a minimum, which provides additional flow, to reduce the possibility of errors in the finished part.

3. FEATURES TOOLS AND PROCESS PARAMETERS

Process analysis of complex molding elements made on the types of tools pneumatic hose ø10 polypropylene with a metal insert.

Fig 2. Finished complex elements with different connection size

For the simulation of the model of injection molding presses, injection molding manufacturer ARBURG, Allrounder A 270 A 350 - 70 (D18). More performance parts for injection molding and mold closing date at the following picture:

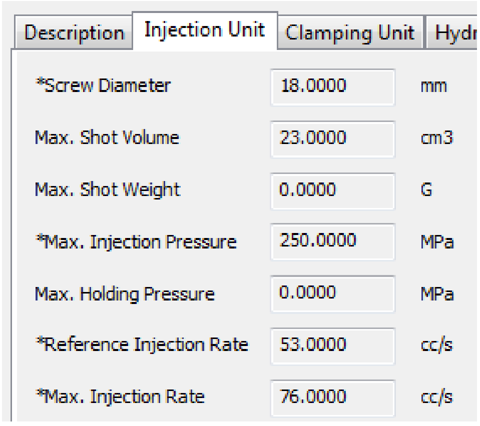

Fig. 3. Characteristics of the virtual model presses for injection molding

Design of the tool is derived from the four forms that provide an acceptable level of productivity. At the beginning of each cycle molding tool is inserted into the metal inserts that are watered polypropylene. Dimensions of form tools are linearly increased in all directions in relation to the finished part of the 2% or the percentage of shrinkage polypropylene process parameters: charging time tools 0,16sec, melting temperature 226°C, the temperature of 34°C.

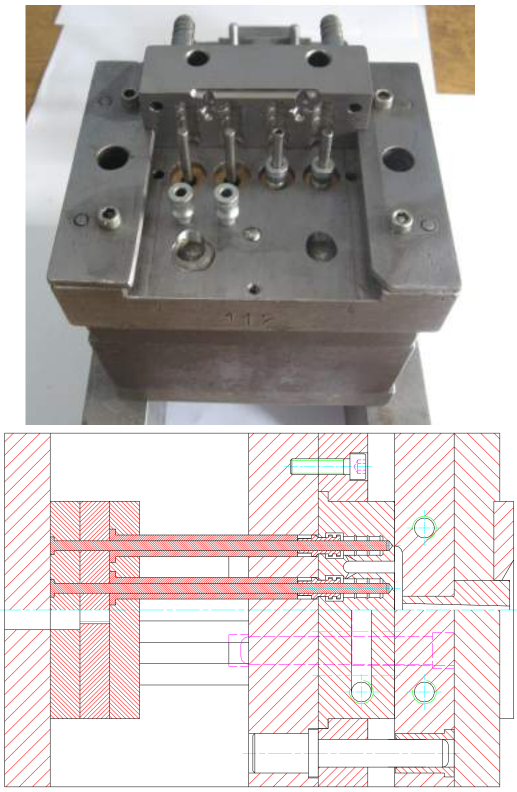

Fig.4. Layout tools and typical cross-section of tools for injection

The inlet system consists Column tapered channel that forms the fueling nozzle, fueling major branches that form a channel in the working plate fixed half of the tool, two distribution channels are formed in the slider and ulivci derived in a place that does not disturb the aesthetic appearance of part and its function.

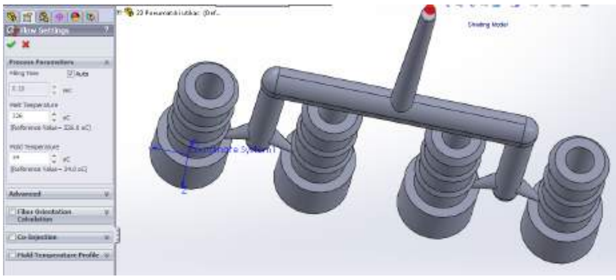

Fig.5. 3D virtual models of finished elements to the input characteristics of the process

4. SIMULATION RESULTS OF THE INJECTION MOLDING

In the described virtual model can monitor different parameters that greatly give a good picture of the process. One of the phenomena that occurs during injection of these elements is the appearance of uneven thickness of the finished parts, tools or incomplete filling of surfaces and areas where the volume is changing cross section (Fig. 6). Directly associated with this parameter is the time filling mold cavity, and part of the first volume of tools and where it comes to a halt. This gives opportunity to remove the virtual model of congestion and small cross-sections melt flow polypropylene to get an even fill throughout the volume [4, 5].
Critical locations in a tool which can cause delays of air are potential points that can disrupt the structure of the finished part. This kind of place it is necessary to eliminate completely resulting in a satisfactory quality of a finished part. The lines connecting the molten polypropylene are also a necessity for this type of technology. Their prediction, reducing their length and eliminating the causes smooth filling and avoiding possible defects in the structure of the finished work [6]. Therefore, a simulation model selected ten of the characteristic points of the filler system and the mold cavity (Figure 7) to the results of change of temperature and pressure melt may indicate possible errors in the phase of design tools for injection molding.

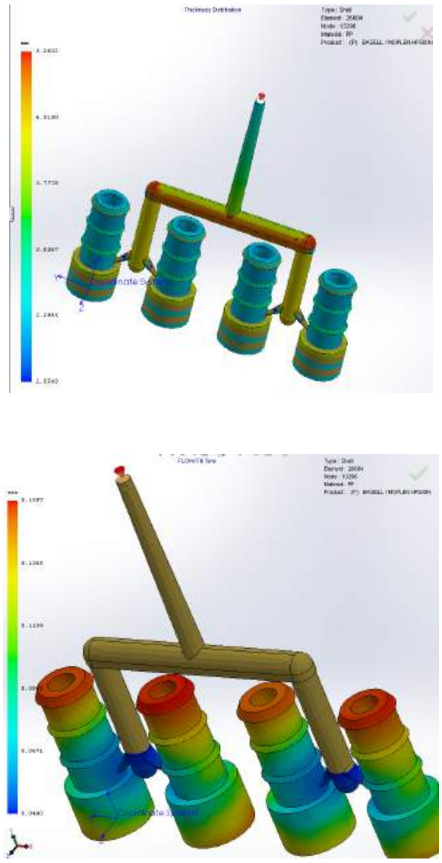

Fig.6. 3D model of change achieved thickness and time the fill tool

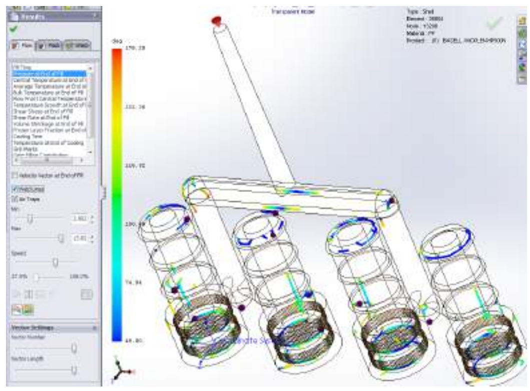

Fig.7. Analysis of the 3D model of merger lines and the potential place of residual air

Temperature field at the end of filling the mold is very important parameter that can be used to explain many of the tool and its contact surfaces with plastics. This field can be monitored at any time, but a moment of complete filling tools play a crucial role in the characteristics and quality of the finished part. It indicates a possible tool breakage, thermal expansion and deformation caused by inaccuracies of the finished part.

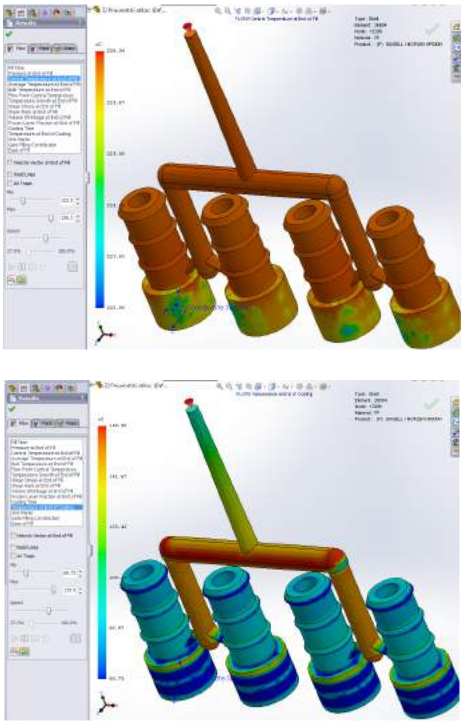

Fig.8. Flow temperature of the melt at the end of injection and just before the ejection of molded part from the mold cavity

Temperature field at the end of the cooling process gives us a picture of residual temperature stresses which can cause poor joint quality injected polypropylene metal insert. In fact at that point there should be a strong enough connection to guarantee the functionality and use of the finished part. The most common problem that occurs is that the sealing compound in place of polypropylene and metal insert is not good or that it is the site reduced elasticity of such a compound. In these cases, small stresses during operation leads to cracking, separation and separation of two different materials.

5. CONCLUSION

The presented analysis shows that the temperature and pressure of injection molding the most important parameters to be monitored and controlled. The chosen material simulation model PP BASSEL / moplene HP500N molded part ejection temperature of the tool is 99°C, and the result of simulation shows that the injection molded parts are cool to the tool during cooling of 8.23 seconds, the temperature of 226°C, the temperature below 80°C, which is quite satisfactory result. At the end of the injection mold cavity, more than 80% of the volume has the same temperature of 226°C, as the temperature of the melt at the start of injection. As for the rest, about 15% have only 1°C lower temperature than the majority 80%, while the remaining 5% in scattered areas has a lower temperature in less than 3°C which is an excellent result. Air inlet branch at the end of injection molding process remains high above 99°C which is not a real solution that can be the subject of further research.

REFERENCES

[1] LEI X, Longjiang Shen and Bingyan Jiang (2011), *Modelling and Simulation for Micro Injection Molding Process*, Computational Fluid Dynamics Technologies and Applications, pp.317-332

[2] PEROSEVIC B. *Kalupi za injekciono presovanje plastomera (termoplasta)*, Naučna knjiga, 1988.

[3] PEJAK M. *Polipropilen - svojstva i prerada*, Hipol korporacija Odžaci, 1994.

[4] SHEN Y.K., YEH S.L. & CHEN S.H. (2002) *Three-dimensional non-Newtonian Computations of Micro-Injection Molding with the Finite Element Method*. Int. Comm. Heat Mass Transfer,Vol 29, No.5, PP. 643-652, ISSN 0735-1933

[5] KEMMANN O, WEBER L, JEGGY C & MAGOTTE O. (2000) *Simulation of the Micro Injection Molding Process*. Proceedings of the Annual Technical Conference, (ANTEC 2000), PP.576-580, ISBN 1566768551, Orlando, FL, USA.

[6] LIOU A. C. & CHEN R. H., (2006) *Injection molding of polymer micro- and sub-micron structures with high aspect ratios*, Int. J. Adv. Manuf. Technol. Vol 28, PP.1097–1103, ISSN 0268-3768

35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
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RELEVANT SURFACE TEXTURE PARAMETERS FOR DEEP DRAWING MADE METAL BEVERAGES

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Abstract: *Ecological aspect of lubricant dosage optimisation in deep drawing metal beverage processing directs our investigation to the textual surface parameters evaluation and selection. Considering that SRPS EN ISO 25178:2013 standard that is published in 2013 in the Republic of Serbia, the objective of this paper is to examine and quantify surface topography parameters that are related to voids. Surfaces imaging are conducted by atomic force microscopy and calculations of numerical values are completed by in-house made Matlab procedures. Results indicate the usefulness of selected set of S and V parameters for characterization of metal beverage surface after deep drawing processing. Selected set of relevant parameters may be used in further investigations and in industrial application in order to predict the surface volumetric lubricant retention capabilities.*
Key words*: Surface texture parameters, atomic force microscopy, lubrication.*

1. INTRODUCTION

In the food metal baverage manufacturers, the inner surface of can is just one of two sides of cup that is made by deep drawing. Consider the food safety it's the important side. Manufacturers use lubricant in deep drawing process and afterwards cans are rinsed with fluid or sprayed with vapour. Food consumers assume that cans are washed thoroughly either after production or prior to food filling. Authors are engaged in project that deals with ecologically based approach in sheet metal parts production. One of the aims of investigation is to diminsh lubricant amount and in this paper the set of relevant surface texture parameters will be presented in order to predict the surface volumetric lubricant retention capabilities.

The lubrication is essential for good quality sheet metal part fabrication and therefeore it cannot be eliminated from this metal forming process [1], but different type of lubricants suitable for food contact as well as environmental requirements can be select [2,3]. Also, the usage of die and punch coatings decrease coeficient of friction and therefore reduce amount of lubricant [4-6]. The surface topography and roughness are important factors in describing the lubrication of surface in deep drawing process. Therefore, an application of profile roughness parameters in deep drawing persist for decays and example of that can be seen in [7-9]. Unlike profile ones the areal surface parameters were hard to find in available references consider deep drawing process. The examples of the more appropriate characterization based on the areal parameters for the blank surface opposed to profile parameters are described in [10] and proving that areal parameters calculated for tinplate and can's surface offer insight into the surface changes throughout deep drawing process is given in [11]. In this paper we intend to investigate the areal surface parameters that are related to lubrications.

2. MATERIALS AND METHODS

We took samples from the cylindrical part of cans during industrial fabrication at metal food baverages factory that are situated in Belgrade, RS Serbia. Surfaces imaging are conducted by atomic force microscopy in NanoLab at University of Belgrade. Calculations of numerical values are completed by in-house made Matlab procedures based on SRPS EN ISO 25178:2013 standard that is published in 2013 in the Republic of Serbia.

2.1. Sample preparation

Mass production of cans in company FMP d.o.o Belgrade, is performed by a sheet feed press CEPEDA (component of the automated manufacturing line) by deep drawing. Cans are made of Double Reduced (DR550) tinplate sheets, that are cold rolled and tin coated steel with high strength and sufficient ductility. This kind of tin plate, before deep drawing, is exposed to lithography and lacquering processes. Magnus Draw Oil L-67 is used as lubricant during deep drawing processing. It is the high quality lubricating oil, formulated for pre-painted steel and recommended for two piece cans which might be subjected to incidental food contact, according to [12].

Samples for the experiment are taken from the cylindrical part of four cans after deep drawing with the ordinary process parameters. After cleaning samples were scanned in NanoLab at University of Belgrade.

2.2. Topography scanning

A commercial scanning probe microscope (JSPM 5200, JEOL, Japan) is used for this investigation. Commercial probe produced by MikroMasch, Estonia, CSC37/AlBS for general purpose is used for contact mode scanning. The probe is a three-lever chip that contains long cantilevers with a Single-Crystal Silicon tip that has conical shape. Typical uncoated tip radius is less than 10 nm, height 15-20 mm, full angle cone is less than 40° and the typical force constant is 0.3–0.65 N/m, resulting tip curvature radius is 40nm due 30nm aluminum back coating, as is stated in [13]. All experiments are performed at room temperature.

2.3. Surface roughness parametars calculation

Microscope JSPM5200 provide conventional roughness analysis for profile or surface based on following standard roughness parameters: average roughness parameter R_a, root mean square R_q, maximum difference between height R_z and 10-point average roughness R_{zijs}, interfacial surface ratio S_{ratio}, as well as histogram and bearing ratio curve of sample profile and area. Since the software WinSPM is made few years before standard ISO 25178 is introduces in Republic of Serbia, for profile and areal parameters the same designation R_a, R_q, R_z and R_{zijs} was used in reports.

In order to update JSPM5200 reports we ought to select group of parameters that will be in acordance to new standard's requirements and calculate their values by in–house made Matlab procedures.

We analyze the group that are consists of four areal amplitude parameters (arithmetic S_a and S_q root mean deviation, skewness S_{sk} and kurtosis S_{ku} of surface height distribution), single hybrid parameter (developed surface area ratio S_{dr}) and three volume parameters dale void volume $V_{vv}(p)$, core void volume $V_{vc}(p,q)$, peak material volume $V_{mp}(p)$).

The surface topography image size of 256×256 pixels, is considered as matrix filed by surface height in each pixel denoted as $z(i,j)$. Such a matrix represents an intensity image type with greyscale map. Matrix size of 256^2 defines number MN. The amplitude parameters are based on surface departures above and below the mean plane $\bar{z}$ of topography image.

We perform custom-made Matlab procedures for calculation of S_a, S_q, S_{sk}, S_{ku} are based on equations (1-4), that are adapted from [14] in order to serve for AFM image characterization.

$$S_a = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M}\left|z(i,j)-\bar{z}\right| \tag{1}$$

$$S_q = \sqrt{\frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M}\left(z(i,j)-\bar{z}\right)^2} \tag{2}$$

$$S_{sk} = \frac{1}{MN\cdot S_q^3}\sum_{j=1}^{N}\sum_{i=1}^{M}\left(z(i,j)-\bar{z}\right)^3 \tag{3}$$

$$S_{ku} = \frac{1}{MN\cdot S_q^4}\sum_{j=1}^{N}\sum_{i=1}^{M}\left(z(i,j)-\bar{z}\right)^4 \tag{4}$$

The hybrid parameter is defined by equation (5). For the developed surface calculation the fractal dimension method is used that is presented in [15] and adopted for the total interfacial area $\Sigma\Sigma A_{i,j}$. We calculate the sum of tiles that cover image over the scanned sample size A that is equal to 10μm x10μm in this case.

$$S_{dr} = \frac{\sum_{j=1}^{N-1}\sum_{i=1}^{M-1} A_{ij} - A}{A}\cdot 100\% \tag{5}$$

In order to calculate three volume parameters we use custom made procedures in Matlab. Surface texture is truncated by the planes at a height corresponding to chosen level. For each section the pixels belong to a surface are colored white and considered as binary 1. The rest of the surface image belongs to valleys, so they represent an empty space that is supposed to fill with lubricant. Those pixels are colored black and are considered as binary 0. The sums of black pixels multiple by there's heights are the void volume.

Peak material volume $V_{mp}(p)$ is the volume of material from the height corresponding to the material ratio level p=10% to the highest peak. Dale void volume $V_{vv}(p)$ corresponding to the default value of level p= 80%. Core void volume $V_{vc}(p,q)$ corresponding to the levels p=10% and q= 80%.

3. RESULTS AND DISCUSTION

We conduct surface roughness assessment at AFM images, which are gathered after deep drawing processing. Topography images size 256x256 pixel are gathered from sample size 10μm x 10μm. Maximal height reveals in WinSPM report for each can image and considers as input value for Matlab calculations. Calculation of S and V roughness parameters values are completed by in-house made Matlab procedures. In this section the calculated parameters' values for four samples are presented in Table 1 and discussed afterwards.

Table 1. Can surfaces' S and V parameters

a) S parameters

	S_a [μm]	S_q[μm]	S_{sk}	S_{ku}	S_{dr}[%]
Mean	0.0558	0.0686	1.5766	2.9603	10.7504
Max	0.0846	0.1008	1.8294	4.1522	13.4105
Min	0.0188	0.0230	1.4415	2.3776	7.4066
Std	0.0280	0.0331	0.1754	0.8220	2.4850

b) V parameters

	V_{mp}[μm³/μm²]	V_{vc}[μm³/μm²]	V_{vv}[μm³/μm²]
Mean	0.00018	0.1357	0.0013
Max	0.00064	0.1940	0.0025
Min	0.00001	0.0636	0.0006
Std	0.00010	0.0543	0.0008

The areal arithmetic mean deviation S_a is insensitive for spatial distribution of the asperities and equalizes peak and valley with same value. The root-mean-square deviation of the surface S_q is more sensitive to extreme data values. Put them both side by side, we have to conclude that the S_q is more appropriate dispersion parameter for deep drawing processed inner surface of can compares to S_a. This areal amplitude parameter may be used for comparison in a case of monitoring tin plate ironing during deep drawing process.

The skewness of topography height distribution of surface S_{sk} has positive values for all images which indicate surfaces with predominantly peaks. The values of kurtosis of topography height distribution of the surface S_{ku} are around 3, which indicates predominantly the Gaussian distribution of high peaks and deep valleys for the images. Based on values for mean and standard deviation which are shown in Table 1, the skewness doesn't provide considerable information that can be used for surface distinguish and therefore the kurtosis is chosen as meaningful distribution parameter for cans' inner surface.

The developed interfacial area over the sampling area defines ratio S_{dr}, which reflects hybrid property of surface that is combination of amplitude and space. This parameter is expressed as the percentage of additional surface area contributed by the texture as compared to an ideal plane the size of sampling area. In this particular case ratio S_{dr} are approximate 10% and can serve as surface flattening indices.

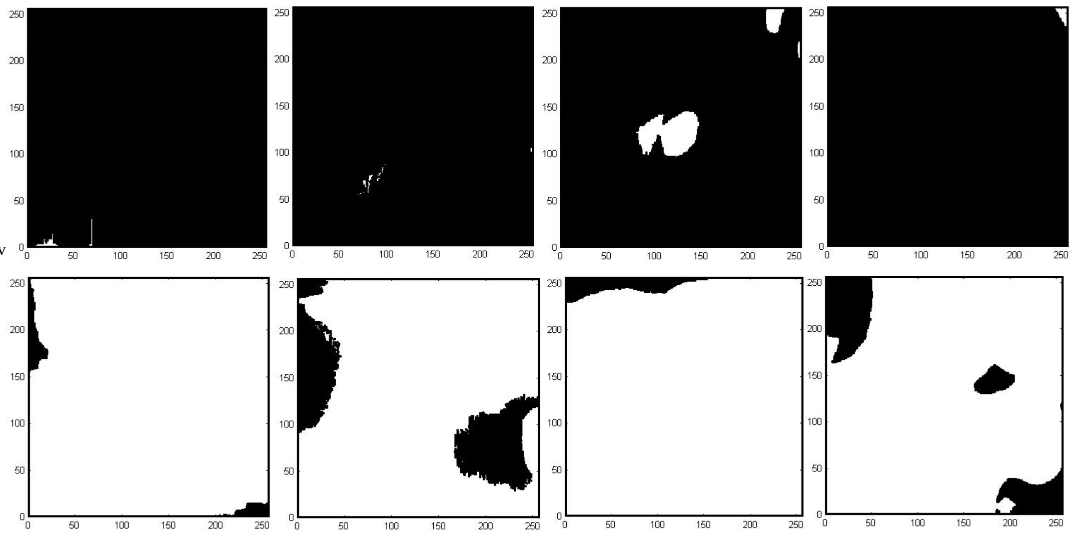
For cans' surface the binary images, that represent bearing area at 10% and 80% from the top, are shown in Figure 1. For each section the pixels belong to a surface are colored white and the rest of the surface image that are colored black are empty space that is filled with lubricant.

Sections with few white spots on black colored background represent all material that may be worn away for a given depth of 10% of the S_q. Those sections are related to peak material volume V_{mp} and may provide insight into the amount of material available for seal engagement. Sections with few black regions on white colored background represent deep valleys under a given depth of 80% of the S_q. Those sections are related to dale void volume V_{vv} and may be useful in indicating the entrap lubrication volume.

This could be important information especially in case of lubricant volume optimization for ecological requirements satisfaction. The dale void volume parameter V_{vv} may be useful in indicating the potential remaining volume resulting in lubricant entrapment that will be difficult to wash.

For that reason, the presented materials volume parameters are useful when considering lubrication behaviour phenomena. The best sealing property among four surfaces consider parameter V_{mp} has surface C, the worst surface B and surfaces A and D have the similar appearance and consequently approximate the equal value. Topography core will keep very low amount of lubricant in case of surface B and others perform suitable lubricant behaviour according to parameter V_{vc}. From ecological point of view the best behaviour exhibits surface A with the lowest value of parameter V_{vv} which is in accordance to visual perception of black deep valleys distribution. In case of surfaces B and C, which have the similar values but quite unlike deep valley distribution, parameter V_{vv} demonstrates superiority compares to visual guiding conclusions. In Figure 2, 3D topography images for four samples are presented.

	A	B	C	D
$V_{mp}[\mu m^3/\mu m^2]=$	0.000044	0.000010	0.000639	0.000047



$V_{vv}[\mu m^3/\mu m^2]=$	0.000645	0.001021	0.000988	0.002492

Fig. 1. Surface sections at given depth - 10% (upper row) and at 80% (lower row)

The core void volume V_{vc} indicates a measure of the void volume provided by the surface between depths of 10-80% of the S_q. This is useful when considering fluid flow during lubrication. The volume parameters are presented in Figure 1. The parameters values provide necessary additional information for adequate conclusions.

Comparison of the materials volume parameters for four images shown in Figure 1, may differentiate surfaces in terms of lubrication sealing, flow and entrapment. The peak material volume V_{mp} should be important parameter that can detect desired sealing can's surface behavior. The core void volume V_{vc} is useful to establish how much lubricant will fill the surface normalized to the measurement area between the 10% and 80% ratio values.

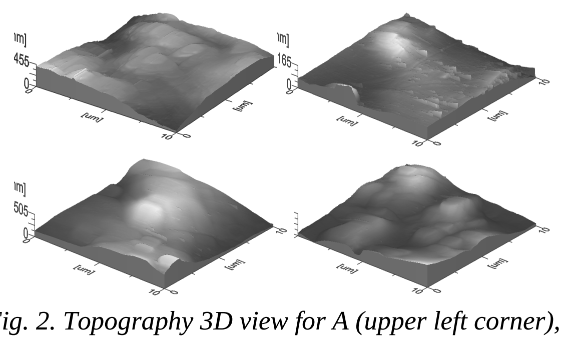


Fig. 2. Topography 3D view for A (upper left corner), B (upper right corner), C (lower left corner) and D (lower right corner)samples

The best lubricant behaviour from ecologically aspect perform surface denoted with A since its dale void volume parameter is the lowest and core void volume has acceptable value even though peak material volume is low. In Figure 2 the surface denoted by A is the one without too deep valleys. The surface D has ecologically unaccepted topography with very deep valleys surrounding by high peaks that will entrap lubricant. It will be difficult to wash out lubricant and therefore convinient to contact and contaminate the food.

4. CONCLUSION

Criteria for the more appropriate food metal beverage surface regarding ecologically accepted lubrication are based on imperative “grant high connected peaks in favour of sealing, provide undisturbed flow and diminish entrapped lubricant hard to wash out”.

Therefore we conduct surface roughness assessment at AFM images, which are gathered after deep drawing processing. In this paper we point out S and V parameters role in characterization of the metal food beverage surface and potential lubrication behaviour:

- Areal parameter S_a is inappropriate dispersion parameter for deep drawing processed can inner surface. Therefore it shouldn’t be calculated.
- Parameters S_q and S_{dr} are chosen as surface flattening indices.
- The skewness S_{sk} doesn’t provide considerable information that can be used for surface distinguish and therefore it shouldn’t be calculated.
- Kurtosis S_{ku} value close to 3, indicates surfaces predominantly normally distributed deep drawing processed can inner surface.
- Low values of $V_{mp}(10\%)$ prevent sealing, which effect lubricant squeezing during the deep drawing process. That affect to the amount of vested lubricant.
- Values of $V_{vc}(10\%,80\%)$ indicate preserved lubricant volume that participate in deep drawing process.
- Low values of $V_{vv}(80\%)$ are desirable to avoid lubricant entrapment and subsequently food contamination.

Finally, as result of presented investigation, we select set of six surface roughness parameters that are relevant for characterization of metal beverage surface after deep drawing processing. Selected set of relevant parameters may be used in further investigations and in industrial application in order to predict the surface volumetric lubricant retention capabilities.

REFERENCES

[1] Kim, H., Han, S., Yan, Q., Altan, T. “Evaluation of tool materials, coatings and lubricants in forming galvanized advanced high strength steels (AHSS)”, in *CIRP Annals-Manufacturing technology*, Vol. 57, pp. 299-304, 2008.

[2] Shashidhara, Y.M, Jayaram, S.R. “Deep drawing of 304L steel sheet using vegetable oils as forming lubricants” in *Int. Journalof Advancementsin Research & Technlology*, Vol 1/7, pp. 1-6, 2012.

[3] Lovell, M., Higgs, C.F, Deshmukh, P., Mobley, A. “Increasing formability in sheet metal stamping operation using environmentally friendly lubricants“ in *Journal of Materials Processing Technology*, Vol 177/1-3, pp. 87-90, 2006.

[4] Klocke, F., Masmann, T., Bobzin, K., Lugscheider, N., Bagcivan, N. “Carbon based tool coating as an approach for environmentally friendly metal forming processes“ in *Wear*, Vol 260/3, pp.287-295, 2006.

[5] Kim, H., Han, S., Yan, Q., Altan, T. ”Evaluation of tool materials, coatings and lubricants in forming galvanized advanced high strength steels (AHSS)”, in *CIRP Annals-Manufacturing technology*, Vol. 57, pp. 299-304, 2008.

[6] Witulski, J., Trompeter, M., Tekkaya, A.E., Kleiner, M. “High wear resistant deep drawing tools made of coated polymers“, in *CIRP Annals-Manufacturing technology*, Vol. 60, pp 311-314, 2011.

[7] Lubbinge, H, ter Haar, R, Schipper, D.J. “The influence of plastic bulk deformation on surface roughness and frictional behaviour during deep drawing processes“, in book *The third body concept*, pp. 705-711, Elsevier Science, 1996.

[8] Masen, M.A, de Rooij, M.B. “Abrasive wear between surfaces in deep drawing“, in *Wear*, Vol.256/6, pp.639-646, 2004.

[9] Manabe, K, Shimizu, T, Koyama, H. “Evaluation of mili-scale cylindrical cup in two-stage deep drawing process“, in *Journal of Materials Processing Technology*, Vol.187–188, pp. 245–249, 2007.

[10] Meiler, M, Pfestorf, M, Geiger, M, Merklein, M. “The use of dry film lubricants in aluminum sheet metal forming“, in *Wear*, Vol.255/6, pp.1455-1462, 2003.

[11] Bojovic, B., Babic, B., Zunjic, A.”Metal sheet surface characterization prior and after processing by areal roughness parameters” in Proceedings of 7th International Working Conference ’’TQM & AIA’’, Belgrade, 2013.

[12] http://www.stowlin.com/products/henkel-products/henkel-magnus-l67/

[13] MikroMasch Product Catalogue 2013, http://www.spmtips.com/pdf_downloads/MikroMasch-Product-Catalogue-2013.pdf

[14] naSRPS EN ISO 25178-2:2013, [Online], Available: www.iss.rs/standard/?keywords=ISO+25178&Submit

[15] B, Bojović, ”Investigation of interaction of engineering surfaces condition and fractal geometry”, PhD Thesis (in Serbian), University of Belgrade, 2001.

Acknowledgement: This paper is a part of the research financed by The Serbian Government, The Ministry of Science and Technological Development. Project title: *An innovative, ecologically based approach to implementation of intelligent manufacturing systems for production of sheet metal parts* (*TR-35004*).

35th INTERNATIONAL CONFERENCE
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FEM SIMULATION TO OPTIMIZE TOOL GEOMETRY FOR SUPPORTING RIBS OF AN AIRCRAFT TAIL USING THE RUBBER PAD FORMING

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To produce a new sheet metal component there is often a trial and error stage necessary to obtain a part without defects, which strongly depends on operator's skill and experience. At this stage, the experience of designer and manufacturers should give an important aid to reduce trials to realize the minimization of response time and cost with maximization of the product equality. Wrinkling is an undesirable result in sheet metal forming, especially when it occurs on outer skin panels where final part appearance is critical. Additionally, large wrinkles may damage dies and interfere with part assembling and function. Removal of this defect of winkling after the forming process may be not only expensive but sometimes impossible, as has been observed in die making. The prediction and prevention of wrinkling are therefore extremely significant in sheet metal operations. In this research Finite element software ANSYS was used to predict the wrinkling in rib of light aircraft horizontal tail in using the rubber pad forming process. These results could then be used as reference for carrying out non-destructive analysis of this problem, leading to savings in inspection cost, lesser repair time and more focused fault isolation.

In aerospace field, parts are produced in small sheet metal bending and small number of components. It means that it is not worthy for large investments sheet metal press formed structures produce. For these reasons it is necessary to use such finite element simulation of manufacturing process during the conceptual design. This study presents numerical simulation of rubber pad forming process of aluminum alloy with different tool geometry for supporting ribs of an aircraft tail. It has been optimized to find out the right design of tool and defect free product

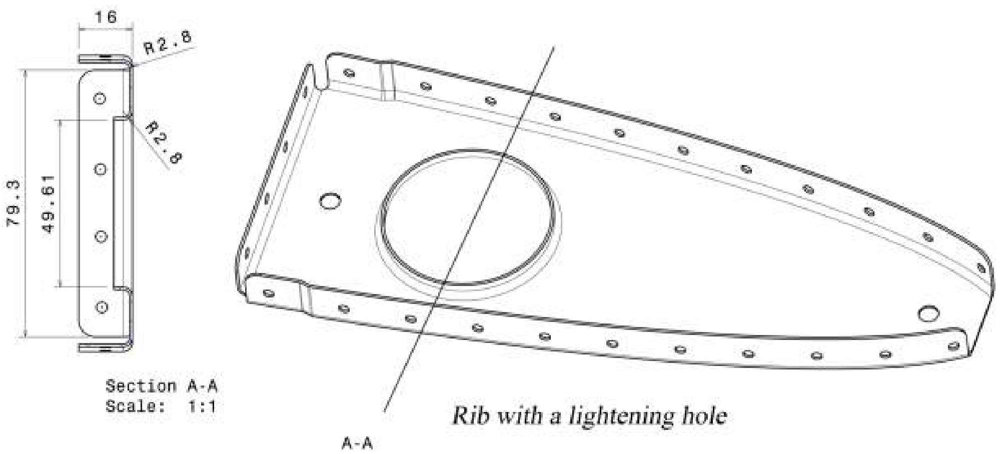
Keywords: *Rubber pad forming, sheet metal forming, FE simulation, Optimization.*

1. INTRODUCTION

Stamping is a metal forming process by which the sheet metal is punched using a press tool that is loaded on a machine or a stamping press to form the sheet into the desired shape. The conventional stamping process is performed through a punch which, together with a blank holder, forces the sheet metal to slide into a die and comply with the shape of the die itself.

Rubber-pad forming is a metalworking process where sheet metal is pressed between a die and a rubber block. In general, an elastic upper die, usually made of rubber, is connected to a hydraulic press. A rigid lower die, often called a form block, provides the mold for the sheet metal to be formed. Because the upper (male) die can be used with separate lower (female) dies, the process is relatively cheap and flexible. However, rubber-pads exert less pressure in the same circumstances as non-elastic parts, which may lead to less definition in forming or to defects appearance.

The advantages of using the rubber-pad forming process instead of the conventional metallic tools are: (i) the same flexible pad can be used to form several different work piece shapes, because the rubber-pad has the ability to return to its original shape; (ii) tool costs are lower compared to conventional forming processes; (iii)



thinning of the work metal, which occurs in conventional deep drawing, is reduced considerably; (iv) set-up time can be reduced considerably in this kind of process, because there are no die clearance or alignment checks that need to be made; (v) lubrication is not necessary and good surface finish can be achieved, because no tool marks are created. However, the rubber-pad forming processes have several disadvantages, such as: (i) the lifetime of the flexible pad is limited (this depends on the severity of forming combined with the pressure level); (ii) lack of sufficient forming pressure results in parts with less sharpness and dimensions of the rigid die). It was found that the smaller internal radius is, the harder is to fill the cavity of rigid die. Authors examined whether the blank filled the cavity of the rigid die or not by using 3D laser scanning measurements system. In this case, numerical simulations of the rubber-pad forming processes were to analyse the blank and rubber behaviour during production of supporting ribs (rib with a lightening hole), as well as to analyse different tool geometry Fig. 1. To find optimal tool shape Non-linear FE analysis was conducted to predict stress and strain distributions, and forming forces during the

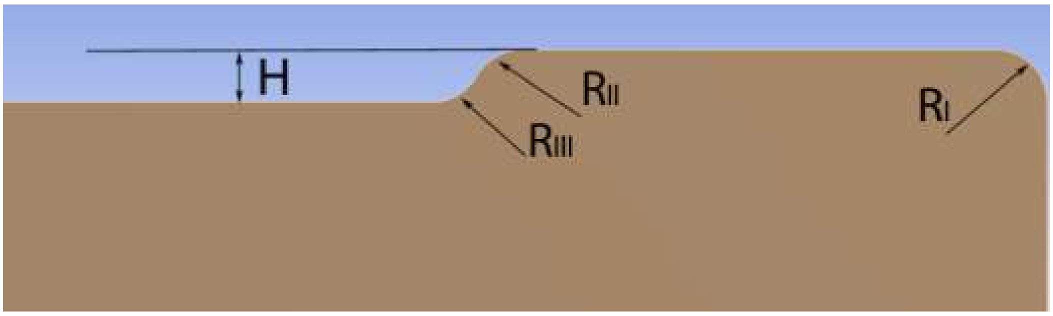


Fig. 1. (a) geometrical model of rib with a lightening hole, (b) geometry parameters using in FE simulations of rubber pad forming in a rib with a lightening hole

or with wrinkle, which leads to reworking the part to its correct shape and dimensions; (iii) low production rate, so it is suitable mostly for small series (typical of the aircraft industry) (iv) dependence of final design on exact geometry of the tool.[1-5] For these reasons it is recommended to use finite element simulation of manufacturing process during the conceptual design Moreover it could give important answers in analysing the process and predicting the defects that may occur. Therefore modification can be easily done before the tool manufacturing and part production. This study presents numerical simulation of rubber pad forming process of aluminum alloy with different tool geometry for supporting ribs of an aircraft tail. It has been optimized to find out the right design of tool and defect free product. This analysis was carried out on a commercially available finite element package with appropriate nonlinear material and friction model.

Many investigations showed that the numerical model could help in better understanding of the forming procedure, and correlations with experimental results were good. M.W. Fu and H. Li[6] have presented 3D-FE simulations and investigated the deformation behaviour of the flexible die forming process. The comparison between the conventional deep drawing and viscoplastic carrying medium based on flexible die forming was conducted in terms of wall thickness reduction, hydrostatic pressure, principle stress distribution and damage factor. The concave and convex rubber-pad forming process using FE simulations and experimental methods was investigated by Liu et al. [7]. The investigations of the forming load, thickness variation of the formed plate and variations in the channel width to rib width ratio were also performed. Fabrication of a metallic bipolar plate for proton membrane in fuel cells is presented in [8] The FE analyses were used to describe the rubber-pad forming process and to investigate main parameters (such as rubber hardness rubber-pad forming process. The main goal was to develop a computer model which would be able to simulate the process and, therefore, to achieve the right design for a tooling set.

2. NUMERICAL SIMULATION

Numerical simulations of the rubber-pad forming processes are complicated mainly because of the large deformation of the rubber-pad. As a consequence, a mesh distortion may occur in a simulation, which could lead to inaccurate and incomplete results. This is why FE analyses must be carried out carefully and with understanding of physical phenomena of the rubber pad forming process.

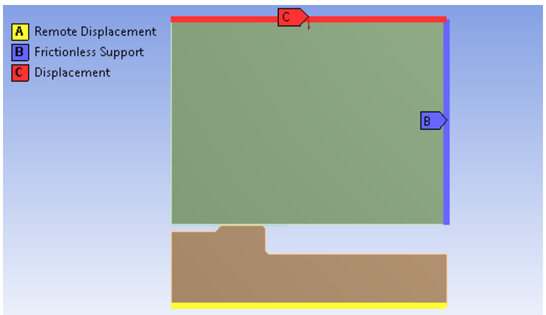


Fig. 2. Constraints as applied in 2D symmetry FE model of rib with lighten hole

The commercial finite element software ANSYS was used to make FE simulation in this study. In order to reduce the processing time and improve the precision of calculations, 2D and 3D FE models were created a rib with a lightening hole and analyses were carried out. The models in FE analyses included three elements only: a rigid die, a blank and a rubber-pad (flexible punch). In order to simplify the numerical model, the container of the rubber-pad was not modelled. To take into account the influence of the container, the frictionless support constraints were applied on opposite sides of the rubber, while displacement constraint was applied on upper edge of rubber model (Fig. 2). The die was modelled as a rigid body because the stress and strain of die were not analysed and die material (steel) is much less deformable than material of blank (aluminum). So, the material properties attached to die were not important, and mesh was not generated either. This eliminated unnecessary calculations causing decrease in both run time and errors in the numerical solution. All deformable materials in FE models have been modelled with Plane 183 finite element. Plane 183 has quadratic displacement, plasticity, hyper-elasticity, creep, stress stiffening, large deflection and large strain simulation capabilities. However in these models the die is modelled as rigid body, so the mesh for the die was not generated. Multilinear isotropic hardening material which existing in ANSYS workbench simulates large plastic strain deformation is applied into blank. Von Mises yield criterion coupled with isotropic work hardening assumption were applied. The behaviour of the non-linear hyper-elastic and incompressible rubber-like material is described by Mooney-Rivlin model. This model based on strain energy function and used for modelling the rubber pad. Two Mooney-Rivilin parameters C10 and C01 are used to describe hyper-elastic rubber pad behaviour. As it is mention above HD70 was used as a rubber pad, when the values of C10 and C01 are 0.736 MPa and 0.184 MPa respectively [4, 7, 8].

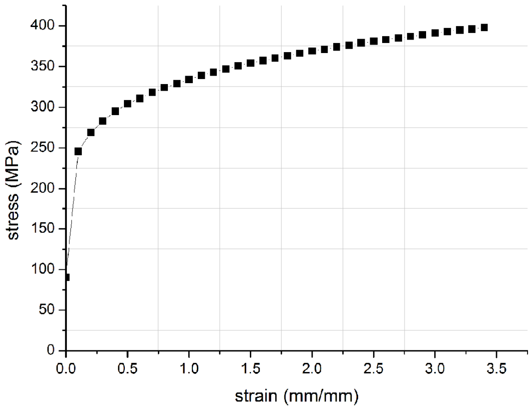


Fig. 3. Experimental tensile-stress-strain curve for the aluminum blank sheet

In this work an Aluminum alloy with thickness of 0.6mm is used as a blank. The material properties of the blank were determined via stress stain curve obtained from the tensile test as shown in Fig. 3. For this material the elastic module (E) is 71GPa and Poisson ratio (ν) is 0.334. The frictional behaviours between rubber pad-blank and die-blank are assumed to follow coulombs model. The friction coefficient at the former and later contact pair were considered to be 0.2 and 0.1 respectively [4, 7, 8].

3. RESULTS AND DISCUSION

Fig. 4 shows that the step by step forming process of deformation supporting rib with a lightening hole as it is mentioned above. Fig. 4 illustrates that the forming process can be divided in to three stages: the first is self-deformation of rubber pad, second is the outer bending forming and finally the blank flows in to the cavity of the die. During the forming process, thinning and thickening phenomena can occur. However if the maximum thickness reduction reaches a critical value, the part will be cracked. This phenomenon should be avoided in real production. According to Sala [2] and Benisa *et. al* [9], the maximum reduction of this alloy is 20% which means that the maximum plastic strain is 0.223, by using the safety factor 1.2. Therefore the plastic strain will be 0.186. This value of plastic strain (0.186) was used as a limit of FE simulation models of the supporting rib with a lightening hole. Furthermore according to Takuda [5], there was a fracture initiation in the tensile specimen with no obvious necking phenomenon, despite that the alloy sheet has a considerable high work-hardening exponent of 0.19 where the elongation was only 17 pct (0.16 in true strain). In this study the model of the rib with lightening hole (Fig. 1(a)), which has reached to 0.186 plastic strain is unacceptable model. Generally speaking some parameters have important factors during the rubber pad forming process such as tool geometry, hardness of the rubber and lubrications. The tool geometry which presented as R_I, R_{II}, R_{III} and H (Fig. 1 (b)) parameters has been studied using the rubber pad forming process. In order to study the effect of the previous geometry parameters values during the simulation of the rubber pad forming process. These parameters have been varied separately by fixing the first three parameters at 2 mm, while the fourth one was changed. This procedure was repeated with the rest of the parameters respectively to see the effect of each of them (three are fixed, one is varied).

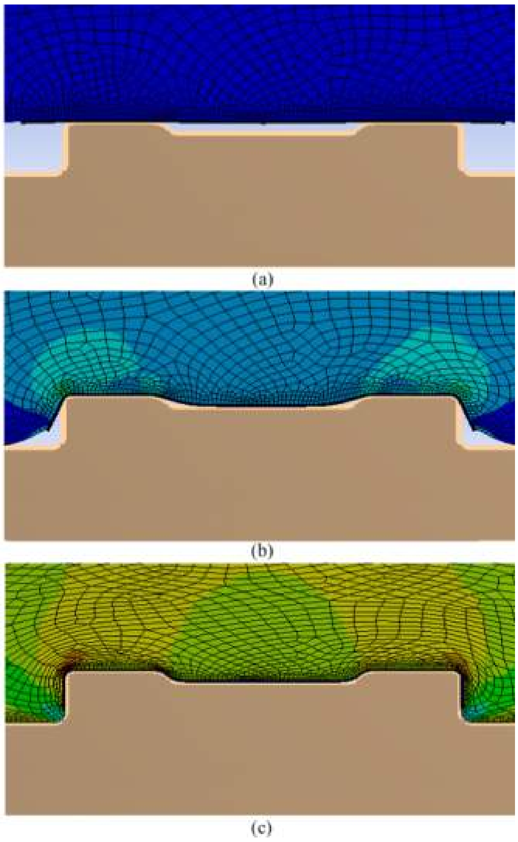


Fig. 4. Three stages of supporting rib forming using rubber pad forming process.

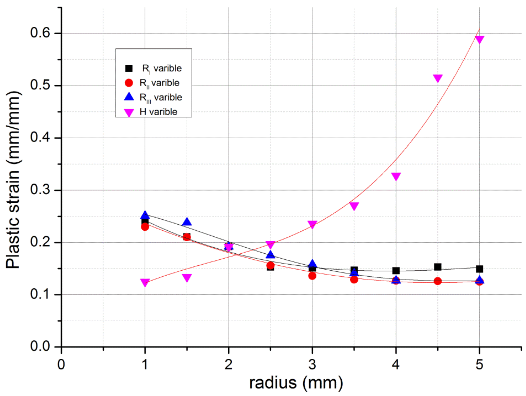


Fig. 5. Influence the fillet radius of the rib on plastic strain

In order to find connections between values of fillet radius and plastic strain and on the basis of these findings, more FE models of tool with different values of fillets´ radii (R_I,R_{II},R_{III} and H) have been developed and analyzed. These simulations showed that the values of stress and strain are strongly depended on the rib geometry.
Different models based on different dimensions were simulated. R_I was varied from 1 to 5mm, and the other parameters (R_{II}, R_{III} and H) were varied from 1 to 5mm.The Fig. 5 illustrates the plastic strain and the geometry parameters relationship for each model. As it is seen in the figure the plastic strain is strongly depended on the geometry parameters (R_I, RII, RIII and H). It is also clear that the increasing of the R_I, R_{II}, R_{III} and decreasing H, the plastic strain decreases. On the other hand the capability of forming the blank increases. However when R_{II} and $R_I \geq 2$ and $H<R_{II}$ the plastic strain was <0.186 mm/mm (Fig. 5). In the case of the R_I 1.5 mm the plastic strain is greater than acceptable plastic strain where reach to 0.211and stress concentrated at radius R_I region 266.4MPa. The reason of that might be referring to the reference [3] which mentioned that the blank could be suffer affected not only by tensile stress and tangential stress but also from stress coming due to bending pressure imposed by the tool. When the $R_I \geq 2$ (R_I=2.5mm), the plastic stain and stress started to decrease and reach to 0.15 mm/mm and 243.9 MPa respectively (Fig. 6). The same for $R_{II}(\geq 2)$as shown in Fig. 7 where two values of R_{II} were selected (1 & 3 mm).
According to the Fig. 8 it should be mentioned that the value of R_{III} in all of the models should be greater than or equal R_{II} to make an easy forming and to avoid uncompleted cavity tool forming. As seen in the Fig. 8 where R_{III} less than R_{II} and equal to 1.5 mm the die cavity was uncompleted filling with higher plastic (0.251 mm/mm).on other hand when increasing the value of R_{III} to 3.5mm the die cavity was completely fill with low plastic strain (0.14 2mm/mm). About the H value it strongly effects on plastic strain in blank. In case of $H \leq R_{II}$ (H=1.5 mm), the plastic strain value is always less than 0.186 and reach to 0.143 mm/mm where the stress was 269.5 MPa, otherwise the plastic strain will be increased higher than the acceptable plastic strain (0.4378 mm/mm) for H=4.5mm, as it is seen in Fig. 9. Moreover when these parameters were randomly selected we got the same results which we reached in the previous case. From these models (randomly selected) for $R_{II}>2$ and $R_I \geq 2$ all models have plastic

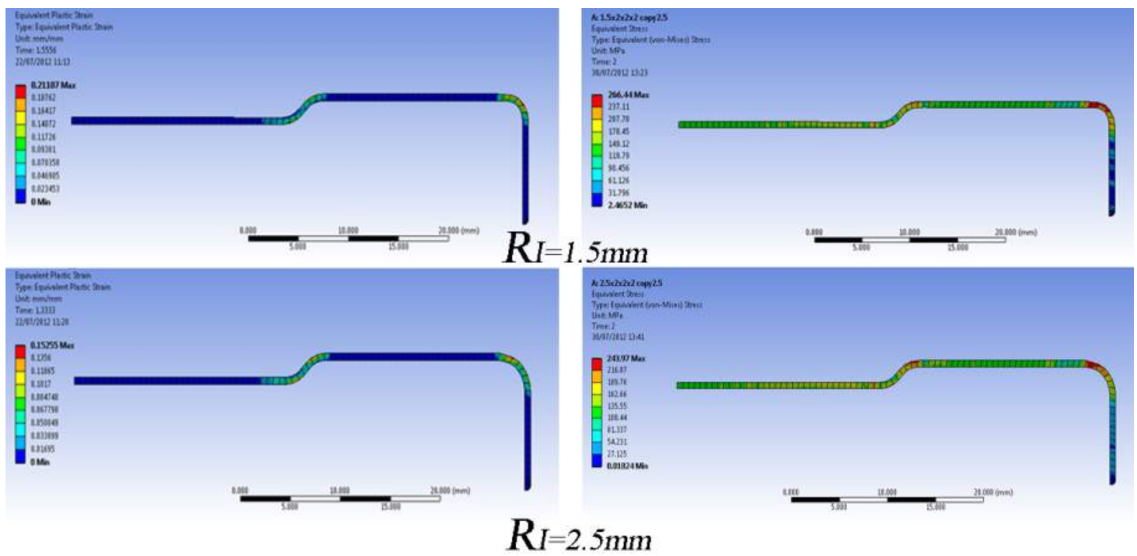


Fig. 7. Plastic strain (left column) and Equivalent stress (right column)

strain within limit. As it has been already mentioned above, if $R_{III}<R_{II}$ in all models the cavity filling will be uncompleted. Though the plastic strain exceeds the reference plastic strain (0.186) if $H>R_{II}$.
To get plastic strain in the blank less than 0.186 and complete filled cavity of the tool the values of RII& RIII should be increased with decreasing of H value. As it is known that increasing of the bending radius the spring back increases which is not preferable. Therefore to get an acceptable tool design we have to make a kind of compromise of the values of these parameters.
In addition, after obtaining satisfactory results in 2D simulation, it was decided to perform more complex and challenging 3D simulations of the same process. In the 3D model definition in Ansys (which is almost the same as model used for 2D analysis), the die has been defined as a

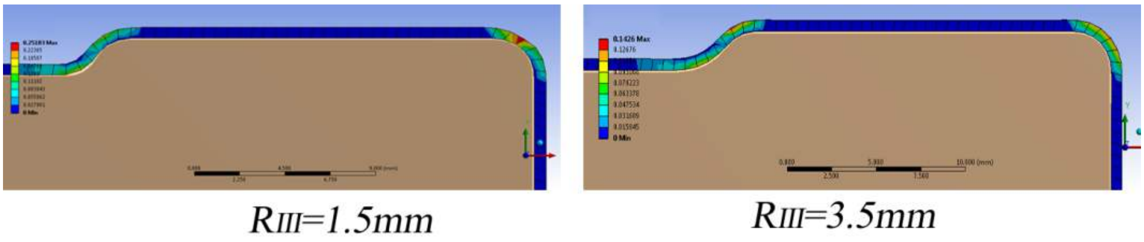


Fig. 8. Effect the R_{III} on the filling the die cavity

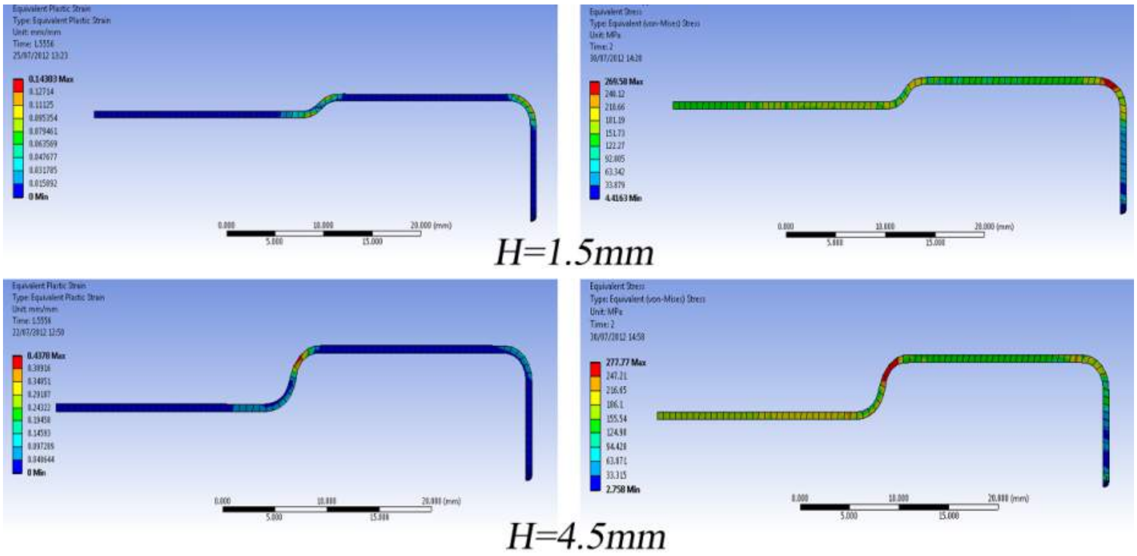


Fig. 9. Plastic strain (left column) and Equivalent stress (right column)

rigid body, while rubber pad and workpiece were represented by a deformable mesh. The friction coefficient, material properties and constrains used in 3D simulation were taken from above mentioned 2D rubber bad forming simulation (Fig. 2 for material properties and Fig. 3 for constrains) Fig. 10 shows complete 3D FE model as used in simulation. It can be seen that one half of the real set-up was modelled and then symmetry conditions were applied.

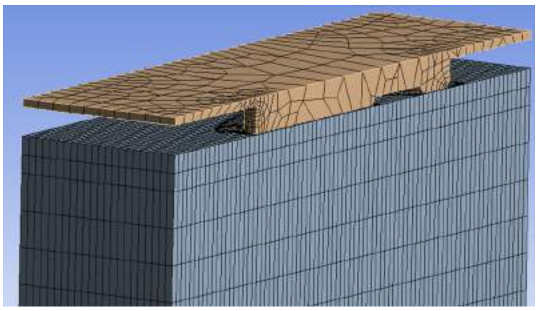


Fig.10. FE mesh used in analysis of symmetrical model of the rib forming using rubber pad

In the FEM simulations, the wrinkling in sheet metal cannot be seen in 2D simulation of sheet metal bending. So, this is why 3D simulations have been used to illustrate the wrinkling region in a rib during rubber pad forming process.

Fig. 11 shows the 3D symmetry model of formed rib with lightening hole as obtained in simulation. As it can be seen in Fig. 11 there is no wrinkling in the straight flange, but the wrinkling occurs in curved flange and it increases as the curvature of the flange increases. This is in agreement with the previously mentioned reference [2], which leads us to conclusion that FE simulation was performed well.

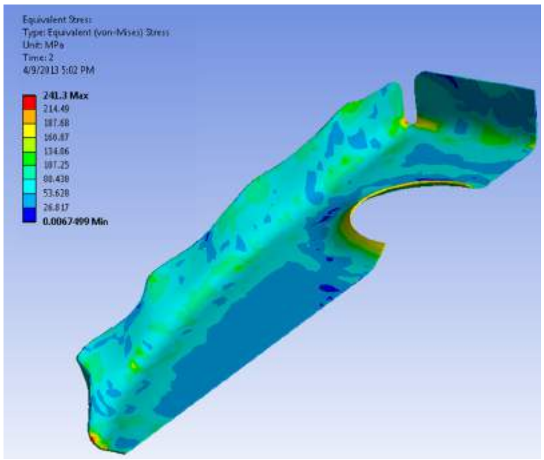


Fig. 11. Wrinkling in FEM model of formed rib with lightening hole

4. CONCLUSION

In this study FE simulation models have been applied to investigate the supporting ribs of aircraft tail using a rubber pad forming process in different tool geometry parameters. These models were analysed in details in numerical simulation. The final conclusion of this study could be:

- Finite element simulation of the rubber-pad forming process in 2D and 3D could be very useful tool for understanding and improving forming operations. Developed FE models of rubber pad forming process allowed us to predict the final shape of the ribs to avoiding any defects which can appear in the product during the forming process.
- The rubber pad forming process can be divided into three steps the first step self- deformation of rubber pad, second is the outer rib pending and the blank fill the cavity of the tool rib (die)
- The value of RI and RII should be grater or equal 2 to avoid stress concentration in their region. However the plastic strain did not reach unacceptable plastic stain.
- To avoid thinning phenomenon and to make an easy forming with complete rib tool cavity filling, the value of H should be less than R_{II} and R_{III} greater than or equal to R_{II}.
- Finally the authors strongly recommend to develop more research in numerical simulation to optimize tool ribs to eliminate the forming defects in the final product with minimal cost.

REFERENCES

[1] ASM Handbook Vol.14B Metal Working: Sheet Forming(2006), P375-385

[2] Sala, G., A numerical and experimental approach to optimize sheet stamping technologies: part II - aluminium alloys rubber-forming Material and Design, 22 (2001) 299–315

[3] Thiruvarudchelvan, S., Elastomers in metal forming, A review, Journal of Material Processing 39 (1993) 55- 82

[4] Dirikolu, H. M., Akdemir, E., Computer aided modelling of flexible forming process. Mater. Process.Technol. 148 (2004) 376-381

[5] Takuda, H., Hatta, N., Numerical Analysis of the Formability of Aluminum 2024 Alloy Sheet and Its Laminates with Steel Sheets, Metallurgical and material transaction A , Vol. 29A, November (1998)

[6] Fu, M.W., Li, H., Lu, J., Lu, S. Q., Numerical study on the deformation behaviours of the flexible die forming by using viscoplastic pressure carrying medium, Computational Materials Science, 46 (2009) 4, 1058–1068

[7] Liu, Y., Hua, L., Lanm, J., Wei, X., Studies of the deformation styles of the rubber-pad forming process used for manufacturing metallic bipolar plates, Journal of Power Sources, 195 (2010) 8177–8184

[8] Liu, Y., Hua, L., Fabrication of metallic bipolar plate for proton exchange membrane fuel cells by rubber pad forming, Journal of Power Sources 195 (2010) 11, 3529–3535

[9] Benisa, M., Babic, B., Grbovic, A., Stefanovic, Z., Computer-aided modelling of the rubber-pad forming process, Materials and technology 46 (2012) 5, 503–510

Nonconventional technologies

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PARETO BASED OPTIMIZATION OF LASER CUT QUALITY CHARACTERISTICS

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Abstract: *Multi-objective optimization of advanced machining processes is of paramount importance. In this paper, multi-objective optimization based on Pareto concept, with surface roughness and kerf width as the objective functions was presented. The CO_2 laser cutting experiments were conducted on AISI 304 stainless steel workpieces with thickness of 3 mm by using Taguchi's experimental design in which laser power, cutting speed, assist gas pressure and focus position were varied at three levels. Using obtained experimental data, mathematical models of surface roughness and kerf width were developed using artificial neural networks. The developed mathematical models were used as objective functions in the formulation of the multi-objective optimization problem. As a result of optimization, a set of optimal solutions was obtained upon which the Pareto optimal front was generated. It was observed that the functional dependence between the surface roughness and kerf width is nonlinear and can be expressed with a higher order polynomial equation.*

Key words*: multi-objective optimization, Pareto front, laser cutting, surface roughness, kerf width.*

1. INTRODUCTION

Because of capability of machining intricate shapes and profiles irrespective of hardness of the workpiece material, advanced machining processes find widespread applications in mould-making tool and die industries, automobile, electronics industries and medicine. Laser cutting is advanced machining process, used for creating complex shapes and geometries on different materials both brittle and ductile materials, ferrous and non-ferrous, thin and thick, hard-to-machine materials, etc. It is a thermal-based advanced machining process in which the material is removed by focusing the laser beam on the workpiece surface, and depending upon the prevailing conditions, the material may be removed by different mechanisms [1]. Its wide application is due to several advantages and unique characteristics including: high processing speed, high dimensional accuracy and surface finish, low waste and noise, localized heat affected zone, low operational costs, narrow kerf, perpendicular cut, ability to machine without dross formation, etc.

The afore-mentioned characteristics are the most important performance measures in laser cutting. On the other hand, laser power, cutting speed, assist gas (type, pressure and purity), focus position, stand-off distance and characteristics of laser beam are the main machining parameters which affect the performance measures. Thereby it has been widely reported that these machining parameters differently affect the performance measures, depending mainly on the selected levels of variation and interaction with other parameters.

In the last few years, market competition led to growing interest in both reducing production cost and improving product quality, which resulted that process modeling and multi-optimization became one of the most investigated areas in laser cutting. Pandey and Dubey [2] presented an integrated approach based on TM and fuzzy logic theory for optimization of multiple responses in Nd:YAG laser cutting of duralumin sheet. The authors demonstrated the effectiveness of the method for simultaneous improvement of the kerf width and kerf deviations at top and bottom sides. In another work [3], the authors presented an approach for simultaneous optimization of kerf taper and surface roughness in Nd:YAG laser cutting of titanium alloy. The implemented methodology consisted of empirical modeling of experimental data using regression analysis and application of genetic algorithms for solving multi-objective optimization. Dubey and Yadava [4] optimized simultaneously kerf deviation and kerf width obtained in pulsed Nd:YAG laser cutting of 8081 aluminum alloy sheet using Taguchi quality loss function. For simultaneous optimization, the normalized quality loss function was computed and weighted to obtain total normalized quality loss for each trial condition. Caydaş and Hasçalik [5] applied hybrid approach of TM and GRA to determine optimum laser cutting parameters (cutting speed and laser power) with multi-performance characteristics (surface roughness, kerf width, and HAZ) during CO_2 laser cutting of mild steel sheet. Multi-objective optimization of CO_2 laser cutting using the non-dominated sorting genetic algorithm (NSGA-II) and ANNs, with surface roughness and material removal rate (MRR) as the objective functions was presented by Madić and Radovanović [6]. From the Pareto front it was observed that the functional dependence between the surface roughness and material removal rate is nonlinear and can be expressed with a second degree polynomial.

The present research paper presents a multi-objective optimization of CO_2 laser inert cutting of AISI 304 stainless steel. The objective of this study is to obtain a set of optimal laser cutting parameters which minimize surface roughness and kerf width values at the same time. To this aim, ANN prediction models were developed in order to explicitly express the relationships between laser cutting parameter such as laser power, cutting speed, assist gas pressure and focus position, and process responses such as surface roughness and kerf width. NSGA-II based optimization strategy was applied in conjunction with the developed ANN models to obtain a set of optimal solutions. Furthermore, the obtained solutions were compared with the solutions obtained by using developed software prototype [7].

2. EXPERIMENTAL PROCEDURE

A 2.2 kW CO_2 ByVention 3015 laser cutting machine provided by Bystronic Inc. was used for conducting the experiment trials. The cuts were performed with a continuous wave and Gaussian distribution beam mode (TEM_{00}) on 3 mm thick AISI 304 stainless steel sheet using the nitrogen as assist gas. A focusing lens with a focal length of 5 in. (127 mm) was used to perform the cut. The conical shape nozzle (HK20) with inner diameter of 2 mm was used. The nozzle-workpiece stand-off distance was controlled at 1 mm. In this study nitrogen with purity of 99.95% was used as assist gas in all experimental trials. The main laser cutting factors such as laser power (P), cutting speed (v), assist gas pressure (p) and focus position (f) were varied at three levels: P=1.6, 1.8, 2 kW; v=2, 2.5, 3 m/min; p=9, 10.5, 12 bar; and f=–2.5, –1.5, –0.5 mm. To carry out experimental work laser cutting experiment was planned and conducted in accordance with the standard L_{27} (3^{13}) Taguchi's experimental design. Laser cutting factors P, v, p and f were assigned to columns 1, 2, 5 and 12, respectively.
Surface roughness on the cut edge was measured in terms of the average surface roughness (R_a) using Surftest SJ-301 (Mitutoyo) profilometer. Each measurement was taken along the cut at approximately the middle of the thickness and the measurements were repeated three times to obtain averaged values. In this paper the kerf width (K_w) represents the top kerf width. Kerf widths were measured at three different places at equal distances along the length of cut. Three measurements of kerf width for each of the cut were taken using the optical microscope (Leitz, Germany) to obtain averaged values. More details about experimental setup and procedure can be found in [1, 6].

3. MATHEMATICAL MODELS OF THE PERFORMANCE MEASURES

Assuming that there exist complex and nonlinear relationships between laser cutting parameters and performance measures such as surface roughness and kerf width, ANNs were applied to model these relationships. Two ANN models with the same architecture (Figure 1) were designed for each of the performance measures.
Table 1 summarizes the ANN design parameters used for developing the ANN models.

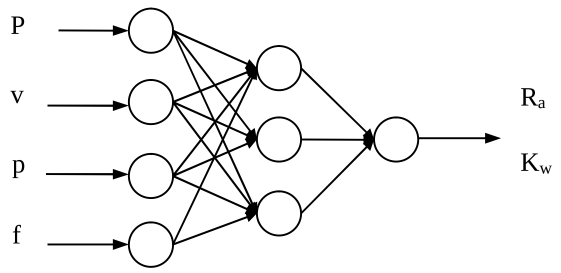

Fig.1. ANN mathematical models for the performance measures

Table 1. ANN design parameters

Number of data for training	19
Number of data for testing	8
Data normalization	into range [–1, +1]
Number of input neurons	4
Number of hidden neurons	3 (determined based on the number of ANN free parameters and number of data for training)
Number of output neurons	1
Initial weights set by	Nguyen-Widrow method
Training algorithm	Levenberg-Marquardt
Max. number of training epochs	300 (training was stopped considering the well known "bias-variance" trade-off)
Transfer function in hidden layer	hyperbolic tangent sigmoid (*tansig*)
Transfer function in output layer	linear (*purelin*)

To test the prediction capability of the developed ANN models, statistical method of absolute percentage error (APE) was computed. The average APE for surface roughness ANN model was found to be 8.71 % and 9.66 % using data for training and testing, respectively. The average APE for kerf width ANN model was found to be 5.5 % and 6.5 % using data for training and testing, respectively. These statistical results indicate that developed ANN models are capable of providing accurate predictions within the scope of laser cutting conditions investigated in the study and thus can serve as objective functions in the formulation of the multi-objective optimization problem.

4. MULTI-OBJECTIVE OPTIMIZATION OF PERFORMANCE MEASURES

In this study an attempt has been made to determine the optimum laser cutting parameters for simultaneous minimization of surface roughness and kerf width. The decision variables are laser power, cutting speed, assist gas pressure and focus position. Multi-objective optimization problem was formulated as follows:

$$\begin{aligned} &\text{Find: } P_{opt}, v_{opt}, p_{opt}, f_{opt} \\ &\text{to minimize: } R_a = f_{ANN}(P,v,p,f) \\ &\quad \text{and } K_w = f_{ANN}(P,v,p,f) \qquad (1) \\ &\text{subject to: } 1.6 \le P \le 2\,(\text{kW});\; 2 \le v \le 3\,(\text{m/min}) \\ &\quad 9 \le p \le 12\,(\text{bar});\; -2.5 \le f \le -0.5\,(\text{mm}) \end{aligned}$$

where f_{ANN} represents mathematical function of the developed ANN model.

4.1. Solving approaches

For solving the optimization problem as formulated in Eq. 1, there are several approaches [8]. A simple approach for handling multi-objective optimization problems is to form a composite objective function as the weighted sum of the objectives, where a weight for an objective is proportional to the preference factor assigned to that particular objective. In such a way multi-objective optimization problem is converted into a single objective optimization problem.

In order to alleviate the difficulties of the afore-mentioned approach in solving optimization problems having non-convex objective spaces, the ε-constrained method is a very popular alternative approach.

The third approach is based on determining of a set of non-dominating solutions (Pareto optimal solutions) using evolutionary algorithms which use a population of solutions in each iteration, instead of a single solution.

Apart from these approaches, the potential for solving multi-objective optimization problems also has Monte Carlo method. The optimization based on Monte Carlo method can be particularly useful for solving multi-objective optimization problems with many local optima and complicated constraints, possibly involving a mix of continuous and discrete variables [9].

Irespectve of applied optimization approach and method, as suggested by Deb [8] the following principle for an ideal multi-objective optimization procedure would be:

- **Step 1.** Find multiple trade-off optimal solutions with a wide range for the objective functions values.
- **Step 2.** Choose one of the obtained solutions using higher-level information.

In this paper, for solving the multi-objective optimization problem formulated in Eq. 1, three optimization methods were applied, that is: NSGA-II, Monte Carlo method and ε-constrained method.

The NSGA-II is an evolutionary, fast and elitist GA which provides multiple Pareto-optimal solutions to the multi-objective optimization problems. NSGA-II is essentially a modified form of conventional GA.

Monte Carlo method is a simple optimization method that uses only random numbers but a large number of computations. Because of its efficiency and it became principle part of many meta-heuristic algorithms such as GA, SA, etc.

The main idea of ε-constrained method is to keep one of the objective functions and restrict the rest of the objective functions within user-specified values. The application of this method was realized using the developed software prototype [7] which uses exhaustive iterative search algorithm so that the optimality of obtained solution for the given discrete search space is guaranteed. It is possible to specify different search steps for each input variable by considering the practical limitations of machine tool or machining process.

4.2. Optimization results

The Pareto-optimal front of surface roughness and kerf width is shown in Figure 2, and the corresponding values of laser cutting parameters are given in Table 2. None of the solutions in the Pareto-optimal front is absolutely better than any other, so as any one of them is an acceptable solution.

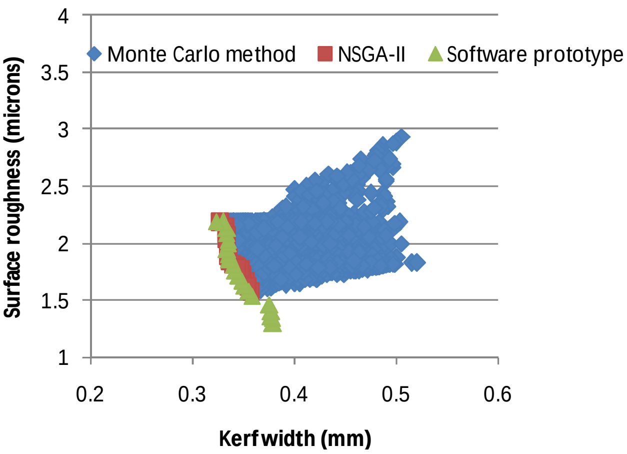

Fig.2. Pareto front generated using different optimization approaches

4.3. Analysis and discussion

Findings can be summarized in the following points:

- Analysis of Monte Carlo simulations from Figure 2 reveals that surface roughness ranges from 1.3 to 2.9 µm and kerf width ranges from 0.32 to 0.53 mm.
- The spread and distribution of non-dominated optimal solutions obtained using ε-constrained method is better than in the case of NSGA-II. This may be result of stochastic nature of NSGA-II or because fine parameter tuning of NSGA-II was not performed.
- Exhaustive iterative algorithm which was implement by ε-constrained method is more convenient for optimization purpose because the resulting parameter values can be more easily adjusted on machine tools.
- From Figure 2 it can be also observed that the relationship between surface roughness and kerf width is nonlinear and can be expressed with a fourth degree polynomial in the form: $y = -2.066x^4+15.52x^3-43.50x^2+53.81x-24.42$, $R^2 = 0.975$.
- Focusing the laser beam near to the top sheet surface and using higher levels of laser power is beneficial for multi-objective optimization of surface roughness and kerf width. By doing so, there is a number of cutting speed and assist gas pressure combinations which produce different trade-off solutions. Given that high assist gas pressure means more gas flow, i.e. higher cost of gas, and higher cutting speed means better productivity, for optimal conditions one can take solutions by which the cutting speed is 3 m/min and assist gas pressure is 9 bar (Table 2, bolded rows).

Table 2. Multi-objective optimization solutions obtained by NSGA-II and ε-constrained method

NSGA-II						ε-constrained method					
P	**v**	**p**	**f**	**R_a**	**K_w**	**P**	**v**	**p**	**f**	**R_a**	**K_w**
(kW)	(m/min)	(bar)	(mm)	(μm)	(mm)	(kW)	(m/min)	(bar)	(mm)	(μm)	(mm)
1.83	2.99	9.37	-0.50	1.965	0.335	2.00	2.00	11.85	-0.50	1.295	0.379
1.80	2.99	9.41	-0.50	2.138	0.333	1.98	2.00	12.00	-0.50	1.348	0.378
1.94	2.59	9.77	-0.50	1.662	0.353	2.00	2.05	12.00	-0.50	1.354	0.377
1.93	2.66	9.47	-0.50	1.724	0.350	2.00	2.10	12.00	-0.50	1.399	0.377
1.89	2.73	9.55	-0.53	1.776	0.347	2.00	2.45	9.15	-0.50	1.464	0.376
1.94	2.43	9.98	-0.50	1.575	0.359	2.00	2.70	10.65	-0.50	1.536	0.359
1.83	2.99	9.40	-0.50	1.989	0.335	2.00	2.95	12.00	-0.50	1.581	0.356
1.82	2.99	9.34	-0.50	2.063	0.334	1.98	3.00	12.00	-0.50	1.625	0.350
1.83	2.99	9.38	-0.50	1.958	0.335	1.94	3.00	12.00	-0.50	1.670	0.348
1.84	2.99	9.39	-0.50	1.919	0.335	1.88	3.00	12.00	-0.50	1.714	0.346
1.86	2.97	9.47	-0.50	1.838	0.337	1.90	3.00	11.10	-0.50	1.765	0.343
1.94	2.52	9.81	-0.50	1.620	0.355	**1.86**	**3.00**	**9.00**	**-0.50**	**1.813**	**0.340**
1.84	2.78	9.74	-0.50	1.805	0.342	1.84	3.00	9.45	-0.50	1.855	0.335
1.84	2.98	9.36	-0.50	1.878	0.336	**1.84**	**3.00**	**9.00**	**-0.50**	**1.903**	**0.335**
1.85	2.98	9.41	-0.50	1.861	0.336	1.82	2.95	9.30	-0.50	1.944	0.334
1.82	2.99	9.36	-0.50	2.036	0.334	1.82	3.00	9.60	-0.50	1.997	0.335
1.90	2.96	9.61	-0.50	1.812	0.340	1.82	**3.00**	**9.00**	**-0.50**	**2.030**	**0.335**
1.81	2.99	9.42	-0.50	2.102	0.334	1.80	2.95	9.15	-0.50	2.090	0.333
1.82	2.99	9.34	-0.50	2.075	0.334	1.62	3.00	11.85	-0.50	2.134	0.334
1.84	2.69	9.77	-0.50	1.787	0.345	**1.60**	**3.00**	**9.00**	**-0.50**	**2.182**	**0.330**
1.68	3.00	9.33	-0.50	2.187	0.327	1.80	2.50	10.50	-1.50	2.188	0.323

5. CONCLUSION

In the context of the multi-objective optimization, this paper considered minimization of surface roughness and kerf width. The concept of the Pareto optimal solutions was considered in the optimization procedure and three optimization approaches were applied, i.e. Monte Carlo method, NSGA-II and ε-constrained method.

On the basis of obtained multi-objective optimization solutions it was observed that focusing the laser beam near to the top sheet surface of the workpiece material and using higher levels of laser power at suitable combination of assist gas pressure and cutting speed is beneficial for obtaining minimization of both surface roughness and kerf width. From the obtained Pareto front one can select the appropriate laser cutting conditions depending on the specific surface roughness and kerf width requirements. It was seen that the surface roughness decreases nonlinearly as the kerf width increases and the functional dependence can be expressed with a fourth degree polynomial.

Regarding optimization methodologies applied it was proven that exhaustive iterative search algorithm applied in the framework of ε-constrained method outperforms the NSGA-II in terms of quality of solutions obtained (spread and distribution). The application of Monte Carlo method was found to be particularly suitable for obtaining of feasible multi-objective optimization space.

REFERENCES

[1] MADIĆ, M., RADOVANOVIĆ, M. (2013) *Application of RCGA-ANN approach for modeling kerf width and surface roughness in CO2 laser cutting of mild steel*, Journal of the Brazilian Society of Mechanical Sciences and Engineering, Vol. 35, No. 2, pp. 103-110

[2] PANDEY, A.K. DUBEY, A.K. (2012) *Taguchi based fuzzy logic optimization of multiple quality characteristics in laser cutting of duralumin sheet*, Optics and Lasers in Engineering Vol. 50, No. 3, pp. 328-335

[3] PANDEY, A.K. DUBEY, A.K. (2012) *Simultaneous optimization of multiple quality characteristics in laser cutting of titanium alloy sheet*, Optics and Laser Technology Vol. 44, No.6, pp. 1858-1865

[4] DUBEY, A.K., YADAVA, V. (2008) *Optimization of kerf quality during pulsed laser cutting of aluminium alloy sheet*, Journal of Materials Processing Technology, Vol. 204, No. 1-3, pp. 412-418

[5] CAYDAŞ, U., HASÇALIK, A. (2008) *Use of the grey rela-tional analysis to determine optimum laser cutting pa-rameters with multi-performance characteristics*, Optics and Laser Technology, Vol. 40, No. 7, pp. 987-994

[6] MADIĆ, M., RADOVANOVIĆ, M. (2013) *Multi-objective optimization of surface roughness and material removal rate in CO_2 laser cutting using ANN and NSGA-II*, Metalurgia International, Vol. 18, No.3, pp. 43-46

[7] KOVAČEVIĆ, M., MADIĆ, M., RADOVANOVIĆ, M. (2013) *Software prototype for validation of machining optimization solutions obtained with meta-heuristic algorithms*, Expert Systems with Applications, Vol.40, No. 17, pp. 6985-6996

[8] DEB, K. (2001) *Multi-objective optimization using evolutionary algorithms*, John Wiley and Sons.

[9] KROESE, D., TAIMRE, T., BOTEV, Z. (2011) *Handbook of Monte Carlo methods*, John Wiley and Sons.

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PROCESS PARAMETERS EFFECT ON CHARACTERISTICS OF KERF GEOMETRY BY ABRASIVE WATER JET CUTTING

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Abstract: *In the last few years, the abrasive water jet technology (AWJ) has shown a rapid development due to its remarkable advantages and its capability to extend to new fields of application. Distinct advantages are: no thermal distortion, high machining versatility, high flexibility and small cutting forces. In AWJ cutting, the final cut surface roughness and the dimensional accuracy are defined by numerous influencing factors, which determinate volume of separate material, as cut quality. Substantial efforts has been made in understanding effects of individual influencing factors, lake: diameters of water and abrasive orifice (nozzle), water pressure, kind, size and flow rate of abrasive, distance of cutting head from material surface, feed rate, etc*
In this paper, an experimental investigation of the kerf characteristics of EN AW-6060 aluminium alloy sheets under abrasive water jets is going to be presented.

Key words*: Abrasive water jet cutting, Process parameters, Kerf geometry*

1. INTRODUCTION

Abrasive water jet (AWJ) cutting is a non-conventional machining process that uses high velocity water with abrasives for cutting a variety of materials. It is most suitable process for very thick, highly reflective or highly thermal-conductive materials, as well as hard materials.
Abrasive water jet machining is appropriate and cost effect for a number of procedures and materials and is applied in nearly all areas of modern industry, such as automotive industry, aerospace industry, construction engineering, environmental technology and industrial maintenance [1].
In the last few years, the AWJ technology has shown a rapid development due to its remarkable advantages and its capability to extend to new fields of application; it is able to cut any kind of material, carry out complex profiles, prevent thermal and mechanical damages on the target material, reduce the burr formation and the delamination phenomena. As a consequence of the aforesaid development, the demand for an elevated finish and working precision has increased.
Abrasive water jet cutting technology offers many advantages over conventional cutting methods. They include:

- Almost any material up to a thickness of 100 mm can be cut with the abrasive water jet.
- The abrasive water jet makes it possible to cut random contours.
- Abrasive water jet cutting is a very precise technique. Tolerances of ± 0.1 mm can be realized in metal cutting.
- The workpiece is not heat-stressed. That mean cold cutting - no heat-affected zones, no hardening.
- Environmentally friendly.

In comparation with other non-conventional manufacturing processes abrasive water jet cutting is slower than laser or plasma [2].
Although this cutting technology includes many advantages, there are some drawbacks. For instance, abrasive water jet cutting can produce tapered edges on the kerf of workpiece being cut. This can limit the potential applications of abrasive water jet cutting, if further machining of the edges is needed to achieve the engineering tolerance required for the part.
Abrasive water jet cutting belongs among complicated dynamical and stochastic processes with incomplete information about mechanism and side effects character. In AWJ cutting, the final cut quality and the dimensional accuracy depends on the process parameters selection [3].
In this paper, an experimental investigation of the process parameters effect on kerf geometry of EN AW-6060 aluminium alloy sheet machined by abrasive water jets is presented.

2. PARAMETERS OF AWJ CUTTING PROCESS

The cutting process is most similar to the grinding. The difference is that the abrasive particles are moved through the material by water rather than by a solid wheel. Abrasive water jet cutting process can be divided into subsequent steps:

- Transformation of the potential energy of water under high pressure into kinetic energy of a water jet.
- Transfer of a part of the kinetic energy of the high-speed water jet to abrasive particles by accelerating them and focusing the resulting abrasive water jet.
- Use of the kinetic energy of the abrasive particles to remove small chips of the work material.

In the process of abrasive water jet cutting the high pressure pump produces the required pressure up to 400 MPa. A high pressure supply line directs the pressurized water from the pump to the cutting head (Fig. 1).

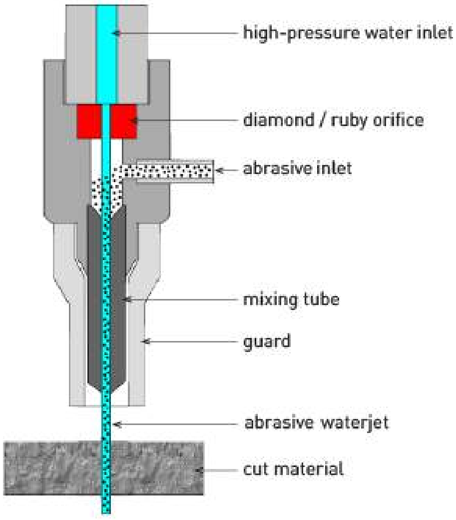

Fig.1. Abrasive water jet cutting

When the pressurized water comes out from the orifice, a water jet is created [4]. The result is a very thin, extremely high velocity (approx. 900 m/s) water jet. Then, solid abrasive particles are added and mixed with the water jet. Resulting abrasive water jet is focused to the material through abrasive nozzle.
Accuracy and quality of the cutting process depend on a wide range of parameters and technological effects of these parameters. These parameters can be classified according to the Figure 2.

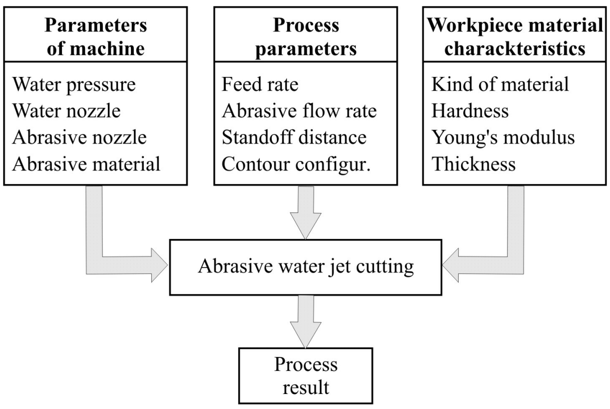

Fig.2. Parameters of abrasive water jet cutting process

Although AWJ cutting involves a large number of variables and virtually all these variables affect the cutting results (kerf width, taper and surface roughness), only few major and easy-to-adjust dynamic variables were considered in the present study. Those are: feed rate (the speed at which the cutting head moves along workpiece during cutting operation), material thickness and abrasive flow rate. The other process parameters were kept constant using the standard machine configuration (d_0 = 0.3 mm; d_A = 1.02 mm; p = 400 MPa).

Feed rate (cutting speed) is the speed of the relative movement of the cutting head relative to the workpiece. The feed rate is an important parameter of this technology because it affects the quality of the cut and amount of removed material. Also, depends on the type and thickness of material being cut, and the desired cut quality.
The abrasive flow rate is the amount of abrasive material per unit of time, which is added to water jet, for mixing and forming abrasive water jet. In the newer machines abrasive flow can be regulated during operation, specified by the program. Higher flow rates leads to higher productivity and better quality of the cut, but with the increased processing costs. Depending on the desired productivity and quality of cut, in practice, abrasive flow rate takes values between q = 300 and q = 400 g/min.

3. EXPERIMENTAL WORK

For the AWJ cutting process evaluation the greatest influence has a group of geometric characteristics, as determined by the geometric layout of the part. The group of geometric characteristics of objects is: dimensional accuracy, shape accuracy and cut quality [5]. Parameters that define the cut quality (geometric characteristics of cut quality and cut surface quality) in abrasive water jet cutting are shown in Fig. 3 [6].

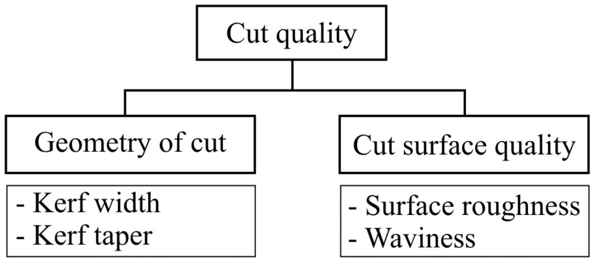

Fig.3. Characteristics of cut quality

As workpiece material, aluminium alloy AA-ASTM 6060 (EN AW-6060; ISO Al MgSi) was used. For each level of the material thickness (6 mm and 10 mm) and three levels of abrasive flow rate (300, 350 and 400 g/min), six levels of feed rates (200, 300, 400, 500, 800 and 1000 mm/min) were used.
Geometry of cut is a characteristic of major interest in abrasive water jet cutting process. Cutting using AWJ can create tapered edges on the kerf, especially when cutting at high feed rates.
The kerf geometry of a through cut generated by abrasive water jets may be described as in Fig. 4.

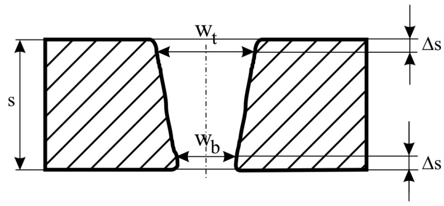

Fig.4. Cut geometry by AWJ cutting

A top and bottom kerf width was measured from the optical microscope images with 40 times magnification, equipped with a CMOS camera and USB connection to a PC (Fig. 5). Camera sensor size is 1/2 inch, a resolution of 1280x1024 dots and wide field of view of 5.4 mm.

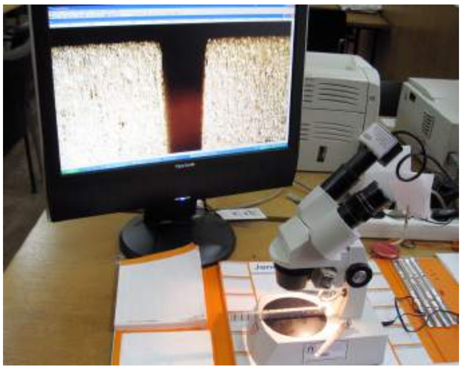

Fig.5. Optical microscope with CMOS camera

The top kerf is commonly wider than the bottom due to the decrease in abrasive water jet power as a unique feature of AWJ technology. As a result of this, a taper is produced. The large kerf taper ratio worsens the perpendicularity of the straightness of the cutting cross-section, resulting in an inaccurate dimensional quality.
Fig. 6 and Fig. 7 show some typical and representative trends and relationships between the kerf geometry (top kerf width W_t and bottom kerf width W_b) and the cutting parameters.

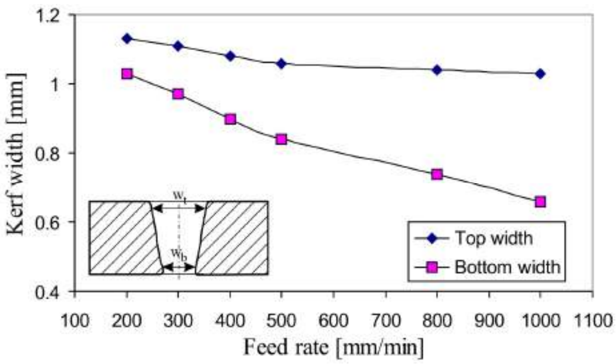

Fig.6. The effect of feed rate on the kerf geometry

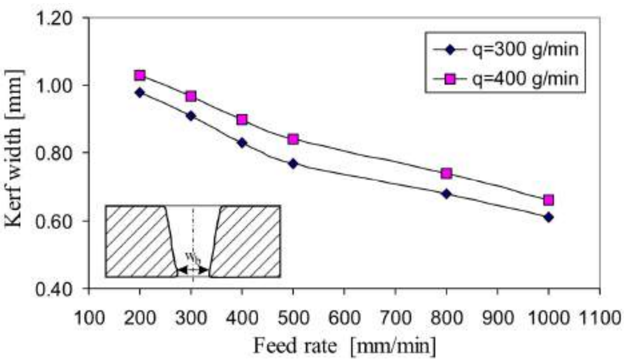

Fig.7. The effect of abrasive flow rate on bottom kerf width

The effect of feed rate on the top kerf width and bottom kerf width is shown in Fig. 4. It can be seen from the figure that the feed rate has a negative effect on both the top and bottom kerf widths. The negative effect of the feed rate on both the top and bottom kerf widths is because a faster passing of abrasive water jet allows fewer abrasives to strike on the jet target and hence generates a narrower slot.
In contrast to brittle materials, ductile materials are sensitive on number of abrasive particles that hits material surface. By increase of abrasive flow rate the larger number of abrasive particles share in machining process, which has positive effect on kerf geometry. The effect of abrasive flow rate is shown in Fig. 6. It can be seen that higher abrasive flow rate produce greater kerf widths, especially bottom kerf width.
The regression analysis is applied in order to develop the mathematical model [7]. Bottom kerf width as a function of feed rate, and material thickness, for constant value of abrasive flow rate of 300 g/min is given in Fig. 8. These three-dimensional surface plot show predicted kerf width as a function of independent variables - factors.

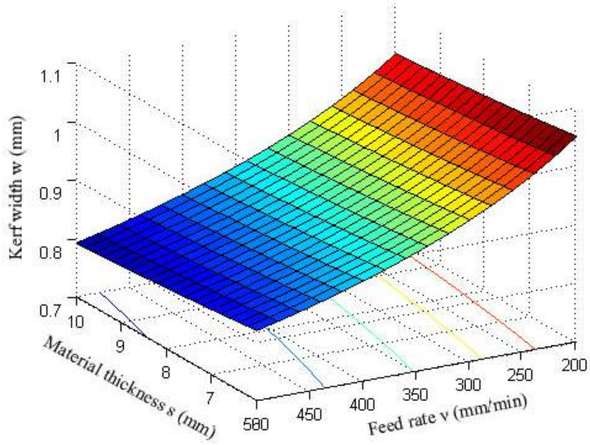

Fig.8. Predicted kerf width as a function of feed rate and material thickness under given conditions

4. CONCLUSIONS

In the battle to reduce costs abrasive water jet cutting provides many unique capabilities and advantages that can prove very effective in the cost battle. Abrasive water jet process is recognized as the most versatile and fastest growing process in the world. This machining technology, no doubt, compliment other technologies, such as milling, laser, EDM, plasma, as well as a host of other traditional and non-traditional processes used in the manufacturing industry.
The primary interests in sheet steel processing are the kerf shape (kerf width). The kerf profile changes with feed rate. Cuts at low feed rate generate almost straight cutting cross-section, whereas high feed rates generate a convergent shape.
In abrasive water jet cutting the final cut surface roughness and the dimensional accuracy depend on the many process parameters. Experimental study shows that, among others, the most important factors influencing the cut surface quality of aluminium alloy are feed rate and abrasive mass flow rate. Summarizing the main features

of the experimental results, the following conclusions may be drawn:
- As the feed rate increases, the AWJ cuts narrower kerf. This is because the feed rate of abrasive water jet allows fewer abrasives to strike on the jet target and hence generates a narrower slot.
- Higher abrasive flow rate produce greater kerf width, especially lower kerf width because the larger number of abrasive particles share in machining process which has positive effect on kerf geometry.
It should be noted that if the kerf width can be predicted, they may be compensated for in the design and process planning stages and by controlling the nozzle in the machine.

Acknowledgments: Paper is result of technological project TR35034 "The research of modern non-conventional technologies application with the aim of increase efficiency of use" which is supported by Ministry of Education and Science of the Republic of Serbia.

REFERENCES

[1] MOMBER, W. and KOVACEVIC, R. (1998) *Principles of Abrasive Water Jet Machining*, Springer, London, New York, 1998

[2] JANKOVIĆ, P, RADOVANOVIĆ, M. (2005) *Nontraditional machining by abrasive water jet cutting*, International Conference Heavy Machinery, University of Kragujevac, Kraljevo, pp. IIA.55-IIA.58

[3] HLOCH, S. and FABIAN, S. (2006) *Qualitative analysis of AWJ factors affecting the surface roughness*, Wissenschaftliche Beitraege, TFH Wildau, Germany, 113-119

[4] AKKURT, A., KULECKI, M.K., SEKER, U. ERCAN, F. (2004) *Effect of feed rate on surface roughness in abrasive waterjet cutting applications*. Journal of Materials Processing Technology, No. 147, pp. 389-396

[5] MAROS Z. (2003) *Quality and efficeincey at abrasive waterjet cutting of an aluminium alloy*. Proceedings of the 6th International MTeM Conference, Cluj-Napoca, Romania

[6] JANKOVIĆ, P., RADOVANOVIĆ, M., BARALIĆ, J. (2011) *Cut quality in abrasive water jet cutting*, 34th International Conference on Production Engineering, University of Nis, Mechanical Engineering Faculty, Nis, Serbia, pp. 435-438

[7] JANKOVIĆ, P, IGIĆ, T., NIKODIJEVIĆ, D. (2012) *Process parameters effect on material removal mechanism and cut quality of abrasive water jet machining*, Journal Theoretical and Applied Mechanics, Vol. 40 (S1), pp. 277-293

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INVESTIGATION ON SURFACE ROUGHNESS OF CARBON STEEL MACHINED BY ABRASIVE WATER JET

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Abstract: *Investigation on surface roughness of carbon steel machined by abrasive water jet is proposed in this paper. Full factorial design of experiment with three factors, abrasive flow rate, traverse rate and standoff distance, and two levels is employed to investigate surface roughness. The analysis of means and analysis of variance are employed to determine influence of factors on surface roughness. Regression analysis was used to find correlation between surface roughness and process factors.*

Key words*: abrasive water jet cutting, surface roughness*

1. INTRODUCTION

Abrasive water jet (AWJ) cutting is a novel machining process. Material cutting by abrasive water jet was first commercialized in the late 1980s. AWJ can cut wide range of materials and thickness. Mix high pressure water jet with abrasives gives an effective cutting tool. AWJ makes it possible to cut random contours, very fine tabs and filigree structures. Tolerances of ±0.1 mm can be realized in metal cutting. There is no thermal effect on the workpiece. AWJ produces very little lateral force. AWJ cutting process is like grinding, except that abrasive particles are moved through the material by water jet rather than by a solid wheel. Scheme of abrasive water jet cutting is shown in Fig. 1.

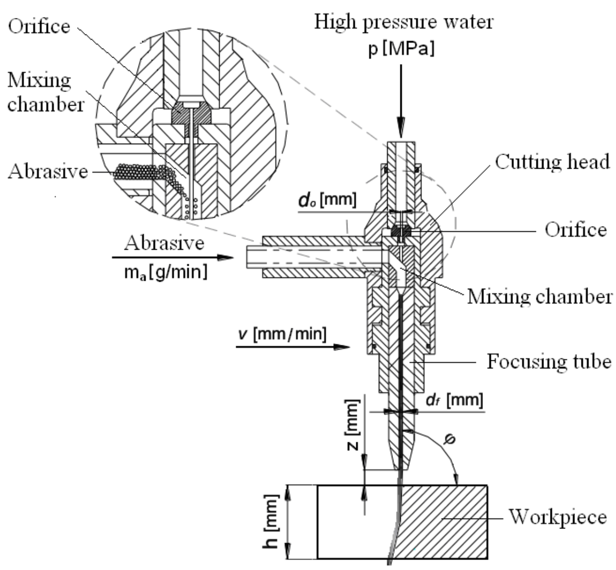

Fig.1. Abrasive water jet cutting

When cutting with AWJ high pressure pump produces water pressure up to 400 MPa. High pressure supply line directs the pressurized water from the pump via accumulator to the cutting head. Cutting head consists of orifice, mixing chamber and focusing tube. Orifice is made of sapphire, ruby or diamond. Orifice is with diameter of 0.15 to 0.35 mm. Focusing tube is made of hard metal. Focusing tube is with diameter of 0.54 to 1.1 mm and length of 50 to 100 mm. Water is pressed out of the orifice in form of jet at a speed of approximately 900 m/s – nearly three times the speed of sound. Result is a very thin, extremely high velocity water jet. Solid abrasive particles are added and mixed with the water jet in the mixing chamber of the cutting head and then focused by a focusing tube. High speed of the water jet creates a partial vacuum in the mixing chamber so that abrasive particles are sucked in and flushed away by the water jet. Focusing tube focuses and directs the abrasive water jet to the workpiece. Abrasive water jet cuts workpiece along the programmed contour guided the cutting head using NC control unit. [1, 2]

Many factors influence on AWJ cutting process. AWJ factors can be classified into categories that relate to: workpiece (material type, thickness, chemical structure, hardness, toughness, grain size), high pressure pump (pump pressure, water flow rate, water purity, accumulator volume), abrasive (material type, hardness, particle diameter, particle shape, particle size distribution, humidity), cutting head (orifice diameter, orifice material, focusing tube diameter, focusing tube length, focusing tube material), motion system (precision, accuracy, stiffness, working conditions) and process (water pressure, traverse rate, abrasive flow rate, standoff distance, impact angle, traverse direction). AWJ cutting performances can be classified into categories that relate to: process (orifice wear, focusing tube wear, temperature, noise, vibration), quality (form deviations, dimension deviations, cut quality: surface roughness, burr, depth of cut, kerf width, kerf taper), productivity (machining time, productivity), and economy (machining cost, power consumption, abrasive consumption).

Surface roughness is a measure of the technological quality of a product. It describes the surface textures of the machined parts. There are several parameters to describe surface roughness, such as arithmetic average roughness (Ra), root-mean-square roughness (Rq) and maximum peak-to-valley roughness (Ry or Rmax), etc. Arithmetic average roughness (Ra) is defined as the arithmetic value of the profile from centerline along the sampling length.

There are some studies regarding investigation of surface roughness in AWJ cutting. Ramulu and Arola (1994) [3] was conducted an experimental investigation to determine the influence of cutting factors on the surface roughness and kerf taper of an abrasive water jet machined graphite/epoxy laminate. Kulekci (2002) [4] presented a detailed explanation of the recent developments in the main components of abrasive waterjet systems. Factors such as water pressure, grain diameters of abrasive and traverse rate influencing surface roughness and depth of cut were studied using experimental data. Akkurt et al. (2004) [5] explained the effects of traverse rate and thickness of workpiece on the surface roughness. Considering experimental data, effects of the composition of the material on surface roughness were assessed. In the study pure aluminum, aluminum alloy 6061, brass-353, AISI 1030 and AISI 304 steel materials were cut with AWJ at different traverse rates. Fowler et al. (2005) [6] were investigated the effects of jet–workpiece traverse rate, number of passes of the jet and abrasive grit size on the material removal rate, surface waviness and surface roughness. Babu et al. (2006) [7] were presented a study on the use of single mesh size abrasives in AWJ cutting of aluminum 6063 T6. Design of experiment with four factors (single mesh size abrasives, water pressure, traverse rate and abrasive flow rate) and three levels is employed to investigate depth of cut, kerf width, kerf taper and surface roughness. Caydas and Hascalik (2008) [8] were presented a study on surface roughness in abrasive water jet cutting process using artificial neural networks and regression analysis method. Artificial Neural Network (ANN) and Simulated Annealing (SA) techniques were integrated by Zain et al. (2011) [9] to estimate optimal process factors in abrasive water jet (AWJ) cutting operation. The considered process factors include traverse rate, water jet pressure, standoff distance, abrasive grit size and abrasive flow rate. The quality of the cutting of machined-material was assessed by looking to the surface roughness (*R*a).

2. DESIGN OF EXPERIMENT

Experimental investigation was conducted in order to study the influence of factors on surface roughness in abrasive water jet cutting of carbon steel. Machine tools used for machining the samples was abrasive water jet cutting machine Hydro Jet Eco 0615 with pump pressure of 150 MPa, power of 7.5 kW and water flow rate of 2.4 l/min. Cutting head is with orifice diameter of 0.35 mm and a focusing tube diameter of 1.02 mm. Focusing tube length is 76 mm. All experiments were conducted with water pressure of 150 MPa. Abrasive material was Garnet with mesh size of 80. Workpiece material used in experimental tests was carbon steel S235 (EN) with thickness 6.5 mm. Chemical properties of S235 are: C 0.13, Si 0.25, Mn 0.58, P 0.013, S 0.008, N 0.01, Cu 0.32, Cr 0.08, Ni 0.10, Mo 0.013, Al 0.033, V 0.001. Mechanical properties of S235 are: $R_{p0.2}$=240 N/mm^2, R_m=360-440 N/mm^2, A=25%.

Design of experiment was conducted using full factorial design. Control factors (independent variables) are: abrasive flow rate (m_a), traverse rate (v) and standoff distance (h). Investigated performance (depended variable) is arithmetic average roughness (R_a). The Hommel Tester T500 has been used for measure of surface roughness. Control factors and their levels are shown in Table 1.

Table 1. Control factors and levels

Code	Control factors	Levels		
		-1	0	+1
A	Abrasive flow rate, m_a (g/min)	300	500	700
B	Traverse rate, v (mm/min)	50	100	150
C	Standoff distance, h (mm)	1	3	5

Three control factors with two levels are arranged in design of experiment with 12 tests (8 tests are for base design and 4 tests for center point). Table 2 shows design of experiment and results. [10]

Table 2. Design of experiment and results

Run	Control factors			Ra
	A	B	C	µm
1	0	0	0	4.22
2	-1	-1	-1	4.12
3	0	0	0	4.24
4	1	-1	-1	4.50
5	0	0	0	4.23
6	0	0	0	4.22
7	1	-1	1	4.45
8	1	1	1	5.18
9	1	1	-1	5.13
10	-1	1	-1	5.18
11	-1	-1	1	4.23
12	-1	1	1	4.99

3. ANALYSIS OF RESULTS

Influence of factors on surface roughness was analyzed using the analysis of means and variance. Normal plot, Pareto chart and main effect plots were generated. In Fig.2 is shown normal plot of the standardized effects and in Fig.3 is shown Pareto chart. From Fig.2 and Fig.3 it is seen effect type of factors and interactions of factors (significant and not significant). Abrasive flow rate and traverse rate are significant factors on surface roughness. Standoff distance is not significant factor. 2-Way interactions abrasive flow rate-traverse rate and traverse rate-standoff distance, and 3-Way interaction abrasive flow rate-traverse rate-standoff distance are significant on surface roughness. Other interactions are not significant.

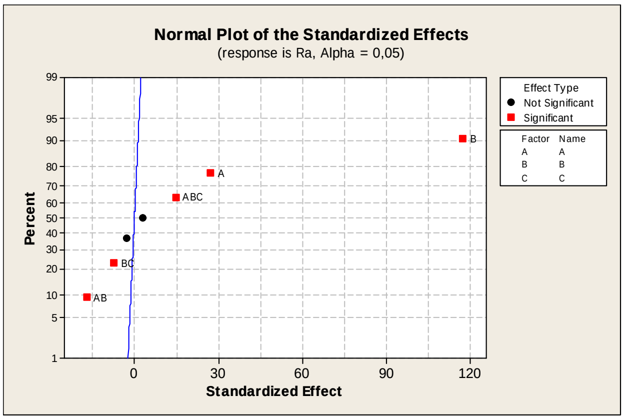

Fig.2. Normal plot

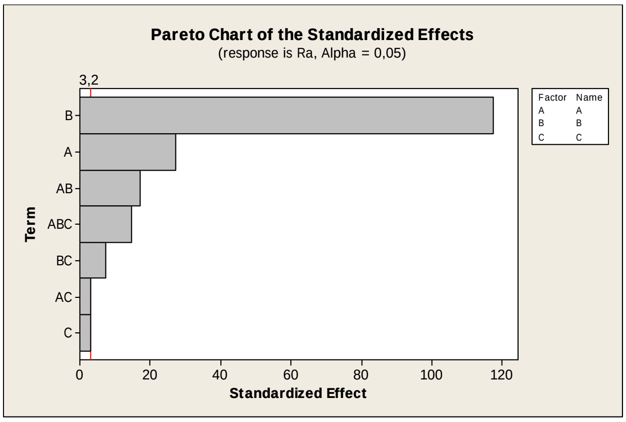

Fig.3. Pareto chart

Main effects plot for surface roughness (Ra) is presented in Fig. 4. The verticality of the line indicates the effect of control factors. Traverse rate is more significant factor as the slope gradient is big.

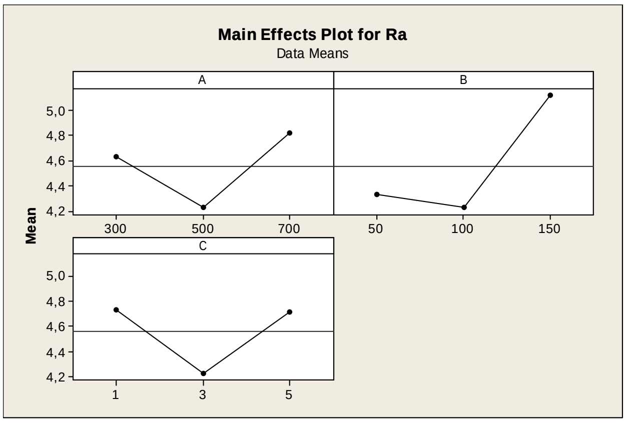

Fig.4. Main effects plot for surface roughness

From Fig. 4 it is seen that as the abrasive flow rate, traverse rate and standoff distance first decrease and after increase the surface roughness.

In Fig. 5 is shown interaction plot for surface roughness. In interaction plot parallel lines indicates that interactions are not significant, such as interaction AC. Analysis of variance (ANOVA) was carried out to find the relative effect of factors on surface roughness. In ANOVA, the ratio between the variance of factor and the variance of error is called Fisher's ratio (F).

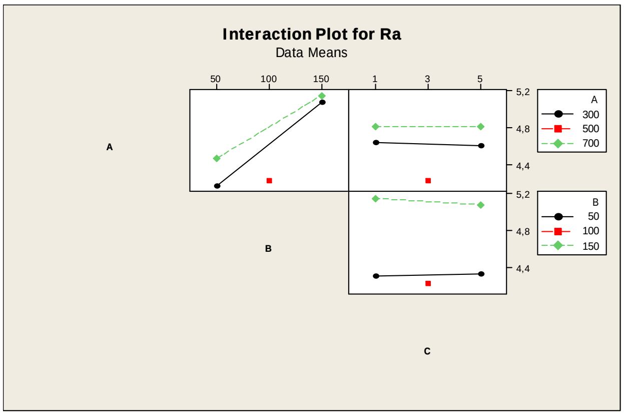

Fig.5. Interaction plot for surface roughness

Fisher's ratio is used to determine whether the factor has a significant effect on quality characteristic by comparing the F table value at the α significance level (F_α). Greater the F-ratio more significant is the factor. Analysis of variance for surface roughness (Ra) is shown in Table 3. Standard F table value at 95% confidence level is $F_{0.05,1,3}$=10.13.

Table 3. Analysis of variance for Ra

Source	DF	SS	MS	F	p	%
Main effects	3	1.33330	0.44443	4848	0.000	65.39
A	1	0.06845	0.06845	746	0.000	3.36
B	1	1.26405	1.26405	13789	0.000	61.99
C	1	0.00080	0.00080	8.73	0.060	0.04
2-Way Inter.	3	0.03225	0.01075	117	0.001	1.58
AB	1	0.02645	0.02645	288	0.000	1.30
AC	1	0.00080	0.00080	8.73	0.060	0.04
BC	1	0.00500	0.00500	54.55	0.005	0.24
3-Way Inter.	1	0.02000	0.02000	218	0.001	0.98
ABC	1	0.02000	0.02000	218	0.001	0.98
Curvature	1	0.65340	0.65340	7128	0.000	32.04
Error	3	0.00028	0.00009	-	-	0.01
Total	11	2.03922	-	-	-	100

DF - degree of freedom, SS - sum of square, MS - mean square, F - variance ratio, p – value, and % - percent contribution

From the Table 3, it is seen that factors: abrasive flow rate, traverse rate and standoff distance have a strong (clearly statistically significant) effect on the surface roughness. Traverse rate is the most significant factor affecting the surface roughness with contribution of 61.99%. Abrasive flow rate affecting the surface roughness with contribution of 3.36%. Standoff distance is not significant factor and affecting the surface roughness with contribution of 0.04%. From Table 3 it is be seen that some of interactions are significant and affect on surface roughness. Interaction abrasive flow rate-traverse rate affecting the surface roughness with contribution of 1.30%. Interaction traverse rate-standoff distance affecting the surface roughness with contribution of 0.24%. Interaction abrasive flow rate-traverse rate-standoff distance affecting the surface roughness with contribution of 0.98%.

Regression analysis (RA) is a powerful tool for mathematical modeling real process. RA includes the experimental data, mathematical methods and statistical analysis. Regression analysis was used to find correlation between surface roughness and process factors. The quasi-linear mathematical model, selected in this paper, have form:

$$Y = Y_e - \varepsilon = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \sum_{i=1}^{n}\sum_{j=1}^{m} \beta_{ij} X_i X_j + \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{p} \beta_{ijk} X_i X_j X_k$$

where Y is the estimated response, Y_e is the measured response, ε is the experimental error, *k* is number of factors, β_0 is the free term, β_i is the linear effect and β_{ij} and β_{ijk} are the interaction effects, X_i are the factors.

Quasi-linear regression equation representing the surface roughness (*R*a) can be expressed as a function of AWJ process factors such as abrasive flow rate (m_a), traverse rate (v) and standoff distance (*h*). The following regression equation, with coefficient of determination of R^2=99.99%, was obtained:

$$\begin{aligned} R_a &= 3.01125 + 0.0017125 m_a + 0.015325 v + 0.1325 h \\ &- 0.00001325 m_a v - 0.000225 m_a h - 0.0015 vh \\ &+ 0.0000025 m_a vh \end{aligned} \quad (1)$$

Surface plot of surface roughness (Ra) versus abrasive flow rate (m_a) and traverse rate (v), according equation (1), is shown in Fig.6.

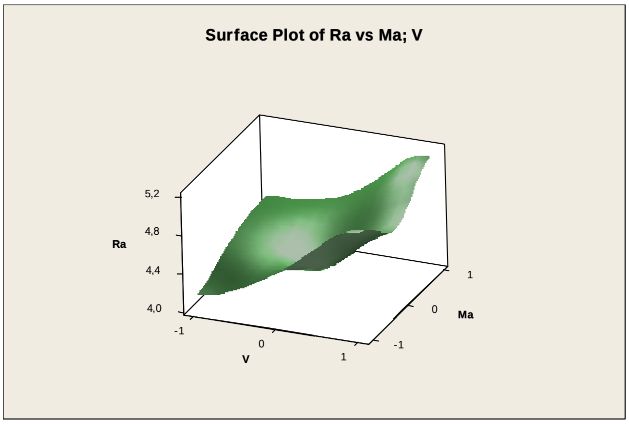

Fig.6. Surface plot of surface roughness versus abrasive flow rate and traverse rate

4. CONCLUSION

The surface roughness of the parts machined by abrasive water jet is one of the most significant quality characteristic. To maximize productivity of abrasive water jet machine, it is essential to have knowledge of the surface roughness in relation to process factors. Experimental investigation of surface roughness when cutting carbon steel S235 with abrasive water jet showed that the process factors traverse rate and abrasive flow rate have a clearly statistically significant effect on the surface roughness with contribution of 65.35%. ANOVA showed that traverse rate is the most significant factor with contribution of 61.99%, followed by the abrasive flow rate with contribution of 3.36%. Some interactions of factors are significant and affect on surface roughness with contribution of 2.52%. Using regression analysis obtained the correlation between the surface roughness and the process factors (abrasive flow rate, traverse rate and standoff distance). Regression model gives a good correlation between the surface roughness and the process factors with coefficient of determination of R^2=99.99%.

Acknowledgement: The paper is a result of the technological project TR35034 which is supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

REFERENCES

[1] RADOVANOVIC M., JANKOVIĆ P., MADIĆ M. (2012) *Predictive models of traverse rate in abrasive water jet cutting based on RA and GA*, Academic Journal of Manufacturing Engineering, Vol.19, No.1, pp 107-112

[2] HERGHELEGIU E., RADOVANOVIC M., BRABIE G., TAMPU N. (2011) *Influence of abrasive material quantity on surface quality generated by abrasive water jet operation*, International Journal of Modern Manufacturing Technologies, Vol.3, No.2, pp 43-48

[3] RAMULU M., AROLA D. (1994), *The influence of abrasive waterjet cutting conditions on the surface quality of graphite/epoxy laminates*, International Journal of Machine Tools and Manufacture, Vol.34, Issues 3, pp 295-313.

[4] KULEKCI M. (2002) *Processes and apparatus developments in industrial waterjet applications*, International Journal of Machine Tools and Manufacture, Vol.42, Issue 12, pp 1297-1306.

[5] AKKURT A., KULEKCI M., SEKER U., ERCAN F. (2004) *Effect of feed rate on surface roughness in abrasive waterjet cutting applications*, Journal of Materials Processing Technology, Vol.147, Issue 3, pp 389-396.

[6] FOWLER G., SHIPWAY P., PASHBY I. (2005) *Abrasive water-jet controlled depth milling of Ti6Al4V alloy – an investigation of the role of jet–workpiece traverse speed and abrasive grit size on the characteristics of the milled material*, Journal of Materials Processing Technology, Vol.161, Issue 3, pp 407-414.

[7] BABU M., CHETY K. (2006) *A study on the use of single mesh size abrasives in abrasive water jet machining*, International Journal of Advance Manufacturing Technology, Vol.29, pp 532-540

[8] CAYDAS U., HASCALIK A. (2008) *A study on surface roughness in abrasive water jet machining process using artificial neural networks and regression analysis method*, Journal of Materials Processing Technology, Vol.202, pp 574-582

[9] ZAIN A., HARON H., SHARIF S. (2011) *Estimation of the minimum machining performance in the abrasive waterjet machining using integrated ANN-SA*, Expert Systems with Applications, Vol. 38, No 7, pp 8316-8326

[10] HERGHELEGIU E. (2011) *Contributions to the optimization of the water jet working parameters, dissertation*, University "Vasile Alecsandri" of Bacau, Industrial Engineering, Bacau, Romania

[11] RADOVANOVIC M., JANKOVIĆ P., MADIĆ M. (2012) *Predictive models of traverse rate in abrasive water jet cutting based on RA and GA*, Academic Journal of Manufacturing Engineering, Vol.19, No.1, pp 107-112

35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
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EFFECT OF TRAVERSE SPEED AND OPERATING PRESSURE ON SURFACE ROUGHNESS IN AWJ MACHINING

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Abstract: *Surface roughness is an important factor in evaluating the abrasive water jet (AWJ) machining. Therefore, development of models for defining the effect of AWJ machining parameters on surface roughness, is of great importance. This study explains the effects of traverse speed and operating preessure on the machined surface roughness. The surface roughness has been evaluated by static quality characteristics, the arithmetic average height Ra. In the study AISI 304 steel materials, 20mm and 30mm thick, are cut with AWJ at different traverse speeds and operating pressures. Based on the results it was found that the increase of operating pressure causes a decrease in surface roughness, while the increase of traverse speed leads to an increase in surface roughness. It was also observed that the surface near the jet entrance is smoother, and the roughest surface is near the jet exit.*

Key words*: surface roughness, abrasive water jet*

1. INTRODUCTION

AWJ is an cold precise, computer controlled contour cutting without any zones of residual stress. This machining process is very suitable for the machining of all metals, and very hard and brittle materials. Those characteristics of the AWJ make it an important tool for cutting new materials such as composites and sandwiched materials that are difficult to machine with traditional machining processes [1], [2].
For any machining process, knowledge of the surface quality and its classification is very important. Measurement of quality of surfaces generated by abrasive water jet is quite difficult. These difficulties are the result of great differences in the surface roughness by the depth ogcut. These surface defects limits wider use of the technology of abrasive water jet in the industry. Taking into account this fact, it is surprising that nowadays there is no a study offering a complex evaluation of the surface topography depending on the machining parameters. The results of some studies showed that the AWJ machining is significantly affected by the variation of machining parameters. Some authors have shown that the traverse speed has a strong influence on the surface roughness of the workpiece and material removal rate [3], [4].

2. ABRASIVE WATER JET

Abrasive water jet is created in the cutting head. Schematic view of the cutting head is shown in Figure 1 [5]. An orifice, usualy made out of sapphire or diamond, is used to convert potential energy of high pressure water into kinetic energy of a high velocity water stream [5]. Downstream there is mixing chamber and a focusing tube. In the mixing chamber vacuum pressure is built up. This vacuum makes entraining of abrasive particles posible. Abrasive is sucked into the mixing chamber from a nearby container. This container has a device for dosing abrasives.
Abrasive water jet is actualy a mixture of water, abrasive particles and air. This mixture entrains the focusing tube, where it is colimated into the high speed and high energy stream.

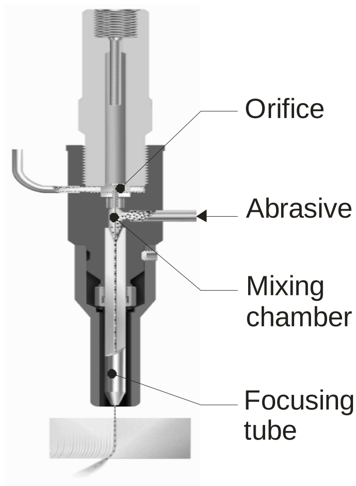

Fig.1. Abrasive water jet cutting head

3. SURFACE MACHINED WITH ABRASIVE WATER JET

The main characteristic of the surface machined by abrasive waterjet is the difference in the surface roughness by depth of cut. Lowest surface roughness is at the entrance of abrasive water jet into the material

workpiece, while the the greatest surface roughness is in the abrasive water jet exit from the workpiece. The distribution of surface roughness profile is considered to be the most important because it provides comprehensive information about the mechanical effect of selection of machining parameters, material properties and interaction between the AWJ and the machined material [6].
The characteristic appearance of the surface machined with abrasive water jet is shown in Figure 2

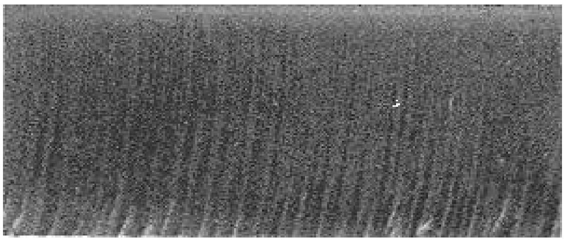

Fig. 2. Appearance of the surface machined with abrasive water jet

Surfaces machined with abrasive water jet can be divided into two areas, fine machining zone or upper zone and the zone of rough machining or lower zone. Irregularities that occur in the upper zone of the machined surface are considered microscopic irregularities and fall within the domain of roughness. Irregularities that occur in the lower zone of machined surface are of macroscopic dimensions. These are mainly appearance of grooves and holes of various sizes. These irregularities fall within the domain of profile waviness in conventional machining.

4. EXPERIMENTAL STUDIES AND RESULTS

In this paper, for the evaluation of the quality of the machined surface, the maximum of roughness - in lower zone of the workpiece - the measuring point 2, was taken, Figure 3.

Fig. 3. Measuring points for the measurement of surface roughness

Effects of traverse speed and operating pressure on the roughness of cut surface were experimentally investigated. The material used in this study was AISI 304 stainless steel. Specimens were prepared in the thickness of 30 mm and 20 mm. Samples were cut with varied working pressure and traverse speed, while the abrasive mass flow rate was constant m_a – 400 g/min. Other significant machining parameters were: stand off distance x_0 – 3 mm, water orifice d_w – 0,30 mm, focusing tube d_f – 1,02 mm.
In all samples, the surface roughness was measured at the upper zone - measuring point 1 (entrance of the abrasive water jet into the workpiece) and the lower zone - measuring point 2 (exit of the abrasive water jet from workpiece), Figure 2. The surface roughness was measured at several locations along the length of the sample and the mean roughness at a certain depth of cut was determined. Measurement of surface roughness was carried out on the measurement system Talysurf 6 (Taylor Hobson). The results of these measurements are given in Table 1.

Table 1. surface roughness in Measuring Points 1 and 2 for all specimens

No	p [MPa]	v_c [mm/min]	h [mm]	Ra[µm]	
				MP 1	MP 2
1.	413	10	30	2.9	2.22
2.	413	20	30	3.17	3.7
3.	413	30	30	3.06	4.31
4.	413	40	30	2.82	8.3
5.	413	50	30	3.69	8.7
6.	413	60	30	3.71	11.46
7.	413	70	30	4.54	14.8
8.	413	35	30	2.67	6.78
9.	335	35	30	3.22	13.2
10.	290	35	30	3.7	17.1
11.	245	35	30	3.06	20.6
12.	205	35	30	3.29	/
13.	270	50	20	2.59	3.965
14.	320	50	20	2.24	3.595
15.	380	50	20	2.325	3.41
16.	413	50	20	2.23	3.21
17.	413	30	20	2.28	2.93
18.	413	50	20	2.35	3.125
19.	413	70	20	2.72	3.445
20.	413	90	20	2.765	3.535
21.	413	110	20	2.66	4.16

Na uzorcima debljine 30mm, kod kojih je varirana traverse speed, hrapavost je merena na vise mesta po dubini reza. Rezultati ovih merenja su dati u tabeli 2.

Table 2. Surface roughness for different traverse speeds and depth of cut

h [mm]	v_c [mm/min]						
	10	20	30	40	50	60	70
2.5	1.86	1.66	1.43	1.76	2.16	1.94	1.62
7.5	1.57	1.32	1.48	1.56	1.82	1.94	2.32
12.5	1.34	1.35	1.24	2.11	2.89	2.72	2.73
17.5	1.04	1.12	1.43	2.7	2.58	4.34	4.55
22.5	1.29	1.83	1.63	2.76	2.84	4.82	-
27.5	1.46	1.64	1.74	3.02	4.52	5.84	-

5. MODEL PROPOSAL

Model for defining the surface roughness, depending on the trverse speed, which is shown in Figure 4, was developed based on the results presented in Table 1.

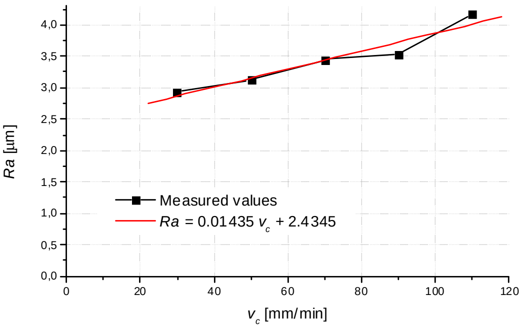

Fig. 4. Surface roughness at measurement point 2 for different traverse speed (AISI 304,# 20 mm)

For defining the effect of traverse speed on the surface roughness, the most suitable is linear model, which is described by equation 1.

$$Ra = 0.01435 \cdot v_c + 2.4345 \quad (1)$$

This model has an R-Square, R^2 = 0.9289. This shows that the model corresponds very well .to measured values. Model described by the equation 1 is only valid for AISI 304, 20 mm thick, which were cut with abrasive flow rate of 400 g/min and at operating pressure of 413 MPa, while the traverse speed was varied. The effect of the traverse speed on surface roughness is also investigated on samples of AISI 304, 30 mm thick. The model which was obtained for these samples (Table 1) is shown graphically in Figure 5.

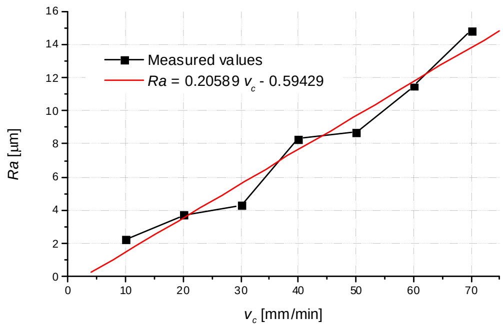

Fig. 5. Surface roughness at measurement point 2 for different traverse speed (AISI 304,# 30 mm)

For these samples the best fit was also achieved using a linear model that is described by equation 2.

$$Ra = 0.20589 \cdot v_c - 0.59429 \quad (2)$$

This model has an R-Square, R^2 = 0.9618, which shows that the model corresponds to measured values very well. As well as previous models, this model is only applicable for AISI 304, 30 mm thick, which were cut with abrasive flow rate of 400 g/min and at operating pressure of 413 MPa, while the traverse speed was varied. Considering that the traverse speed is the machining parameter, which is most often varied in real production conditions, a model that defines the effect of traverse speed and depth of cut on the surface roughness, was developed. The model is described by equation 3.

$$R_a = 0.365 \cdot v_c^{2.674} \cdot h^{1.621} \cdot 10^{-6} + 1.462 \quad (3)$$

Graphical representation of traverse speed effect on surface roughnes is shown in Figure6.

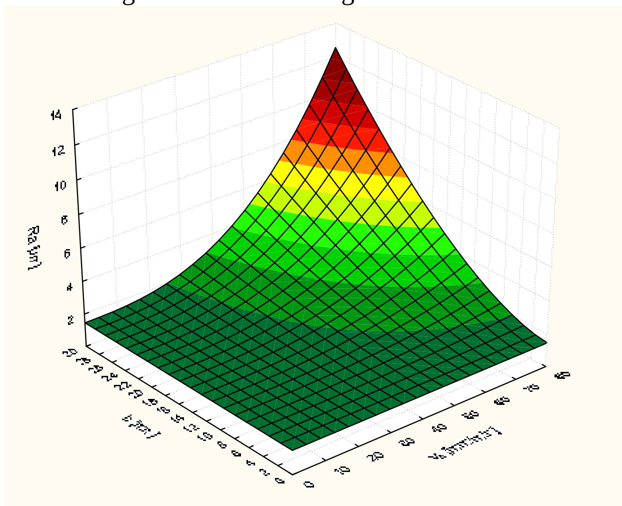

Fig. 6. Surface roughness for different traverse speed and depth of cut (AISI 304, # 30 mm)

For the model described by equation (3), R-Square, R^2 = 0.9145. As well as previous models, this model has limited application. It is only applicable for AISI 304, 30 mm thick, which were cut with abrasive flow rate of 400 g/min and at operating pressure of 413 MPa, while the traverse speed was varied. The values of machining parameters for the samples that were used to develop this model, are given in Table 2.

Model for defining the effect of the operating pressure on the surface roughness, has been developed based on the results that are shown in the Table 1.

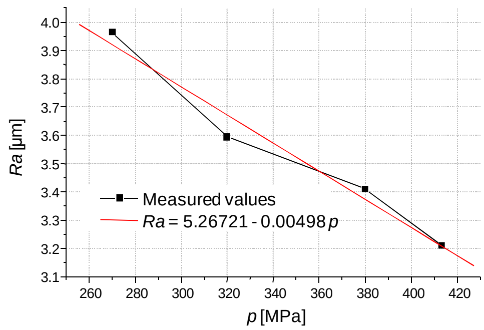

Fig. 7. Surface roughness at measurement point 2 for different operating pressure (AISI 304,# 20 mm)

From Figure 7 we can see that, for the defining effect of the operating pressure on the surface roughness, the most appropriate is linear model, which is described by equation 4.

$$Ra = 5.26721 - 0.00498 \cdot p \quad (4)$$

This model has an R-Square, R^2 = 0.9702.

The influence of the operating pressure on surface roughness was also investigated on samples of AISI 304, 30 mm thick. The results obtained by measuring the surface roughness are shown in Table 1. Figure 8 presents a model obtained on the basis of these results.

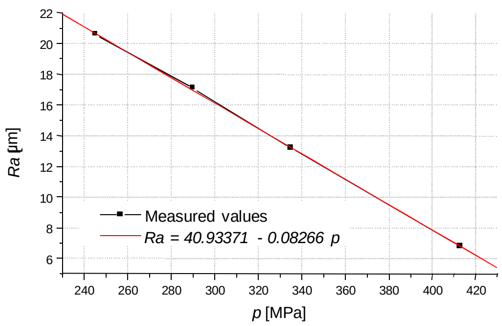

Fig. 8. Surface roughness in measurement point 2 for different operating pressure (ISI 304,# 30 mm)

From Figure 8, we can see that for these samples the most appropriate is linear model which is described by equation 5.

$$Ra = 40.93371 - 0.08266 \cdot p \qquad (5)$$

For the model described by equation 5, R-Square, R^2 = 0.99974. This shows that the model very well corresponds to measured values. For surface roughness at the measuring point 1 models are not developed. In the previous section, where the results of the measurements were analyzed, it was observed that there is no significant change in surface roughness at the entrance of abrasive water jet into the workpiece for different machining parameters.

6. CONCLUSION

Machining with abrasive water jet is a complex process of interaction between abrasive water jet and machined material. This process is affected by a variety of factors, so it is very important to know and define their influence, both on the process and on the surface quality, which is the output of the process.

This paper presents the results of research and modeling of abrasive waterjet machining. Based on the results we can conclude that with the increase of the operating pressure leads to decrease in surface roughness, while increase of the traverse speed leads to increase of the surface roughness. These phenomena are due to the change of energy which is delivered to unit volume of machined material. The growth of operating pressure increases energy of abrasive water jet and quality of machined surface, while an increase of traverse speed does not change the energyof abrasive water jet, but the energy is allocated to larger volume of material to be machined.

All models shown in the paper are valid only for AISI 304 of certain thickness, so that the following investigations should tend to develop more general models.

Acknowledgments: The authors would like to thank to the Ministry of Science and Technological Development of the Republic of Serbia. Paper is result of technological project TR35034: "The research of modern non-conventional technologies application in manufacturing companies with the aim of increase efficiency of use, product quality, reduce of costs and save energy and materials" which is supported by Ministry of Education and Science of the Republic of Serbia.

REFERENCES

[1] KALPAKJIAN, S. (1995) *Manufacturing Engineering and Technology*, Addison Wesley Publishing Company, USA

[2] ÖJMERTS, C., AMINI, N., (1994), *Discrete approach to the abrasive waterjet milling process*, in: Proceedings of the 12th International Conference on Jet Cutting Technology, Rounen France, pp:425–434.

[3] KULEKCI, K., (2002), *Processes and apparatus developments in industrial waterjet applications*. International Journal of Machine Tools & Manufacture 42, pp:1297–1306.

[4] LEMMA, E., CHEN, L., SIORES, E., WANG, J., (2002), *Optimising the AWJ cutting process of ductile materials using nozzle oscillation technique*, International Journal of Machine Tools and Manufacture 42: pp:781–789,

[5] ZENG, J., OLSEN, J., OLSEN C., *The abrasive waterjet as a precision metal cutting tool*, OMAX Corporation, Auburn, Washington, U.S.A.

[6] Valíček, V., Hloch, S., Kozak, D., (2009), *Surface geometric parameters proposal for the advanced control of abrasive waterjet technology*, Int J Adv Manuf Technol , pp:323-328.

[7] CHEN, F.,L., SIORES, E., PATEL, K., (2002), *Improving the cut surface qualities using different controlled nozzle oscillation techniques*, Int J Mach Tools Manuf 42, pp:717–722.

[8] HASHISH, M., (1988), *Visualisation of surfaces machined with abrasive—waterjet cutting process*, Exp. Mech. 28 (2) 159–168.

[9] HASHISH, M., (1991), *Characteristics of surfaces machined with abrasive—waterjet*, J. Eng. Mater.Technol. 113, pp: 354–362.

[10] HASHISH, M., (1989), *Pressure effects in abrasive waterjet machining*, J. Eng. Mater. Technol. 111, pp:221–228.

Joining and casting technologies

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SIMULATION OF TEMPERATURE FIELD IN THE WIRE DURING GMA WELDING

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Abstract: *Control of GMA welding process is based on the principle of the self regulation of welding arc length. Constant arc length is maintained by variations in wire melting rate. This article analyzes the effect of welding parameters such as welding current, arc voltage and wire feed speed on wire temperature field. A model of heat exchange in wire is developed based on the energy conservation laws. Developed model was adapted for computer simulation using appropriate numerical methods.*

Key words: *GMAW, wire melting rate, heat transfer, simulation, numerical methods*

1. INTRODUCTION

Welding is the dominant method for joining materials by indissoluble connection in most industrial applications: automotive, shipbuilding, manufacture of pressure vessels, pipeline, etc… GMA welding is widely used due to low cost and high productivity. One of the

A large number of welding processes is based on the rapid change of temperature in the welding area or filler material. In case of GMAW, filler material which moves with speed v_w is heated to the melting point. In order to predict and simulate these changes, we need to establish a simulation model of the process with appropriate accuracy.

Process of the model formation can be divided into three phases [1]:

- geometric approximation
- model of heat source,
- initial and boundary conditions.

2. GEOMETRIC APPROXIMATION

Heat transfer during welding depends among others on the shape and dimensions of the body. Welded elements can have a complex shape which makes computations of heat distribution difficult. Therefore, we use computational models in order to calculate the temperature fields of the heated body.

For the modeling of the heat transfer in the wire we used model of a rod. Rod represents a body of cylindrical shape, fig. 1. Temperature distribution in the cross sections of rod is even.

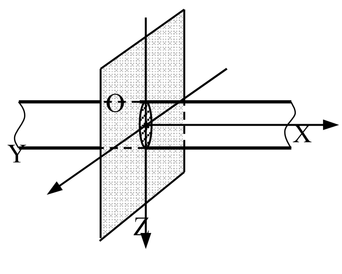

Fig. 1. Rod [3]

3. MODEL OF A HEAT SOURCE

The interaction between the heat source (arc) and molten pool is a complex physical phenomenon which has not been described accurately. Power arc is approximately equal to its electrical power:

$$q_a = U \cdot I$$

U – arc voltage (V)
I – welding current (A)

Effective power of arc is equal to:

$$q_a = \eta_i \cdot U \cdot I$$

η_i - coefficient of efficiency of welding arc, Table 1.

Table 1. Coefficient η_I [2, 3]

Welding process	η_i
GTAW	0,50 - 0,60
GMAW/active gas	0,58 – 0,75
GMAW/inert gas	0,70 – 0,80
SMAW	0,70 – 0,85
FCAW	0,80 – 0,95

In case of GMA welding, wire is heated by electric arc and by Joule effect. Amount of heat that is generated in control volume by Joule effect, Fig. 2, can be calculated as:

$$E_{gen} = j^2 \rho A dx \qquad (1)$$

Specific heat that is transferred by conduction can be calculated as a difference between specific flux that enters and leaves control volume, Fig. 3.

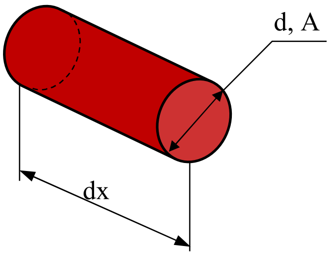

Fig. 2. Control volume

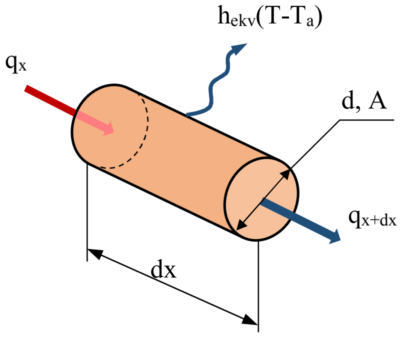

Fig. 3. Heat transfer by conduction/convection

Specific fluxes transferred in and out of control volume can be expressed as:

$$q_x = -\lambda_x \frac{\partial T}{\partial x} \tag{2}$$

$$q_{x+dx} = q_x + \frac{\partial q_x}{\partial x}dx = q_x - \frac{\partial}{\partial x}\left(\lambda_x \frac{\partial T}{\partial x}\right)dx \tag{3}$$

Amount of energy which is used for heating of a control volume is equal:

$$\left(E_{in} - E_{out}\right)_{heat} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right)Adx - h_{eq}\left(T - T_a\right)2r\pi dx \tag{4}$$

Considering that wire is moving at constant speed, heat is also transferred by advection. Amount of transferred heat is equal to difference between enthalpies that enters and leaves control volume, Fig. 4.

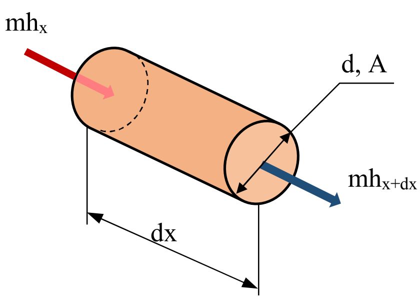

Fig. 4. Advection in control volume

Specific enthalpies are equal to:

$$h_x = c_p dT \tag{5}$$

$$h_{x+dx} = h_x + \frac{\partial h_x}{\partial x}dx = h_x + \frac{\partial (c_p T)}{\partial x}dx \tag{6}$$

Amount of energy transferred by advection is equal to:

$$\left(E_{in} - E_{out}\right)_{mass} = m\left(h_x - h_{x+dx}\right) = -\gamma v_w \frac{\partial (c_p T)}{\partial x} dxA \tag{7}$$

Assuming that:

$\lambda_x = \lambda_y = \lambda = const.$ and $c_p = const.$

First law of thermodynamics bring us to following equation:

$$\gamma c_p \frac{\partial T}{\partial t} = \lambda \frac{\partial^2 T}{\partial x^2} - \gamma c_p v_w \frac{\partial T}{\partial x} - \frac{2h_{ekv}}{r}(T - T_a) + j^2 \rho \tag{8}$$

In case of welding with constant electrode extension, temperature field in wire is steady:

$$\frac{\partial T}{\partial t} = 0 \tag{9}$$

And equation becomes:

$$\frac{\partial^2 T}{\partial x^2} - \frac{v_w}{\alpha}\frac{\partial T}{\partial x} - \frac{2h_{ekv}}{\alpha \gamma c_p r}(T - T_a) + \frac{j^2 \rho}{\alpha \gamma c_p} = 0 \tag{10}$$

4. NUMERICAL SOLUTION

Equation is solved by finite difference method. Derivatives are approximated using central finite differences.

$$\frac{\partial^2 T}{\partial x^2} = \frac{T_{i+1} - 2T_i + T_{i-1}}{\Delta x^2} \tag{11}$$

$$\frac{\partial T}{\partial x} = \frac{T_{i+1} - T_{i-1}}{2\Delta x} \tag{12}$$

Equation now becomes:

$$aT_{i+1} + bT_i + cT_{i-1} + d = 0 \tag{13}$$

$$a = \left(1 - \frac{v_w \Delta x}{2\alpha}\right) \qquad b = -\left(2 + \frac{2h_{ekv}\Delta x^2}{\alpha \gamma c_p r}\right)$$

$$c = \left(1 + \frac{v_w \Delta x}{2\alpha}\right) \qquad d = \left(\frac{2h_{ekv}T_a + j^2 \rho r}{\alpha \gamma c_p r}\right)\Delta x^2$$

Temperature at point i now can be calculated as:

$$T_i = -\frac{1}{b}\left(aT_{i+1} + cT_{i-1} + d\right) \tag{14}$$

c – specific heat capacity (J/kgK)
γ - density (kg/m^3)
λ - thermal conductivity (W/mK)
T_a – ambience temperature (K)

T_m – melting point of wire (K)
T_{ct} – temperature of contact tip (K)
L – latent heat of melting (J/kg)
r –radius of wire (m)

5. BOUNDARY CONDITIONS

Partial differential equation describes heat transfer inside the wire and in general have an infinite number of solutions. To obtain the solution which describes the given problem, additional conditions are necessary. In this case, boundary conditions are shown on Fig. 5.

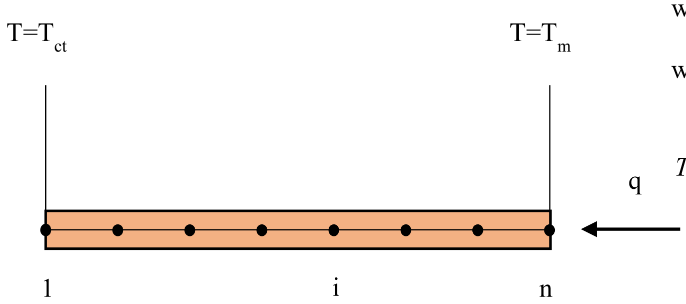

Fig. 5. Boundary conditions

The amount of heat that enters at the end of electrode is equal:

$$q = \eta UI - v_m \gamma r^2 \pi \left[c_p \left(T_m - T_a \right) + L \right] \quad (15)$$

Boundary condition at the end of electrode can be expressed as:

$$\lambda \frac{T_{n+1} - T_{n-1}}{2\Delta x} = \eta UI - v_t \gamma r^2 \pi \left[c_p \left(T_m - T_a \right) + L \right] \quad (16)$$

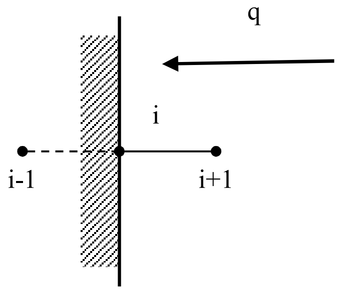

Fig. 6. Boundary condition at the end of electrode

where T_{i+1} is fictitious point, Fig. 6.

which leads us to:

$$T_{n-1} = -\frac{1}{(a+c)} \left(d + \frac{2a\Delta x \left[\eta UI - v_t \gamma r^2 \pi \left(c_p \left(T_m - T_a \right) + L \right) \right]}{\lambda} + \ldots \right.$$
$$\left. \ldots + bT_n \right)$$

also, temperature at the end of electrode is equal to:

$$T_n = T_m$$

Considering F|ig. 5, temperature of electrode at point i=1 is equal:

$$T_1 = T_{ct}$$

Upon applying the boundary conditions we get following equations:

$$T_1 = T_{ct} \quad (18)$$

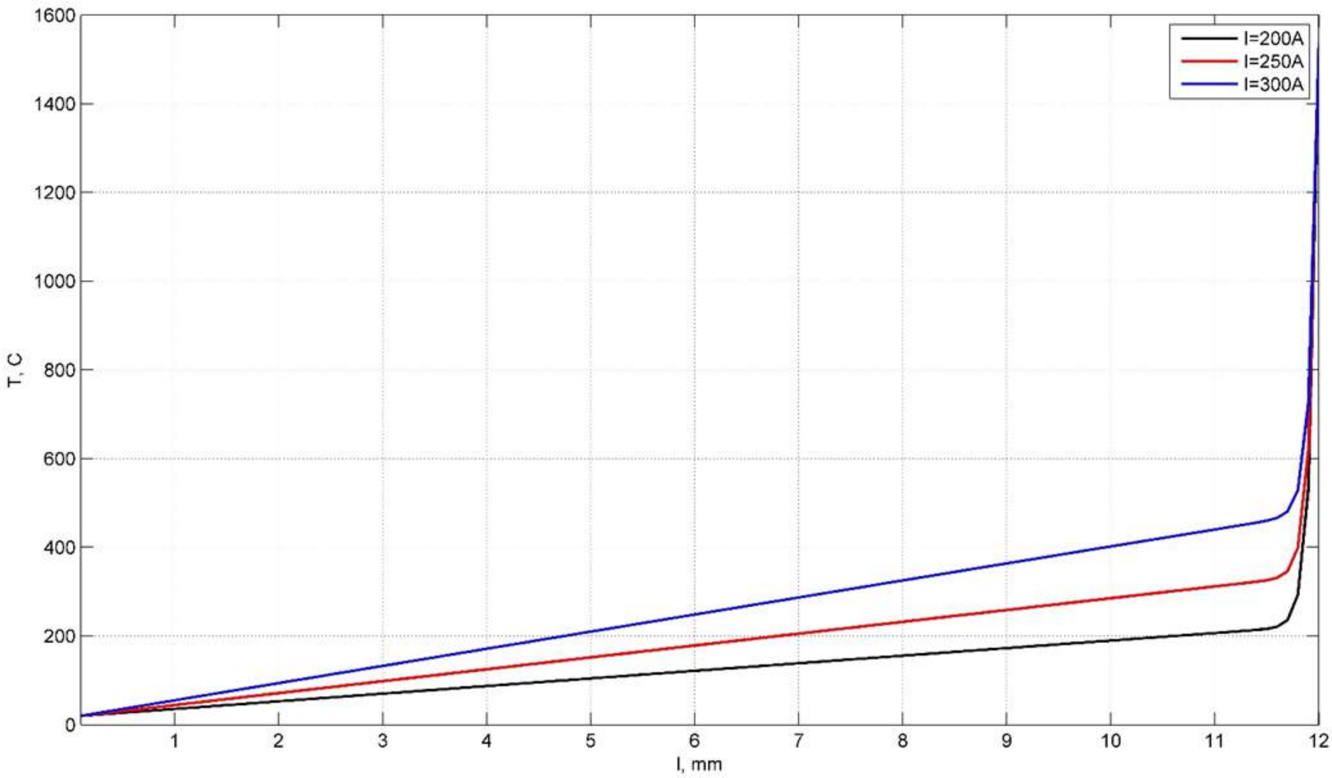

Fig. 7. Temperature field in the wire

$$T_i = -\frac{1}{b}\left(aT_{i+1} + cT_{i-1} + d\right) \quad i = 2, n-2 \tag{19}$$

$$T_{n-1} = -\frac{1}{(a+c)}\left(d + \frac{2a\Delta x\left[\eta UI - v_i \gamma r^2 \pi \left(c_p\left(T_m - T_a\right) + L\right)\right]}{\lambda} + bT_n\right)$$

$$T_n = T_m \tag{21}$$

These equations are solved using iterative numerical procedure in MATLAB with following input parameters:

electrode extension = 12 mm
arc voltage = 20, 22.5, 25
welding current = 200, 250, 300 A
wire diameter = 1.2 mm
density = 7200 kg/m^3
specific heat = 450 J/kgK
thermal conductivity = 22 W/mK
melting temperature = 1803 K
ambience temperature = 293 K

Results of simulation are shown on Fig. 7.

6. CONCLUSIONS

Model of a heat transfer in the electrode is developed using basic thermodynamic principles. Results of simulations shows that temperature inside the wire changes linearly along the wire. Near the electrode tip, the temperature rises sharply as a consequence of arc influence.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to Serbian Ministry of Education and Science for support through project TR37020.

REFERENCES

[1] Goldak J.A., Akhlaghi M., *Computational welding mechanics*, New York: Springer, 2005

[2] Рыкалин N.N., *Расчеты тепловых процессов при сварке*, Москва: Машгиз, 1951

[3] Николаев Г. А. (ред.), *Сварка в машиностроении. Справочник 1-4,* Машиностроение, Москва, 1978.

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VIRTUAL WELDING ON SIMULATOR CS WAVE

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Abstract: *The role of Virtual Welding Training System -VWTS is to visualize and register basic four parameters of welding process. Orientation, distance, speed and trajectory are the fundamental parameters which characterize movement of torch and arc during welding. All four parameters are followed by sensors in order to identify and by computer simulation visualize welding process. CS Wave welding simulator provides a cheaper, faster, more qualitative, safer and ecologically more acceptable training of welders by using MMA (111) procedure, butt weld (BW) and fillet weld (FW) of plates in all positions except in overhead position (PE). The paper shows the use of welding simulator for the welders' training. Welding simulator provides welding monitoring in real time through control center. Skillfulness of welders is achieved through training of motion path, distance between electrode and the object, welding speed and electrode angle in relation to the object and motion direction.*

Key words*: Welding simulator, Virtual welding, Welders' training*

1. INTRODUCTION

The welders' job is deficient and difficult; on the other hand, it is not very attractive for the young IT generation. Introduction of welding simulator in education of welders is a response to this. Those high-tech systems are primarily aimed at simplifying the welders' education as well as at adjusting to young generations growing up with modern technical devices.

Several welding simulators have been developed over the past decade. Development of these systems is mainly in connection with welding training centers or with the manufacturers of welding devices on the one, and with WR technology manufacturers on the other side.

There are several different independent systems on today's market: CS WAVE by Diginext- France, RW SOLD by Simfor-Spain, WELDTRAINER by Apolo, 123 Certification by ARC+ Canada, Virtual Welding by Fronius- Austria, VRTEX 360 by Lincoln- USA, GSI SLV by Halle GmbH [1].

Different technical solutions for implementation of virtual reality have been developed for the VWTS applications. Movement of welding torch and welding arc is the first important parameter of weld simulation controlled by motion sensors. Three different technical solutions are used for motion sensors in VWTS – electromagnetic, optical and ultrasonic. Electromagnetic motion sensors are mostly used in VWTS constructions.

Basic training is concentrated on the skill to perform butt and fillet welds in different welding position. There are individual solutions for each VWTS concerning welding positions.

2. CS WAVE WELDING SIMULATOR

Welding simulator CS Wave has been produced by a French company Diginext since 2003 and it enables simulation of the welding process REL, MIG/MAG and TIG using butt weld and fillet weld procedures of tins in root pass in all positions except in overhead position [3]. Unlike other systems, this system functions on the basis of ultrasound sensors and without a virtual helmet which reduces the natural eye focal length which makes the simulators inadequate for longer trainings. On the other hand, the weight of the electrode holder equals the real electrode holder (unlike other systems using a plastic holder), so movements may easily be practiced in real welding [5].

Welders skillfulness is achieved by trainings (fig. 1): welding path, distance between electrode and the object, welding speed and electrode angle in relation to the object and the direction, while the look of a virtual piece in 3D is shown in fig.2.

Fig. 1 Work on the simulator

The welding simulator CS Wave enables a cost-efficient training due to base and filler material saving; a faster and more qualitative training because the trainees practice the correct movements from the very beginning of the training; a safer training, because there is no danger of electric shock and radiation; and an environmentally-friendly training because no harmful gases are produced.

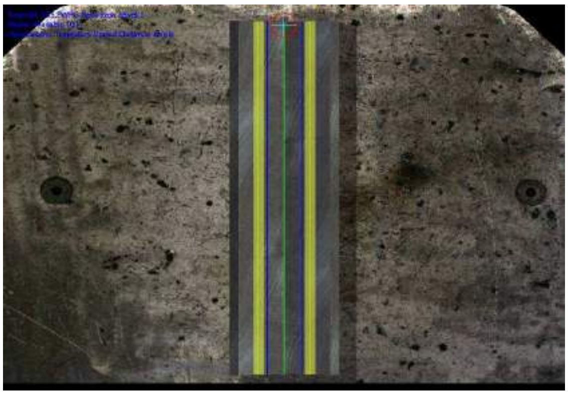

Fig. 2 A look of a virtual piece

The control center enables adjustment of the material type and the electrode type as well as the tolerance in relation to the ideal parameters.

It is also possible to select a particular set of exercises – curriculum (E1, E2, E3, E4) for REL (111) welding procedure for every welder according to the IAB-089r4-12-Minimal requirements for education, training, examination and qualification of welding personnel-International Welder (IW) which includes the welding simulator in welders' training with 20% of practical exercises [4].

The welding simulator CS Wave enables simulation of the welding process with REL (111), MAG (135) and TIG (141) processes. Figure 3 shows the simulator used for welding process selection.

Fig. 3 Welding process selection

When the welding process is selected, the type of assembly is selected and it can be BW or FW (fig.4). The selection of the welding position depends on the type of assembly selected and is shown in figure 5. The welding parameters selection includes determination of: trajectory, welding speed, distance between the electrode and the object and electrode angle in relation to the object and motion direction (fig. 6).

Fig. 4 Type of assembly selection

Fig. 5 Selection of welding position

Fig. 6 Welding parameters determination

Selection of welding parameters combination is shown in figure 7. The exercise start and the parameters to be recorded are shown in fig.8.

Parameters	Succeed tries	Total tries	Total time
Trajectoire	0	0	0:00:00
Speed	0	0	0:00:00
Distance	0	0	0:00:00
Angle	0	0	0:00:00
Trajectoire - Speed	0	0	0:00:00
Trajectoire - Angle	0	0	0:00:00
Speed - Distance	0	0	0:00:00
Trajectoire - Distance	0	0	0:00:00
Speed - Angle	0	0	0:00:00
Distance - Angle	0	0	0:00:00
Trajectoire - Distance - Angle	0	0	0:00:00
Trajectoire - Speed - Angle	0	0	0:00:00
Speed - Distance - Angle	0	0	0:00:00
Trajectoire - Speed - Distance	0	0	0:00:00
Trajectoire - Speed - Distance - Angle	0	1	0:00:00

Fig. 7 Selection of welding parameters combination

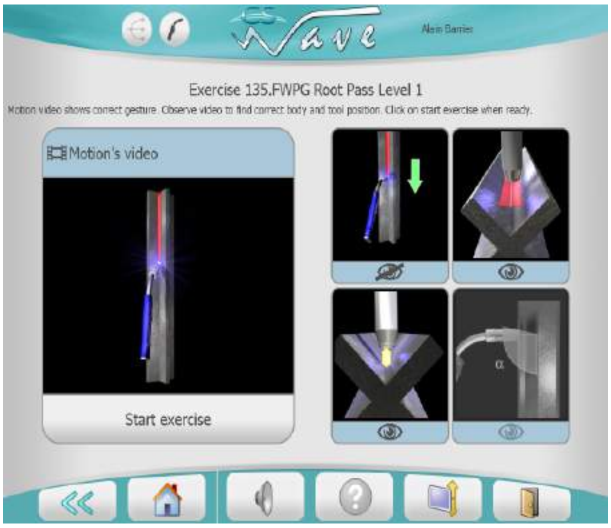

Fig. 8 Exercise start

3. RESULTS OF WELDING

The results of the virtual welding are shown in fig. 9 which shows the name of the exercise (welding process, welding position, whether it is root pass or filling pass), welding time, the total percentage of accuracy, the percentage of accuracy of certain welding parameters. The arrows show advancement in relation to the previous attempt (green: better, yellow: same quality, red; worse). By clicking on a parameter, better results may be seen. A more detailed overview is enabled by a graph showing certain parameters and by reproduction of electrode or torch motion in 3D which enables detection of the moment when the mistake occurred. The comparative overview of the three previous welding attempts is shown in fig. 10.

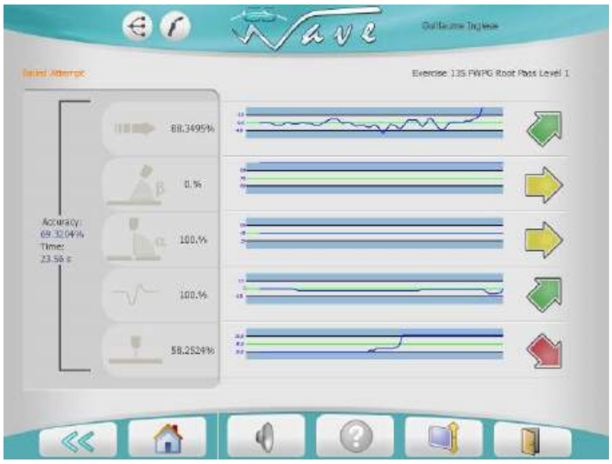

Fig. 9 Graphic overview of welding results

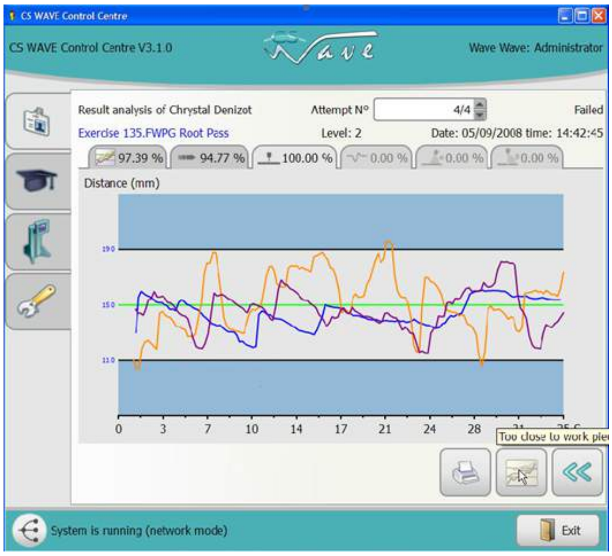

Fig. 10 Comparative overview of the three previous welding attempts

4. CONTROL CENTER

Analysis of the results and advancement in training are important factors in successful training of welders. The control center is a main tool used by the instructor to monitor and analyze the results and learning advancement of candidates (*Fig. 11).* The control center is a part integrated in the simulator system and enables long distance data transfer from the simulator by means of the network and server. Therefore the instructor can timely monitor each candidate doing a particular exercise and assess his achievement. A detailed analysis of recorded exercise enables the instructor to detect the causes of mistakes and to make justified corrections aimed at quality improving of a candidate's following attempts. Each attempt is recorded by the date and the hour so each candidate has his map with graphic presentation of individual welding parameters throughout the welding training process. Based on these data, the instructor has a possibility to define learning steps for each candidate with the possibility of necessary corrections. This helps him find the most optimal manner for each candidate to achieve the foreseen objective.

Rating the simulator by 100 respondents is shown in figure 12 where 1% evaluated the simulator as poor, 4% as fair, 41% as good, 29% as great and 25% as excellent. On the other hand, 90% respondents younger than 35 rated the simulator as great and excellent.

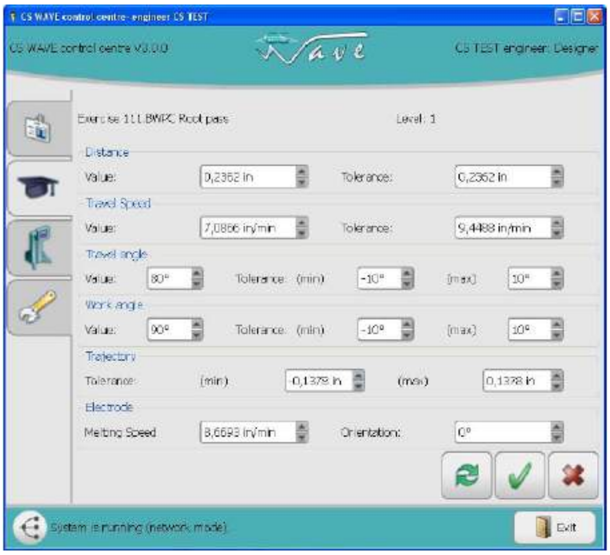

Fig. 11 Parameters adjustment in the control center

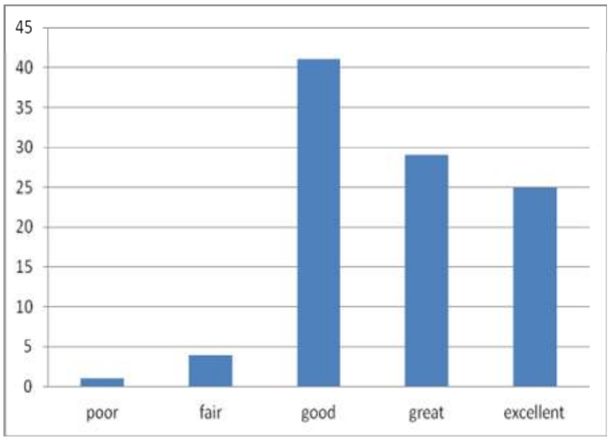

Fig. 12 Overall ratings of welding simulator

4. CONCLUSION

The use of welding simulator in training of welders has been recognized by the International Institute of Welding which recommended the use of simulator in welders' training in 20% of exercises in its document IAB-089r4-12-Minimal requirements for education, training, examination and qualification of welding personnel-International Welder (IW).

The main objective for the education of welding personnel is to present the effect of different alternatives of each parameter on quality of welds and peculiarities of each process. In this case it is generally recommended to spend up to 50 % allocated to the practical training on welding simulator presentation and practical demonstration and training.

General recommendation is that trainee should pass the test on welding simulator for one condition first and then to move to welding booth and perform practical training in the welding booth. It has been recognized that time for training on VWTS depends on the skill of individual trainee

VWTS teaches welding without the use of costly base material, shielding gas, welding electrodes as well as other supplies and consumables. The system also does not require weld fume removal. VWTS systems make it possible to learn welding in an eco-friendly manner.

Welding simulator is equipment which can help to turn welding from 3D (dusty, dirty, dangerous) to 3C (clean, clever, cool) GREEN joining technology.

REFERENCES

[1] JOVANOVIĆ,M.,ŠPRAJC,P.,Virtuelno zavarivanje-veliki pomak u edukaciji zavarivača, 26.Savetovanje sa međunarodnim učešćem Zavarivanje 2010, Tara 2.-4.06.2010, Srbija.

[2] DA DALTO,L.,BENUS,F.,BALET,O.,Improving the welding training by a wise integration of new technologies, Proceedings of the IIW 2009 International Conference on Advances in Welding and Allied Technologies, Singapore, July 16-17, 2009, ISBN 978-981-08-3259-9, paper fqc-5

[3] DIGINEXT- Advanced Coputeing systems, www.diginext.fr

[4] IAB-089r4-12- Minimal requirements for education, training, examination and qualification of welding personnel-International Welder (IW)

[5] JOVANIC D., JOVANOVIC M., JONAS Z.: CS Wave welding simulator – results analysis and training progress, Welding and welded structures, ISSN 0354-7965, No 1, Vol.58, 2013, pp 41-46.

Processing of nonmetal materials

35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
Faculty of Mechanical and Civil Engineering in Kraljevo

APPLICATION OF PHOTOACOUSTIC TECHNIQUES FOR CHARACTERIZATION OF MATERIALS

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Abstract: *Photoacoustic effect represents emission of sound waves by an illuminated object. The frequency of the sound is the same as the modulation frequency of the light beam that illuminates the object, but the intensity and phase of the sound wave depend on properties of both the illuminated surface and sub-surface layers. Therefore, photoacoustics provides interesting new opportunities for development of new non-destructive techniques for characterization and study of microstructure of materials. Depending on the interpretation and representation of the measured data, two types of photoacoustic techniques are being developed at the present moment, photoacoustic tomography (PAT) and photoacoustic microscopy (PAM). PAT enables study of the entire volume of a sample, while the PAM represents the sample as sequence of layers. The paper presents principles of photoacoustic technics and analyses their application for characterization of materials in engineering. It can be concluded that the photoacoustic techniques may be the preferable choice for study of thin multi-layer and porous materials.*

Key words: *photoacoustic effect, non-destructive characterization.*

1. INTRODUCTION

The problem of the non-destructive testing of materials is for a long time a subject that attracts attention of researchers. Its importance may be measured by number of studies that were carried out and by the variety of the proposed techniques, like X-ray and γ-ray radiography, ultrasound techniques, eddy current technoques, the penetrant testing, magnetoscopy and various optical techniques.

Photoacoustic effect belongs to the class of optical techniques. The photoacoustic (PA) effect comprises emission of acoustic waves due to the light absorption and subsequent heat generation [1-5]. It belongs to a quite wide family of related phenomena, commonly called photothermal (PT) phenomena, which are caused by heat generation due to the light absorption. Their potentials as tool for non-destructive and material characterization and evaluation [4-8] lead to extensive studies of the PT phenomena during the last three decades.

Measurement techniques based on PT effect are being studied and applied as an alternative non-destructive tool for measurement of thermal, optical and other related physical properties, especially when standard methods are not applicable [1-4]. Besides, the PT measurement techniques are increasingly used for investigations of subsurface structure and macroscopic defects [1−6].

PT methods are based on direct or indirect recording of the surface temperature variations, which are caused by generation and transfer of the heat that is produced as consequence of absorption of light. Usual sources of the light are harmonically modulated beams of ordinary light sources or pulse laser beams [1-14].

The principle of this method makes it a non-destructive, non-contact, flexible, easily customizable technique that allows the study of 100 micrometers of material depth (which is not still possible with the other procedures of non-destructive testing). It also makes the method limited to the study of the thin materials (up to some centimeters in thickness) and properties of surfaces.

The techniques that perform imaging of the structure and profilometry are of particular interest. Their main advantage is ability to detect and characterize types of flaws (material defects and interfaces) that are not visible optically or acoustically [3,4,13]. Examples of these kinds of defects include disbonds and poor adhesion in layered media, subsurface cracks or crystal damage in opaque solids, and electrical defects in active circuits.

2. PHOTOACOUSTIC EFFECT

The underlying principle of PA and PT methods is detection of changes occurring in a sample due to heat produced by absorption of an incident energetic beam. The absorption and the subsequent non-radiative deexcitation i.e. relaxation processes represent heat source in the sample, which may be distributed throughout its volume, or confined to its surface. This heat source gives rise to temperature, pressure, density, and free charge (if exists) fluctuations within the samples, which are then detected optically or by thermal or acoustic, or even both, sensing devices. In most cases, the heat deposited in the sample is due to the absorption of optical radiation and this is the reason for the name (photoacoustic and photothermal) of these techniques. Primary physical processes that occur during PA and PT characterization, i.e. PA and PT microscopy, are schematically depicted in Fig.1.

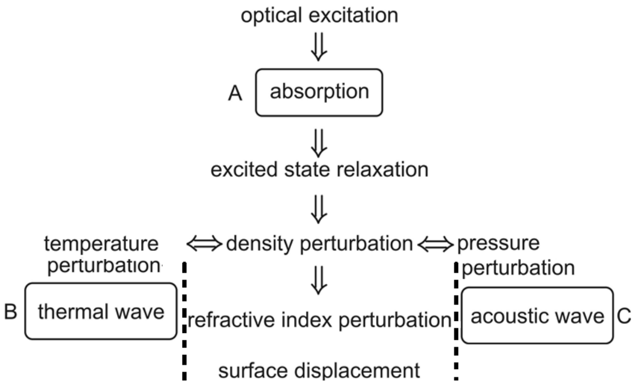

Fig. 1. Physical processes that occur during PAM and PTM.

Process A involves the absorption of the intensity-modulated incident energy, which can be either in the form of photons or particles such as electrons or ions. Process B involves the generation and propagation of the thermal waves (TWs) that result from the energy absorption during process A and from subsequent generation of charge carriers. Finally, process C involves the generation and propagation of elastic waves that arise as a direct consequence of heating during process B.

Process A provides information about local absorption or reflection/scattering properties of the sample. If light is used as an energy source, then A is the same process that provides visualization in an optical microscope. If electrons, or other particles, are used as the incident energy beam, then process A is the same process that provides microscopic visualization in an electron or particle microscope. Obviously, the ultimate resolution of process A is determined by the wavelength of the photons or electrons (particles) [14]. Also, the depth of visualization is set by the penetration depth of the photons or electrons in a transmission microscope, or by the escape depth of the photons or electrons in a back scattering microscope. Depth profiling, that is, visualization at selected and variable depth in the sample, is not readily possible with process A.

Process B is unique to TW microscopy, and does not occur in either optical (particle) or acoustic microscopy. This process provides information about local thermal properties such as thermal diffusivity, thermal memory properties, thermal conductivity, and the thermal expansion coefficient of the sample [4-15]. Visualization results from the interaction of the thermal waves with features in the sample that exhibit variation in thermal properties. The ultimate resolution in process B is determined by the wavelength of the thermal waves [13-15]. The thermal wavelength varies with frequency f at which the TW is generated. For most solids, the thermal wavelength, and thus the ultimate resolution, ranges from 30-300 µm at f = 100 Hz to 0.3-3 µm at f = 1 MHz.

Process C provides information about the local elastic properties of the sample. This is the same process that permits both surface and subsurface visualization in conventional ultrasonic flaw detectors and in acoustic microscopes. The ultimate resolution here is determined by the wavelength of the acoustic waves. For the most solids, it limits the ultimate resolution to 5-10 µm, even for acoustic microscopes operating at 1000 MHz. Higher resolutions are very difficult to achieve because of the excessive acoustic attenuation that occurs at these frequencies. Depth profiling is not possible in conventional transmission ultrasonics, although it can be performed in reflection mode using pulse-time techniques. Depth-profiling has apparently not been possible with acoustic microscopes.

In general, PA and PT microscopes will provide information about the sample from all three of the physical processes, A, B, and C, although in many cases one or more of these processes can be neglected. When process A dominates, the PA/PT image will be identical to that obtained with a conventional optical or electron microscope. When process C dominates, the image will be identical to that obtained with conventional ultrasonics or with an acoustic microscope. This will be true as long as the non-radiative or heating mode is primary de-excitation mechanism for the optically (or electron-) excited energy levels. The truly unique feature of a PA/PT microscope lies in its capability for providing surface and subsurface visualization through the interaction of thermal waves with sample.

Processes A, B, and C produce the photothermal phenomena listed in Figure 2:

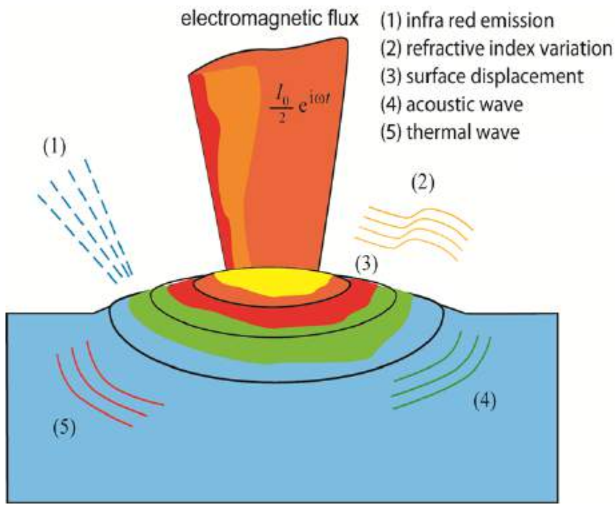

Fig. 2. Photothermal phenomena that are consequence of optical heating of the sample

The consequences of the optical heating are temperature changes on the surfaces of the sample, changes within the infrared spectrum, propagation of deformation wave through the sample, propagation of an acoustic wave through the environment of the sample, deflections of the sample's surface, appearance of optical refractive index gradient within the sample and changes of the optical refractive index gradient in the environment (mirage effect). These phenomena could be detected by appropriate detection techniques.

3. CHARACTERIZATION WITH PHOTOACOUSTIC TECHNIQUES

Characterization of the materials by PA techniques is based on detection of some of the phenomena mentioned at the end of previous section. When the characteristics of a source $S(x,t)$ (like intensity of the light $I(x,t)$) are known, then it is possible to determine the characteristics of the sample on the basis of PA response by solving inverse PA problem. In order to find solution of the inverse PA problem is needed a sufficiently accurate model of the PA effect.

A typical configuration for PT measurements is schematically presented at the Fig. 3. A solid sample with a flat front surface and the length l_s is mounted on a backing with the length l_b, and its front surface is exposed to a light beam, which passes through an air column with the length l_a. The air and the backing present the environment of the sample, and the ambient temperature, which is initial temperature of the sample and the environment is T_{amb}. As a consequence of absorption of light by the sample, it is heated, and due to transfer of the heat, temperature distributions in the sample $T^{(s)}$, the air column $T^{(a)}$, and the backing $T^{(b)}$ change. Temperature variations due to PT heating, defined as $T - T_{amb}$, are proportional to the PT response signal.

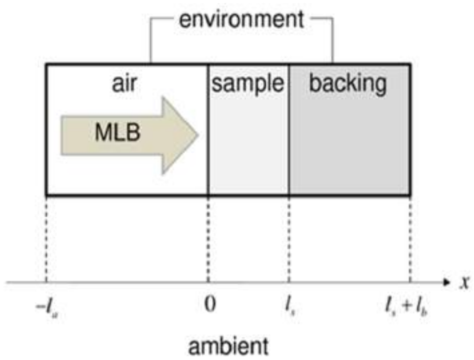

Fig. 3. A typical setup for PT measurements (MLB stands for the modulated optical beam)

The variation of temperature distribution due to the heat generation and transfer in a medium is then given by the expression:

$$C\frac{\partial T(x,t)}{\partial t} = S(x,t) - \frac{\partial q(x,t)}{\partial x} \qquad (1)$$

where $T(x,t)$ represents temperature at the position x at instant t, C represents volumetric specific heat of the medium, and q represents heat flux. This equation enables determination of the temperature distribution in a medium, representing a quite good theoretical model of PA effect. However, numerous weak influences that affect the PA response make solutions of the inverse PA problem instable and lead to large errors.

PA effect represents emission of sound waves by an illuminated object. The frequency of the sound is the same as the modulation frequency of the light beam that illuminates the object, but the intensity and phase of the sound wave depend on properties of both the illuminated surface and sub-surface layers. Therefore, photoacoustics provides interesting new opportunities for development of new non-destructive techniques (NDT) for characterization and study of microstructure of materials.

Some of characteristics that can be determined from PA experiments are optical absorption coefficient, optical reflection coefficient, thermal characteristics, elastic characteristics, electronic characteristics of the sample, and other related characteristics of the sample. Furthermore, it is possible to perform imaging of the structure and profilometry.

4. PA AS NON-DESTRUCTIVE TECHNIQUES

With the wealth of already mentioned and well-developed NDT techniques like ultrasonic, radiographic, magnetic-particle, liquid penetrant and eddy-current techniques the application of PA techniques is justified only when no other technique can be applied. PA techniques are not standardized and still not commercially available, but there are the cases when other techniques cannot be applied. For example, if there is a need to test thin foils, of micrometer order, on industrial product line, PA techniques can offer unique capabilities. In general, characterization of thin materials seems to be suitable for application of PA techniques.

Table 1. Detection methods of PA and PT techniques

Thermodynamic parameter	**5. Measured property**	**6. Detection technique**
Temperature	Temperature	Photothermal calorimetry
	Infrared emission	Photothermal radiometry
Pressure	Acoustic wave	Photoacoustic techniques
	Surface deformation	Photoacoustic techniques
Density	Refractive index	Photothermal lens Photothermal interferometry Photothermal deflection Photothermal refraction Photothermal diffraction
	Surface deformation	Surface deflection

Table 1 lists measured properties and related detection techniques. These techniques are important for characterization of materials from the Table 1, but photothermal techniques are also gaining attention for their abilities to provide visualization of the internal structure of the samples [16]. This can be achieved by two techniques, PA tomography and PA microscopy.

4.1. PA tomography (PAT)

The PA effect arises when heat, generated by light-absorbing molecules, launches ultrasonic waves by boosting pressure, which detectors can read to create images. PA tomography allows scaling of spatial resolution according to desired imaging depth, while maintaining a high depth-to-resolution ratio: as a rule of thumb, the achievable spatial resolution is approximately 1/200 of imaging depth, up to thicknesses of a centimeter order. Moreover, PAT provides inherently background-free detection because PA amplitude is proportional to optical absorption (non-absorbing components present no background). By exciting different molecules at different optical wavelengths, PAT reveals rich optical contrasts according to chemical composition.

PAT imaging is performed by optical absorption with 100% sensitivity, which ensures no leakage of excitation photons into detectors, being speckle-free, and finally, while conventional ultrasound imaging measures only mechanical contrasts, PAT measures both optical and thermo-elastic contrasts.

PAT has three major implementations: focused-scanning PA microscopy (PAM), PA computed tomography (PACT), and PA endoscopy (PAE). While PAM and PAE usually aim to make images with depth of the order of millimeter with micrometer-scale resolution, PACT can be implemented for both microscopic and macroscopic imaging.

4.2. PA microscopy (PAM)

In PAM, both optical excitation and ultrasonic detection are focused, and the dual foci are usually configured confocal to maximize the sensitivity. Each laser pulse produces a one-dimensional (1D), depth-resolved image without mechanical scanning, and 2D transverse scanning generates a 3D image. Axial resolution is determined by the acoustic time of flight, whereas lateral resolution is determined by the overlap of the dual foci. Depending on whether the optical or ultrasonic focus is finer, PAM is further classified into optical-resolution (OR-PAM) and acoustic-resolution (AR-PAM) varieties.

OR-PAM provides lateral resolution from a few hundred nanometers to a few micrometers. If such resolution were to be achieved acoustically, the center frequency of the acoustic signal would have to be at least 300 MHz. At such a high frequency, ultrasonic waves sustain severe propagation losses and can penetrate only a few hundred micrometers in material.

At depths beyond the optical diffusion limit and up to a few millimeters, AR-PAM achieves high resolution by taking advantage of relatively low acoustic scattering. Despite diffuse optical excitation, lateral resolution of tens of micrometers is achieved by diffraction-limited acoustic detection. The system provides 45 μm lateral resolution with a few millimeters of imaging depth.

7. CONCLUSION

The PA techniques may be the preferable choice for studies of thin multi-layer structures and porous materials. The materials are characterized by solving the inverse PA problem, thus finding optical absorption coefficient, optical reflection coefficient, thermal characteristics, elastic characteristics, electronic characteristics of the sample, and other related characteristics of the sample.

Acknowledgments: This work is supported by the Serbian Government - the Ministry of Education, Science and Technological Development under grant *TR37020*.

REFERENCES

[1] A. C. Tam, "Application of Photoacoustic Sensing Techniques”, Rev. Mod. Phys, 58, 381-431 (1986)

[2] H. Vargas and L. C. M. Miranda, "Photoacoustic and related photothermal techniques", Phys. Rep. 16, 45-101 (1988)

[3] S. E. Bialkowski, “Photothermal Spectroscopy Methods for Chemical Analysis”, New York: John Wiley & Sons, Inc. (1996)

[4] M. Terasina, N. Hirota, S.E. Braslavsky, A. Mandelis, S.E. Bialkowski, G.J. Diebold, R.S.D. Miller, D. Fournier, R.A. Palmer, A. Tam, “Quantities, terminology, and symbols in photothermal and related spectroscopies”, Pure Appl. Chem. 76, 1083-1111 (2004)

[5] S. Galović, Z. Šoškić, D. M. Todorović, “Thermal wave microscopy: fundamentals and applications in “Microscopy book: Science, Technology, Applications and Educations”, Spain: Formatex, 1506-1515 (2010)

[6] A. M. Mansanares, T. Velinov, Z. Bozoki, D. Fournier, and A. C. Boccara, ″Photothermal microscopy: Thermal contrast at grain interface in sintered metallic materials″, J. Appl. Phys, 75, 3344-3350 (1994)

[7] A. Rosencwaig and A. Gersho, ″Theory of the photoacoustic effect with solids″, J. Appl. Phys 47, 64-69 (1976)

[8] F.A. McDonald, G. Westel, “Generalized theory of the photoacoustic effect”, J. Appl. Phys. 49, 2313-2322, (1978)

[9] F.A. McDonald, “Practical Quantitative Theory of Photoacoustic Pulse Generation”, Appl. Phys. Lett. 54,1504-1506 (1989)

[10] G. Rousset, F. Lepoutre, L. Bertrand, “Influence of thermoelastic bending on photoacoustic experiments related to measurements of thermal diffusivity of metals”, J. Appl. Phys 54**,** 2383-2391 (1983)

[11] A. Mandelis, B. S. H. Royce, “Time-domain photoacoustic spectroscopy of solids”, J. Appl. Phys, 50, 4330-4338 (1979)

[12] A. Rosencwaig, “Thermal wave microscopy with photoacoustics”, J. Appl. Phys. 51, 2210-2211 (1980)

[13] S. Galovic and D. Kostoski, Photothermal wave propagation in media with thermal memory, J. Appl. Phys. 95, 2063-2070 (2003)

[14] B. Cretin, “Scanning near-field thermal and thermoacoustic microscopy: performances and limitations”, Superlattices and Microstructures, 35, 253-268 (2004)

[15] S. Galovic, Z. Stojanovic, D. Cevizovic, M. Popovic, “Photothermal microscopy: a step from thermal wave visualization to spatially localized thermal analysis”, Journal of Microscopy 232, 558-561 (2008)

[16] L.V. Wang and S. Hu, Science, 335, 1458-1462 (2012)

Surface engineering and nanotechnologies

35th INTERNATIONAL CONFERENCE
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Kraljevo - Kopaonik
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GRAPHICS WHICH CONNECT BASIC ROUGHNESS PARAMETERS OF MACHINED SURFACE BY SURFACE GRINDING OF STEELS

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Abstract: *The relationship between individual roughness parameters of a machined surface is approximately given by tables. More accurate relationships between maximal roughness height mean aritmetic deviation of the profile from mean line and bearing ratio maximal roughness height in exponential and linear form are also given. Expreimental results were processed for statistical valid sample N = 192 > 50, and pointed strong correlation between roughness parameters. Combined graphics between all three parameters based on previous models are given, in the paper.*

Key words*: Machined Surface, Roughness, Maximal Roughness, Mean Roughness, Bearing Ratio*

1. INTRODUCTION

Relationship between particular parameters of roughness is given very often in simplified form. Independent of kind of process and work piece material, and another conditions which follow the process.

For example relationship between the maximal roughness height and arithmetic deviation of the profile feom the mean line, i.e. their numerical values, is given in the table (German standard DIN 4767/70) and relationship of the mean height is ten points and the aritmetic deviation of the profile from the mean line according to Yugoslav JUS M.A1.020/79, with a remark on the approximation.

Relationship between maximal height of the roughness and the mean arithmetic deviation of the profile from the mean line Rmax = f(Ra), in exponential form.

Rmax = 6,1595 Ra 0,98

is given independent on the conditions which follow the process. However, that the exponent in the last equation is approximatly one, it can be concluded that, between maximal roughness height and mean arithmetic deviation of the profile, there is a proportionality, i.e.

Rmax = 6,16 Ra

The correlation between bearing ratio and mean roughness height, for finish turning for a statistically valid sample, in exponential

$$R_{max} = B\, R_a^{\,a}$$

$$p_n = B\, R_a^{\,a}$$

and linear form

$$R_{max} = aR_a + b$$

$$p_n = B\, R_a^{\,a}$$

have been used, in this paper.

2. EXPERIMENTAL INVESTIGATION

The materials of the work pieces was:

1. constructional steel for the improvement C.1730 (JUS) (DIN C60) dimensions 50x50x130mm. According to JUS standard, the chemical composition is provided as follows: 0,65% C; 0,35% Si; 0,8% Mn; 0,045% P and 0,045% S, and mechanical charasteristics: tensible strenght of material σ_M = 700-1050 N/mm^2, yield strenght σ_v = 500 N/mm^2 and elongation δ_5 = 14%.
2. steel for carbonizing C.4721 (JUS) (DIN 20CrMo5), dimensions 40x40x150mm. Chemical composition: 1,4% C, 0,35% Si, 1,2% Mn, 0,035% P and 0,035% S. Mechanical charasteristics: tensible strenght of material σ_M = 1000-1300 N/mm^2 yield strenght σ_v = 700 N/mm^2 and elongation δ_5 = 8%.

Grinding was performed using the wheels: B60H 8V, B60K 8V, B60K N8V and B60 R8V. The experiments were performed on surface grinding machine type URB-750, made by LZTK, table dimensions 1130x300 mm, the cross feeds 2 to 20 mm/l the surface velocity of work 2 to 25 m/min, spindle electromotor power 4 kW and number of wheel revolutions 1500 rev/min.

The roughness parameters were measured using the Perth-O-Meter, type “Universal”.

For the purpose of giving providing enough reliable relationships between varialbe values for investigated materials, the statistically valid sample of N = 192 > 50, is taken.

Standard data processing, using the least squere method next relationships

$$R_{max} = AR_a^{\,b} \qquad p_n = aR_a^{\,b}$$

$$R_{max} = CR_a + D \qquad p_n = cR_a^{\,d}$$

After numerical data processing next equations for particular roughness parameters

$$R_{max} = 7{,}89365\, R_a^{\,0{,}76480} \qquad (r=0{,}90)$$

$$R_{max} = 6{,}12807\, R_a + 1{,}75474 \qquad (r=0{,}88)$$

$p_n = 39{,}07863\, R_a^{-0{,}78235}$ *(r=0,82)*

$p_n = -\,33{,}57150\, R_a + 76{,}46860$ *(r=0,79)*

are given.

By them we have high correlations coefficient.
Combining Fig.1., and Fig.2., so to cover scale R_a, graphics which connect all three parameters R_{max}, R_a, p_n, Fig.3., are given. On Fig. 4 and Fig. 5 graphics in linear and exponential coordinates, for practical use, are given. So, if the one roughness parameter is known we can determine another two.

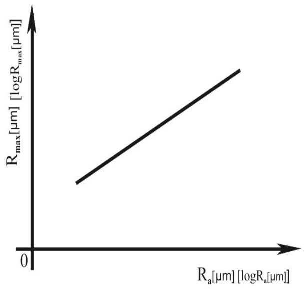

Fig. 1

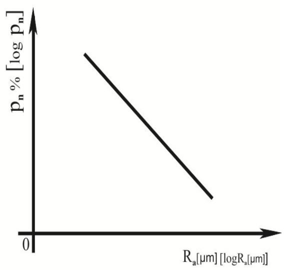

Fig. 2

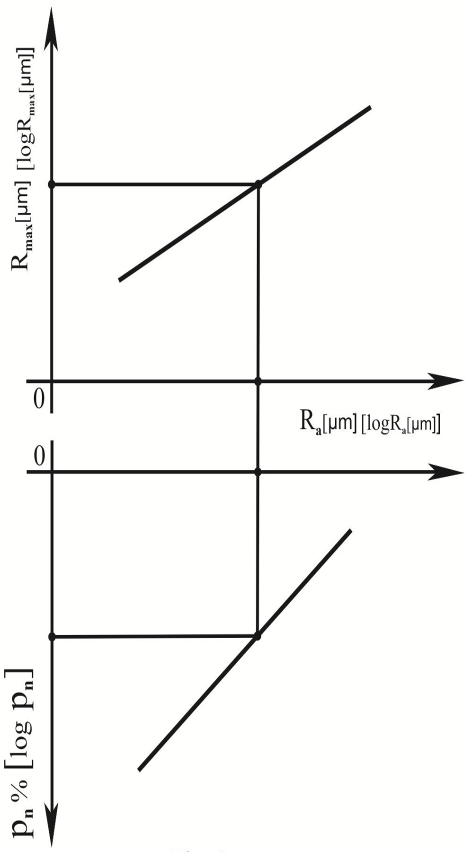

Fig. 3

Combined graphics in log-log and linear coordinates on Fig. 4 and Fig. 5, for practical use are given.

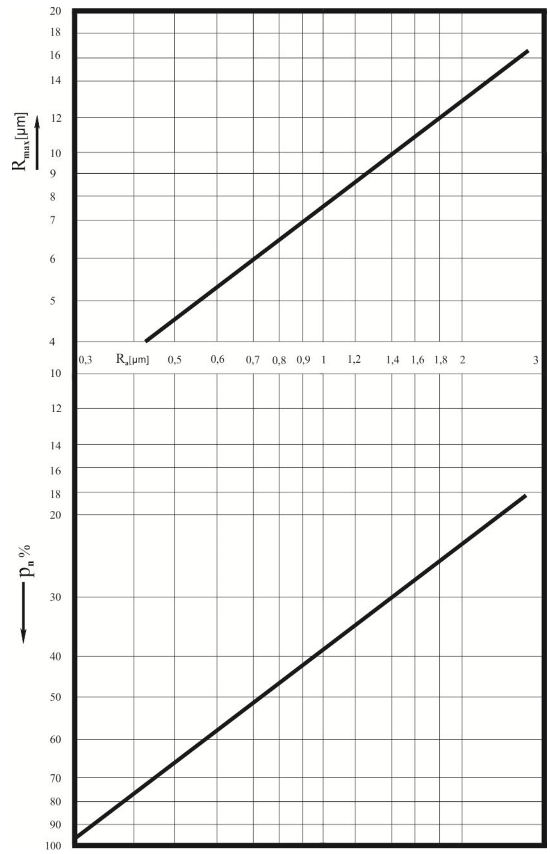

Fig. 4

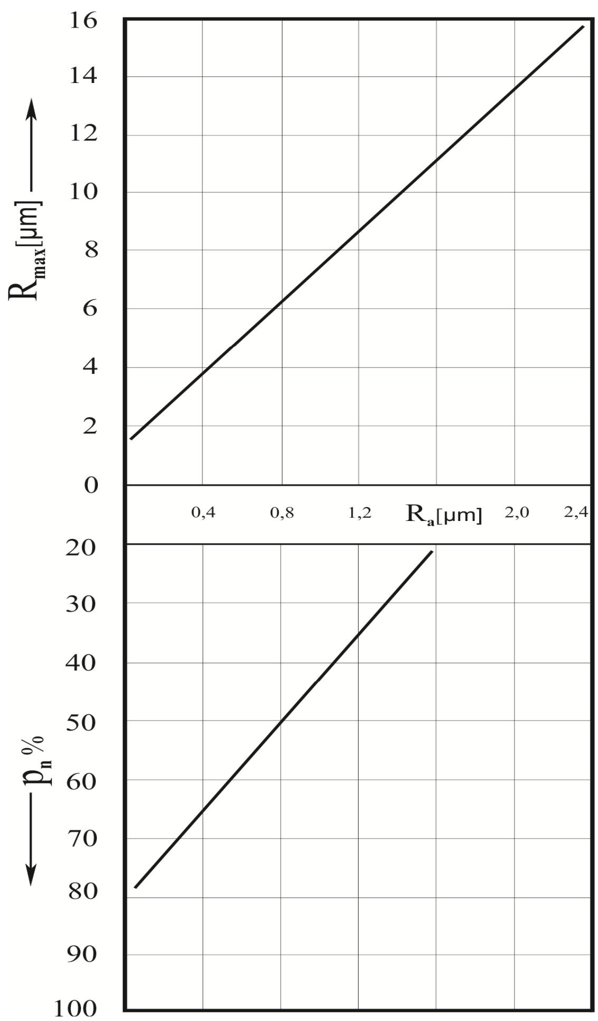

Fig. 5

3. CONCLUSION

Refering to the above mentioned we conclude:

- combine graphics which connect all three roughness parameters if one of them is known that other two can be directly easy determined.
- graphics in exponential and linear form can be equaly used, but linear is more appropriate.

REFERENCES

[1] Dyachenko, P.E., and all., About elaboration International standard of machined surface roughness Surface Quality machine elements, Papers of Seminar of the surface quality Proceedings A, Edition AN SSSR Moscow, 1959. (in Russian)

[2] Sekulic, S., Kovac, P., Correlation between the maximal roughness height and aritmetic deviation of the profile from the mean line of machined surface in finish turning, Tribology in Industry, vol. VIII, No.1, 1986. (in Serbian)

[3] Sekulic, S., Kovac, P., Correlation between bearing ratio and mean aritmetic deviation of profile from mean line of machined surface. Proceedings International Conference on Advanced Manufacturing and Technology – AMST 187, October, 1987., Opatia (in Serbian)

[4] Sekulic, S., Kovac, P., Correlation Between bearing ratio and mean arithmetic deviation of profile from mean line of the machined surface by surface grinding, Proc. of the first Yugoslav conference on Tribology, Sept. 1989, Kragujevac, 1989.

[5] Sekulic, S., Kovac, P., Correlation between some roughness parameters of machined surface in surface grinding, Publication of the School of Engineering Sciences, Novi Sad, Vol. 19&20, Novi Sad, 1988&1989.

[6] Sekulic, S., Kovac, P., Correlation between maximal hight roughness and mean line of the machined surface by surface grinding, Proc. 2nd Yugoslav conference on Tribology, Sept. 1991., Kragujevac, 1991.

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CHARACTERISTICS OF CHROMIUM COATINGS IN PROGRAMMED CURRENT REGIME

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Abstract: *Electrolytical chromium coatings have wide and various application, due to characteristics of these coatings. They are deposited with aim to give the surface of base material wanted characteristics such as: wear resistance, chemical stability, esthetic appearance etc. Investigations of galvanic chromium coatings are mostly directed to the connection of the coating with base material, while there is very few data of influence of base material to coating characteristics. Chromium is deposited on steel base from chromate-sulfate electrolyte. For investigation of galvanic chromium coatings model of programmed deposition is set in system of planparalel plates. Program of chromium deposition using direct current is projected. Process of coating deposition, values of parameters at the beginning and during the process, were followed and regulated computer. In this paper are presented results of investigation of influence of hardness and topography of base surface on chromium coating characteristics deposited in programmed regime with direct current.*

Key words*: galvanic chromium coatings, hardness, adherence*

1. INTRODUCTION

Creating of metallic electrolytic coatings on surface of another metal has double role: protection of corrosion and change oh characteristics of metal surface, such as hardness, electrical conductivity, decoration etc.

Influence of machining method and conditions of previous machining and preparation of base surface, technological heritage, is very rarely investigated. Surface layers of machined surfaces obtained by different machining methods can have different structure, which can appear during exploitation. According to this, it can be said that characteristics of surface layers are formed as a result of different machining conditions in technological chain of final product production. Base parameters inherited through technological process can be divided in two groups. On one hand there are parameters concerning material characteristics: composition, structure, stress state etc, and on the other hand are parameters concerning macro and micro-geometry of the surfaces (geometry parameters), corrosion resistance, wear resistance etc. [1, 2]. It signifies problem complexity and need for investigations.

Final machining of surfaces has large influence on forming of physicochemical characteristics and structure of surface layer. In this paper is conducted investigation of influence of previous surface machining and surface hardness on characteristics of chromium coatings.

2. GALVANIC CHROMIUM COATINGS

Electrolyticaly obtained chromium coatings have mirror like shine of silver-steel color with blue shade. It is possible to make chromium coatings on almost any metal but during coating chromium with coatings of other metals good connection cannot be obtained, due to chromium tendency to passivation even on air. Therefore, potential of chromium coating in all known cases is electrically more positive than steel, so for iron and its alloys chromium coating is only mechanical protection. Chromium coatings are highly porous even in thick layer, so chromium coating for corrosion protection is conducted after application of object inter-coatings from other metals such as copper and nickel. So chromium only protects layers beneath from mechanical damages and preserves decorative appearance of the product. Hard chromium coatings have use in production of different tools, machine parts, army industry etc. Depending on nature of base material, presence of interlayer, and element function, thickness of chromium coatings varies from 0.5 to 500 µm [3].

Depending on chosen deposition regime (ampere density and electrolyte temperature) during chromium deposition with direct current characteristics of coatings are changed (shine, corrosion and wear resistance, hardness, stress state, surface defects...). During chromium deposition with direct current there is also a problem if the current is interrupted during the process, because of chromium surface passivity. It is almost impossible to deposit other layer with good adherence on the layer deposited before process interruption [4, 5].

3. EXPERIMENTAL INVESTIGATIONS

Samples for investigation are plates with dimensions 6,3x15x10 mm (according to ASTM G 77). After samples are produced by milling, thermal machining was conducted for different hardness. Final machining of samples was conducted by grinding in different regimes and polishing. In this way are obtained different characteristics of surface layer and different topographies of sample surfaces. Steel Č5730 (according to GOST-u 30HN2FA 1) was chosen for the base for coating deposition. Chemical composition of this steel is presented in Table 1.

Table 1. Chemical composition of the base

No.	Element	Chemical composition (%)
1	C	0,27 -0,34
2	Mn	0,30 - 0,60
3	Si	0,17 -0,37
4	Ni	2,0 -2.4
5	Cr	0,60 - 0,90
6	Mo	0,20 - 0,30
7	V	0,10 -0,18
8	S	max 0,025
9	P	max 0,025
10	Cu	max 0,025

After final machining of the sample, and before deposition of the coating, hardness and topography parameters are measured in longitudinal and transversal direction (Table 2).

Table 2. Coating characteristics

Sample	Machining method	Ra μm	Base hardness HRC
54	grinding	0.818	38
56		0.719	39
65		0.844	19
92		0.720	37
112	belt grinding	0.600	35
124		0.550	38
126	sandblasting	0.870	35

Chromium coatings are deposited in programmed regime of direct current, according to experiment plan (Table 3), with constant electricity amount of 14 Ah. During deposition process, parameters of direct current are controlled and regulated in defined intervals. Anodes used were made from lead with 10% of antimony.

Chemical corrosion of base metal surface was conducted in 20% solution of sulfuric acid with following parameters:

- working temperature 250ºC,
- time of machining 4 minutes

After corrosion samples are minutely rinsed in fluid water. Deposition of chromium coatings was conducted in chromate-sulfate electrolyte with following concentrations:

- Chromium (VI) oxide, CrO3 from 250 to 270 g/dm^3 ,
- Sulfuric acid, H2 SO4, from 2.5 to 2.7 g/dm^3.

Table 3. Parameters of coating deposition

Parameters of electrolysis	Program of chromium coating deposition			
	I		II	
Current density during deposition, A dm^{-2}	30	30	70	70
Current, A	4.5	4.5	9	9
Time of deposition, h	3	6	3	6
Working temperature of deposition is 55 ±1ºC				

Electrolyte is formed with lowest concentration, but during work part of electrolyte evaporates so the concentration gets higher. Investigation shows that the change of electrolyte concentration has no influence on deposition process according to program that was set. After deposition of coatings samples were rinsed in fluid water, then in warm water, and then dried with warm air.

Coating appearance was followed visually on daylight under 45^0 angle. Coating thickness was determined with magnet method. Thickness measurement was conducted in 15 spots, according to the scheme presented in Picture 1. Based on the results of thickness measurement, graphic models of coating thickness distribution on the surface were determined.

In Table 4 are presented values of coating thicknesses for samples 92 and 126. Graphic model of distribution of coating thickness for samples 92 and 126 is presented in Fig. 2.

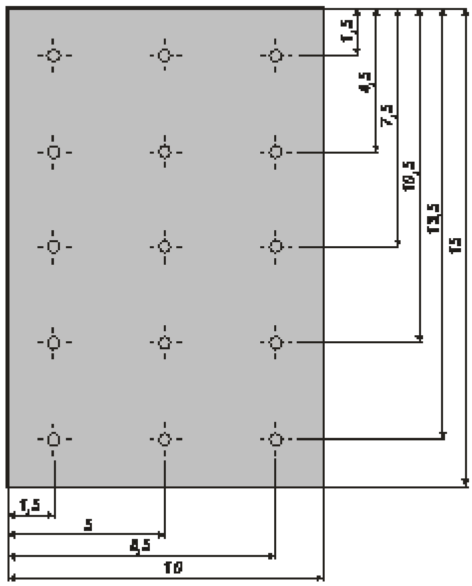
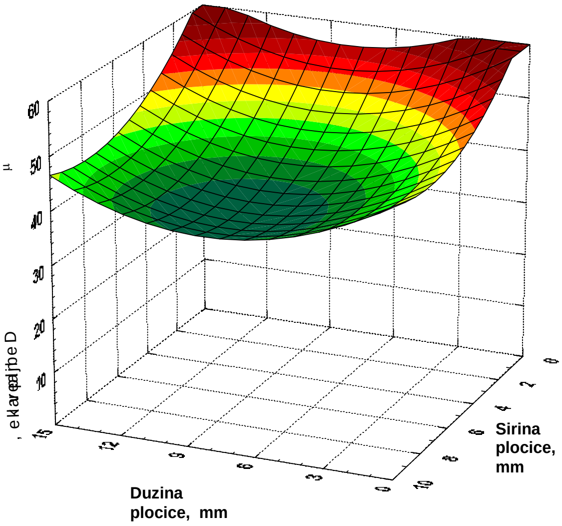


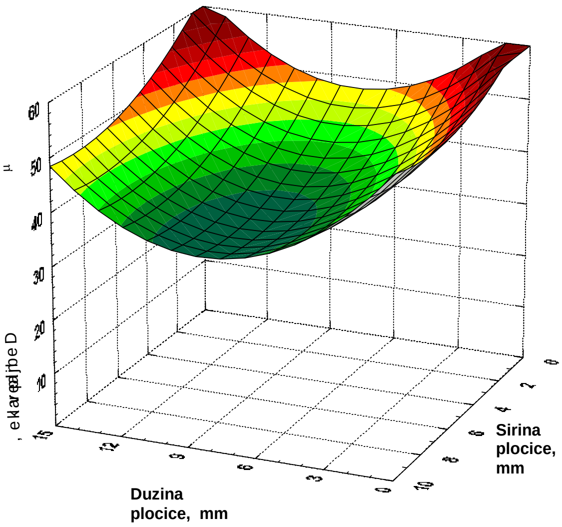
Fig. 1. Coating thickness distribution scheme

Table 4. Coating thicknesses for samples 92 and 126, μm

Sample	x/y	1.5	4.5	7.5	10.5	13.5
92	1.5	55	55	48	48	55
	5	46	43	40	40	45
	8.5	45	40	38	39	42
126	1.5	55	43	45	45	55
	5	55	36	40	38	40
	8.5	45	40	33	40	43



Sample 92



Sample 126

Fig. 2. Distribution of coating thicknesses for samples 92 and 126

Adherence of the coating was determined with thermal shock model, according to ISO 2819.

Conditions of investigation:

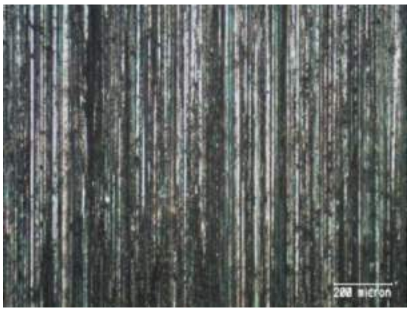
- Temperature of sample heating T=370°C (according to standard T =350°C - 370°C),
- Time of heating 2 hours
- Wetting with cold water jet.

Hardness was determined with Vickers method with load of 0.981 N.

In Fig. 3. is presented appearance of samples 92 and 126 before and after coating.

4. RESULT ANALYSIS

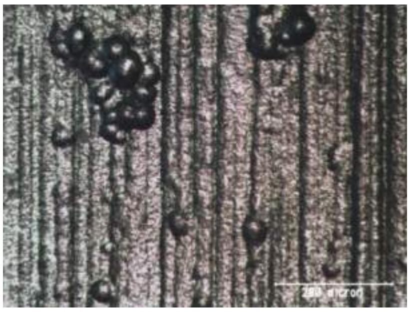
As deposition was conducted in shiny chrome area (electrolyte temperature 55°C, with use of current density 30-70 A/ dm2), shiny coatings were obtained. Edge effect was noticed on coating surfaces. Presence of edge effect was confirmed by results of measuring of coating thickness.


without Cr coating


with Cr coating

Sample 92


without Cr coating


with Cr coating

Sample 126

Fig. 3. Appearance of samples before and after coating

Thickness was measured in 15 spots. In Picture 2 is presented distribution of coating thicknesses on samples 92 and 126. As shown in Picture 2, coating thickness is different and irregular both in length and in width. Highest values for coating thickness were measured in peripheral spots, at lengths 1.5 mm and 13.5 mm of measured samples. Considering clearly expressed edge effect (known in literature) this is logical and expected thickness distribution. Coating thickness depending on deposition program was within limits from 30 µm to 80 µm. Independent from used technological parameters, adherence of the coating to the base metal was good, as internal adherence between layers. Confirmation of good adherence to the base metal and between layers is presented in Picture 4.

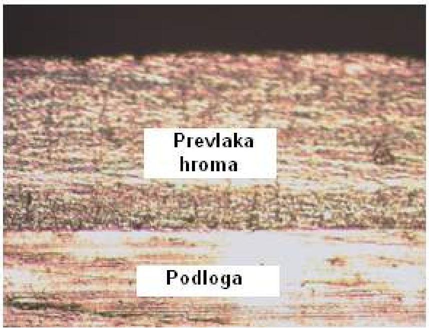


Fig. 4. Structure of chromium coating

As shown in Fig. 4, during sample cutting compactness of all length connection between coating and base metal wasn't disturbed. Also, during heating of coated samples, bubbling of coating and separation of base metal wasn't noticed, Fig. 5. Adherence of deposited chromium coatings is good, changes in coating that indicate separation from base material weren't noticed. During investigations with thermal shock model, after heating within conditions set by standard, samples are exposed to cold water jet. The coating must stay unaffected, layers mustn't separate from base material.

Investigated samples meet the standard.

Fig. 5. Morphology of chromium coating

Hardness is one of the basic characteristics of chromium coatings of higher thicknesses. High hardness of electrolytic chromium is explained mainly by specificity of its cathode crystallization and forming of fine grained structure. Electrolyte temperature and current density highly effect on hardness of chromium coatings.

Coatings deposited in chromate-sulfate electrolyte on temperatures from 50 to 56^oC, in wide area of current densities (40 - 80 A/dm^2), have highest hardness levels [8]. Coatings deposited during experiment have thickness in area from 30 µm to 380 µm, and deposition temperature was 55^oC. Values of micro-hardness of chromium coating are within area from 890 $HV_{0.2}$ to 960 $HV_{0.2}$, which is in accordance with literature data [7, 9, 10, 11], obtained for coatings deposited on surfaces with grinding as final machining. If base material hardness is considered, it can be observed that it has no significant influence on coating hardness.

5. CONCLUSIONS

Chromium coatings were deposited in programmed regime of direct current from chromate-sulfate electrolyte on temperature of 50^OC. Coatings are shiny with highly expressed edge effect. Investigated coatings are deposited on samples with different topography and hardness. Adherence of chromium coatings to base metal is satisfactory, which confirms validity of programmed model set for coating deposition. Results of investigation of change of surface topography depending on type of chromium coating show that topography significantly changes after coating. It was observed that surface roughness grows with prolonged time of deposition, roughness is in direct correlation with coating thickness, which is in accordance with literature data. Micro-hardness of chromium coating is stable and in accordance with literature data [7], obtained for coatings deposited on surfaces with grinding as final machining.

REFERENCES

[1] Зинченко В. М.: Технологическая наследственность при изготовлении деталей, Технология металлов, 2007. № 5,

[2] Ящерицын П. И.: Технологическое наследование эксплуатационных параметров деталей машин. Справочник, Инженерный журнал № 9, 2004,

[3] Sully A., Brandis E.: Chromium, Plenum Press, New York. 1987,

[4] Đorđević S., Maksimović M., Pavlović M., Popov K.: Galvanotehnika, Tehnička knjiga, Beograd, 1998,

[5] Грилихес С., Тихонов К.: Электролитические и химические покрытия, Химия, Ленинград, 1990,

[6] Петровић Б.: Проблеми при програмираном таложењу хрома из саморегулишућих електролита, Заштита материјала, вол.42, број 1, 2001,

[7] Солодкова Л., Соловьева З.: Защтита металлов, 24, 1982,

[8] Leisner P., Bech-Nielsen G., Moller P.: J. Appl. Electrochem, 17, 1993,

[9] A. DarbeIdaa, J. von Stebuta, M. Bartholeb, P. Belliardc, L. Le1ait, G. Zacharied, Comparative tribological study of chromium coatings with different specific hardness, Surface and Coatings Technology, 68/69 (1994) pp.582-590.

[10] Aimin Liang, Liwei Ni, Qiao Liu, Junyan Zhang, Structure characterization and tribological properties of thick chromium coating electrodeposited from a Cr(III) electrolyte, Surface & Coatings Technology 218 (2013) 23–29

[11] V. O. Hordienko, V. S. Protsenko, S. C. Kwon, J.Y. Lee, F. I. Danilov1, Electrodeposition of chromium coatings from sulfate–carbamide electrolytes based on cr(iii) compounds, Materials Science, Vol. 46, No. 5, March, 2011

Acknowledgments: The authors would like to thank to the Ministry of Science and Technological Development of the Republic of Serbia. Paper is result of technological project TR35034: "The research of modern non-conventional technologies application in manufacturing companies with the aim of increase efficiency of use, product quality, reduce of costs and save energy and materials" which is supported by Ministry of Education and Science of the Republic of Serbia.

35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
Faculty of Mechanical and Civil Engineering in Kraljevo

COATING: A WAY TO IMPROVE BIOMEDICAL PROPERTIES OF AISI 316L STAINLESS STEEL

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Abstract: *Stainless steel 316 L has widely applied in many areas, such as process and food industry, nuclear and pharmacy plants, dentistry and medicine. However, low wear resistance, in some cases susceptibility to pitting and crevice corrosion in body environment and release of toxic ions from the surface are the basic disadvantages which this material prone to be. It has still applied as a biomaterial due to its excellent mechanical strength, acceptable corrosion resistance, good formability and cost-effectiveness. Surface engineering aims to improve surface-dominated properties, like resistance to corrosion, ion release or wear, without compromising the mechanical properties of the bulk. In this paper, some of methods for the surface engineering of the stainless steel as a biomaterial are reviewed.*

Key words*: Stainless steel 316 L, surface engineering, coating.*

1. INTRODUCTION

Biomaterials are commonly characterized as materials used to construct artificial organs, rehabilitation devices, or implants to replace natural body tissues. Biomaterials definitely improve the quality of life for an ever increasing number of people each year. The range of applications is wide and includes joint and limb replacements, artificial arteries and skin, contact lenses and dentures. To successfully apply implants in the human body, an adequate level of tolerance of the material used with the living organism is required, in other words a high grade of biocompatibility. Biocompatibility has been defined as ‘‘the ability of a material to perform with an appropriate host response in a specific application’’ [1, 2]. This means that the material or any leachable products from it do not cause cell death, chronic inflammation or other impairment of cellular or tissue functions. Mechanical property is the primary aspect for hard tissue replacements, to establish the mechanical formation of an implant. However, to achieve a high grade of compatibility of a material system with the host tissue, key factors are surface determined such as biocompatibility and corrosion resistance. Indirectly these surface factors also effect mechanical behaviour such as stress shielding, wear debris or fatigue failure. But most importantly, the surface of the synthetic device is in direct contact with the living organism. Therefore major attention must be paid to the surface of a material system as its reaction with the host tissue is often decisive on success or failure of implantation [3].
In the past few decades, increase in the utilization of self-operating machines, participation of many persons in sports, defence activities, increased interest in motorcycles and bicycles, and day-to-day increasing traffic, has resulted in enormous increase in the number of accidents. This has necessarily led people to opt for orthopaedic implants for early and speedy recovery and resumption of their routine activities [4]. Chemical stability, mechanical behaviour and biocompatibility in body fluids and tissues are the basic requirements for successful application of implant materials in bone fractures and replacements. Corrosion is one of the major processes affecting the life and service of orthopaedic devices made of metals and alloys used as implants in the body. Currently, orthopaedic implants make up the bulk of all devices implanted (approximately 1.5 million per annum worldwide) at a cost of around $10 billion [5]. Many researchers have looked for methods that will cost-effective 316 L stainless steel make good enough, especially for temporary implants, but also to create opportunities for the safe use of this material for permanent implants. The aim of this paper is to present current research in the field of surface engineering that improve the properties of AISI 316L stainless steel for medical application.

2. STAINLESS STEEL AISI 316 L AS A BIOMATERIAL

Austenitic type AISI 316L stainless steel (SS) is a low-carbon version of the AISI 316 SS used extensively in many purposes due to its very good corrosion resistance, smoothness, biocompatibility and clean ability after electro polishing treatment. Stainless steel AISI 316LVM is molybdenum alloyed vacuum remelted stainless steel for the production of both temporary and permanent implants Beside its enormous application in the nuclear and processing industry, it has widely used for implants (orthopaedic fixation plates, screws, dental prostheses, vascular stents). 316LVM (using the American iron and steel industry nomenclature), is a more expensive than AISI 316L and posses higher corrosion resistance due to its purer structure. AISI 316L SS has reasonable corrosion resistance, biocompatibility, tensile strength, fatigue resistance and suitable density for load-bearing purposes thus making this material a desirable surgical-implant material. SS is a widely used cost-effective orthopaedic implant material for internal fixation because of its mechanical strength and the possibility of bending and shaping the implant. Examples of SS applications include aneurysm clips, bone plates and screws, femoral fixation devices, intramedullary nails and pins, joints for ankles, elbows, fingers, knees, hips, shoulders and wrists [6]. However, major disadvantages of SS are well-documented. Upon prolonged contact with human tissue (elevated temperature and saline conditions) surface corrosion phenomena takes place resulting in a high rate of locally and systemically released corrosion products [7]. Release of large amount of certain metal ions may lead to harmful deceases [8]. The ions released from SS are mostly of iron, nickel and chromium. Specially nickel is recognized as a strong immunological reaction medium and may cause hypersensitivity reactions, contact dermatitis, asthma, and moderate cytotoxicity [9]. Keeping in mind previous considerations, SS is mostly used for temporary orthopaedic implants such as bone screws, plates and implanted medical devices, besides surgical instruments. Time period for bone healing, over which the host is exposed to the bone screw/plate is 3–12 months [10].

Principally, the nature and stability of a passive film on a particular biomedical metal or alloy depend on the environmental conditions, such as the composition of the electrolyte, the redox conditions, the exposure time and temperature. Depending on the type of oxide formed, the passive film may or may not remain stable and hence sustain passivity upon exposure to the biological environment. Under certain conditions, localized breakdown of passivity takes place, leading to fast dissolution at the site of breakdown. Localized corrosion typically starts at sites characterized by inhomogeneities either in the material, or in the surrounding environment. Even though most of the surface is still covered by the intact passive film, the corrosion rate at locally activated sites can reach very high values. Localized corrosion may thus lead to unexpected deterioration of the whole system with disastrous consequences, although the total mass loss is actually small. Therefore, localized corrosion processes are more dangerous in nature and far less easy to predict than uniform corrosion [11].

The passive state of a metal can be prone to localized instabilities, under certain circumstances. Localized corrosion is triggered by specific aggressive anions (halogenides) and typically starts at sites characterized by inhomogeneities either in the material, or in the surrounding environment. From an electrochemical viewpoint, the initiation of corrosion can be due to the various conditions existing along the implant surface. These conditions may be responsible for the formation of electrochemical cells accompanied by active metal dissolution at favoured localized spots at the implant-body fluid interface. There are a series of other factors which can result in altering the local environmental conditions and lead to various forms of corrosion and/or failure of the implant. The final result is the formation of an active pit in the metal, an example for localized breakdown of passivity. Even though most of the surface is still covered by the intact passive film, the corrosion rate at locally activated sites can reach very high values. Localized corrosion may thus lead to unexpected deterioration of the whole system with disastrous consequences, although the total mass loss is actually small. Therefore, localized corrosion processes are more dangerous in biomedical applications and far less easy to predict than uniform corrosion [12, 13]. Corrosion can have two effects: the first, the implant may weaken and the premature failure of the implant will occur; the second effect is the tissue reaction leading to the release of corrosion products from the implant. No metallic material is totally resistant to corrosion or ionization within living tissues.

Orthopaedic implants include both temporary implants such as plates and screws and permanent implants that are used to replace hip, knee, spinal, shoulder, toe, finger etc. The corrosion mechanisms that occur in temporary implants are crevice corrosion at shielded sites in screw/plate interface and beneath the heads of fixing screws and pitting corrosion of the implants made of SS [14, 15]. The main cause for the failure of the orthopaedic implants is wear, which in turn is found to accelerate the corrosion [16].

Studies on retrieved implants show that more than 90% of the failure of implants are due to pitting and crevice corrosion attack [17, 18]. These localized corrosion attacks and leaching of metallic ions from implants necessitate improvement in the corrosion resistance of the currently used type 316L SS by bulk alloying or modifying the surface [19].

There has been a constant attempt by engineers and scientists to improve the surface-related properties of biomaterials to reduce the failure of implants due to poor cell adhesion and leaching of ions due to wear and corrosion [20]. The various surface modification techniques used for bioimplants have been reviewed by Anil Kurela et al. [21] and Bauer et al. [3]. Preventing corrosion using inhibitors is not possible in an extremely sensitive and complex bio system and hence several surface passivation and coating methods have been adopted. The techniques such as chemical treatment, plasma ion implantation, plasma source ion implantation (PSII)), plasma electrolytic oxidation (PEO), laser melting (LSM), laser alloying (LSA), laser nitration, ion implantation, and physical vapor deposition (PVD) and also surface texturing are widely applied for surface engineering of SS. However, each of these methods also has some limitations.

3. SURFACE ENGINEERING

Mechanical properties of materials used for biomedical devices and components are the primary aspect for hard tissue replacements. They are the most important for establishing mechanical formation of implants. However, to achieve a high grade of compatibility of a material system with the host tissue, key factors are surface determined, such as biocompatibility and corrosion resistance. Indirectly, these surface factors effect mechanical behaviour such as stress shielding, wear debris or fatigue failure. Therefore major attention must be paid to the surface of a material system as its reaction with the host tissue is often crucial on success or failure of implantation. On the other hand, surface characteristics such as roughness, topography and chemistry play a pivotal role in specific cell responses such as attachment, migration, proliferation and differentiation of connective tissue progenitor cells. Consequently, surface modification can be a key technology to enhance the in vivo performance of biomaterials. Proper surface modification techniques not only retain the desired bulk attributes of biomedical materials, but also improve specific surface properties required by different clinical applications. The influence of surface roughness on the rate of osseointegration and biomechanical fixation of hard tissue implants has been identified as a key factor. Mainly surface topographies at the micron level were reported as important and several surface modification techniques operating at this length scale were developed [3].

The goal of surface engineering is not only to fit the demands of avoiding negative effects of implanted materials on the surrounding tissue but even more to enhance the interplay between the designed technical material and the living matter. There are pretty number of methods for improving biocompatibility of the 316 L SS, which can be classified as mechanical, chemical, heat treatment, electrochemical and coating technologies. A variety of surface treatments and coatings are commonly performed on medical implant materials to promote corrosion and wear resistance and biocompatibility.

3.1. Coating

Coating is a logical way to enhance surface-dominated properties, like resistance to corrosion, ion release or wear, without compromising the mechanical properties of the bulk [22]. The long-term performance of the coating/substrate system, however, may be challenged by the loss of the mechanical integrity of the coating because maximum stresses during use occur at the surface, hence the need to develop “hard yet tough” coatings when considering load-bearing engineering applications. In this context, the toughness of the coating is as important as, if not more important than, super hardness. Particularly, calcium phosphates are known for their bioactive properties and their increased bone binding effects. Therefore, calcium phosphate coatings, similar to the mineral phase of bone, have been extensively investigated as bioactive coatings on bioinert implant materials [23-25]. For example, metal implants have been coated with layers of calcium phosphates mainly composed of hydroxyapatite. While hydroxyapatite resembles in its chemical structure apatites, carbonate apatite comprises a chemical composition that is more close to the human bone. F.-H. Lin et al. [26] employed chemical method to establish and induce a bioactive HAp layer on the surface of 316L SS. When the metallic substrates treated with 10 M NaOH aqueous solution and subsequently heated at 600°C, a thin sodium chromium oxide layer was formed on the surfaces as the linking layer for HAp and 316L SS.

D. Gopi et al. [27] reported a successful electro deposition method for coating hydroxyapatite (HAp) onto surgical grade SS. Pure HAp coatings could be achieved and the coating resistivity was assessed by potentiodynamic polarization and impedance techniques which showed that HAp coatings deposited onto the borate passivated SS specimens possess maximum bioresistivity in Ringer’s solution. The coatings were characterized by X-ray diffraction (XRD), Scanning electron microscopy (SEM) and Atomic force microscopy (AFM). The results have showed that the borate passivation followed by HAp coating performed on 316L SS could enhance the longevity of the alloy in the simulated body solution (Ringer’s solution).

J. Tavares et al. [28] presented a novel plasma treatment involving the deposition of ethylene glycol plasma polymer-coated titanium nanoparticles on a 316L SS surface. The deposition of ethylene glycol plasma polymer-coated nanoparticles confers properties to the surface making it more biocompatible, which is beneficial in applications of SS 316L as a blood-contacting implant (e.g. vascular stents, heart valves). These properties include increased hydrophilicity and general corrosion resistance of the surface, and reduced substrate-dependent denaturation of adsorbed protein fibrinogen.

Methods such as physical vapour deposition coating (TiN, TiC), ion implantation (N+), thermal treatments (nitriding and oxygen diffusion hardening), and laser alloying with TiC have been examined for improving wear. Ion implantation has been the most common treatment employed. V. Muthukumaran et al. [29] AISI 316L SS implanted with two different ions: nitrogen and helium. The crystallographic orientation and surface morphology were studied using X-ray diffraction (XRD) and scanning electron microscope (SEM). The effects of ion implantation on the corrosion performance of AISI 316L SS was evaluated in 0.9% NaCl solution using electro chemical test both on the virgin and implanted samples. The subsequent Tafel analysis showed that the ion implanted specimens were more corrosion resistant when compared to the bare specimens. The results of the studies indicated that there was a significant improvement in both corrosion resistance and hardness of implanted samples.

In recent years, attention has also focused on the use of Nb and Ta as implant materials due to their outstanding biocompatibility, superior corrosion resistance and excellent fatigue properties. However, in the pure form, Nb is mechanically weak. This inadequacy in strength has excluded their use for the construction of load-bearing prosthetic materials, although strengthening can be achieved through the application of powder metallurgy techniques. An alternative method to benefit from the biocompatibility of Nb, without any sacrifice in overall component strength, is to deposit Nb on suitable substrate. Here the rationale assumes that the substrate provides the necessary mechanical properties associated with load-bearing implants, while the Nb coating provides enhanced biocompatibility and corrosion resistance [30, 31].

M. Omrani et al. [32] reported the results of TiN-ions implantation into the SS 316L samples as bipolar plates, Plasma Focus device operated with nitrogen gas for 10, 20, and 30 shots in order to improve the corrosion resistance and electrical conductivity of samples. The corrosion potential of the TiN coated samples increased compared to the bare SS 316L and corrosion currents decreased in TiN implanted samples. The thickness of coated layer which was obtained by cross sectional SEM was about 19 nm.

Polymer coatings can be used for fabrication of protective coatings on medical devices too. One of the polymers used today for medical devices is parylene (poly-para-xylylene) due to its excellent biocompatibility and possibility to form a thin, continuous and inert film [33]. Pre-treatment with the organic silane A174 prior to parylene coating is the recommended surface preparation. Basically, silane is used as an adhesion promoter owing to its intermediate character and thus can serve as an electrostatic glue between inorganic (metal surface) and organic (parylene coating) interfaces [34]. The corrosion resistance of a two-layer polymer (silane+parylene) coating, on implant SS was investigated by microscopic observations and electrochemical measurements. Long term exposure tests in Hank's solution revealed that the coating can be successfully used for corrosion protection. However, the addition of H_2O_2, simulating the inflammatory response of human body environment causes a dramatic destruction of the protective coating [35].

Nanostructured films were deposited on conductive substrates (SS foils and graphite) and exhibited a fibrous, crack free and porous microstructure with pore size in the range 10–100 nm. It was suggested that the porous structure of manganese dioxide deposits was beneficial for ionic conductivity, whereas CNT could provide improved electronic conductivity MnO_2/CNT composite deposits obtained by electrophoretic co-deposition (deposition voltage 15 V) from a sodium alginate solution [36].

Y. Liu et al. [37] evaluated **s**ilver **n**anoparticle/**p**oly(DL-lactic-co-glycolic acid) (PLGA) coated 316L stainless **s**teel **a**lloy (SNPSA) as a potential antimicrobial implant material. From a materials and device development perspective, SNPSA exhibited strong bactericidal and osteoinductive properties that make it a promising pharmaceutical material in orthopedic surgery. Their results indicated that silver nanoparticle/PLGA coating is a practical process that is non-toxic, easy to operate, and free of silver nanoparticle aggregation too. In addition, the results revealed that the antibacterial and osteoinductive activities of SNPSA are silver-proportion-dependent, raising the interest in increasing the silver proportion of the coating in future investigations.

Novel biomaterial surfaces with antibacterial Ag agents and a wear-resistant S-phase have been generated on SS by duplex plasma silvering–nitriding techniques for application to load-bearing and other medical devices. A silver and nitrogen alloyed duplex surface system was developed for the first time by two-step plasma alloying: DG plasma silvering followed by active screen plasma nitriding. The Ag wass embedded in a hard substrate (Fe_4N and nitrogen S-phase). The surface roughness, hydrophilicity, surface free energy and N content were found to be increased by the duplex plasma process. The remaining presence of silver on the surface under a scratching was confirmed and the wear resistance of the Ag/N duplex alloyed surface was more than two orders magnitude higher than that of untreated 316LVM SS. Thus a duplex surface system that combines bacterial inhibitory and wear-resistant properties might provide long-term antibacterial function for load-bearing biomedical surfaces [38].

With a view to developing a smart coating combining both biocompatibility and corrosion resistance over bioimplants, polypyrrole/TiO_2 nanocomposite coatings were electrochemically synthesized by cyclic voltammetric technique on 316L SS in an aqueous solution of oxalic acid. The results showed that the nanocomposite coatings exhibited superior biocompatibility and enhanced corrosion protection performance over 316L SS than that of pure polypyrrole coatings [39].

Plasma electrolytic oxidation (PEO) is based on conventional anodic oxidation of metals and alloys in aqueous electrolyte solutions, but operated above the breakdown voltage, which results in formation of plasma micro-discharge events. This allows the formation of coatings composed of not only predominant substrate oxides but of more complex oxides containing the elements present in the electrolyte. PEO is a very attractive, cost-effective, environmentally friendly surface engineering technique for light alloys. A variety of oxide ceramic coatings with different properties can be produced by PEO, which can effectively improve the tribological and corrosion properties of Ti, Al and Mg alloys. In particular, PEO is a unique and irreplaceable technique to fabricate functional coatings for specific applications [40].

The PEO technique has many advantages [41], such as: a) wide range of coating properties, including wear-resistance, corrosion-resistance and other functional properties; b) no deterioration of the mechanical properties of the substrate materials is caused because of negligible heat input; c) high metallurgical bonding strength is measured between the coating and the substrate; d) there is the possibility of processing parts with complex geometric shape or large size; e) equipment is simple and easy to operate; f) cost is low, as it has no need of experience vacuum or gas shielding conditions; g) the technique is ecologically friendly, as alkaline electrolytes are employed.

Currently, PEO processes are in a transition phase from research to commercial applications, mainly focused on the corrosion- and wear-protection of metal alloys. It is necessary to further study the fundamentals of the PEO technique to advance scientific understanding and to explore new functional PEO coatings for high-tech applications.

One of the PEO application to improve the surface hardness and wear resistance of austenitic AISI 304 stainless steel is by using a duplex diffusion/coating process of plasma electrolytic nitrocarburising (PEN/C) with plasma-immersion ion-assisted deposition (PIAD) of diamond-like carbon (DLC) [43]. It was demonstrated that plasma electrolytic techniques, such as plasma electrolytic oxidation (PEO) and plasma electrolytic saturation (PES) with PEN/C being an example of the latter, can potentially provide beneficial surface modifications to a range of steels and light metal alloys [44, 45]. C. Tsotsos et al. reported that the PEN/C+DLC duplex treatments can reduce significantly both the volumetric wear rate and the friction coefficient of AISI 304 austenitic stainless steel [46].

X. Jin, et al. [47] introduced a novel rapid surface hardening technology on steels, namely cathodic plasma electrolytic oxidation (CPEO. The oxide coatings of 35 μm – 180 μm thick on AISI 304 stainless steel were prepared by cathodic plasma electrolytic oxidation in 15% borax electrolyte with additive at 260 V. They found that the oxide coatings contained two layers: one loose outer layer which mainly consisted of Fe_3O_4 phase and one compact inner layer with Cr and Ni aggregation where $FeCr_2O_4$, $NiCr_2O_4$, Fe_3O_4 and FeO phases were detected. The microhardness of CPEO coating increased with increasing coating thickness, and its maximum microhardness was up to 1335 HV. They also reported that the CPEO treatment can significantly improve wear resistance of AISI 304 stainless steel. The friction coefficient of stainless steel was reduced from 4-6 times by using CPEO treatment.

4. CONCLUSIONS

In recent years, surface modification and coating of AISI 316L stainless steel has been recognized as one of the main directions of implant material development and various methodologies and techniques have been tried. Among the most promising methods are surface coatings with multi-layered thin films, bioglass and silver coatings and biocompatible nano-composite layers. Different studies have pointed out that plasma electrolytic techniques, such as plasma electrolytic oxidation can potentially provide beneficial surface modifications to a range of steels, but further research are needed to introduce this procedure from research to an application level.

Acknowledgment: This paper is part of project III41017 Virtual human osteoarticular system and its application in preclinical and clinical practice, funded by the Ministry of Education, Science and Technological development of Republic of Serbia, for the period of 2011-2014.

REFERENCES

[1] Williams DF, Consensus and definitions in biomaterials, In: de Potter C, de Lange K, de Groot K, Lee AJC, editors. Advances in biomaterials. Amsterdam: Elsevier; 1987. p. 11–6.

[2] Ratner BD, A perspective on titanium biocompatibility. In: Brunette DM, Tengvall P, Textor M, Thomson P, editors. Titanium in medicine j. material science, surface science, engineering, biological responses and medical applications. Berlin: Springer; 2001. p. 2–12.

[3] S. Bauer et al., Progress in Materials Science 58 (2013) 261–326.

[4] U Kamachi Mudali et al, Corrosion of bio implants, Sadhana Vol. 28, Parts 3 & 4, 2003, pp. 601–637.

[5] B.M. Holzapfel et al., Advanced Drug Delivery Reviews 65 (2013) 581–603.

[6] M. Cies´lik et al., Metal release and formation of surface precipitate at SS grade 316 and Hanks solution interface – Inflammatory response and surface finishing effects, Corrosion Science 51 (2009) 1157–1162.

[7] G.D. Krischak, F. Gebhard, W. Mohr, V. Krivan, A. Ignatius, A. Beck, N.J. Wachter, P. Reuter, M. Arand, L. Kinzl, L.E. Claes, Arch. Orthop. Trauma Surg. 124 (2004) 104–113.

[8] T. Hanawa,, Mater. Sci. Eng. C 24 (2004) 745–752

[9] K.T. Oh, K.N. Kim, Eur. J. Orthod. 27 (2005) 533–540.

[10] Enderle John D, Bronzino Joseph D, Blanchard Susan M. Introduction to biomedical engineering. second ed. Amsterdam; Boston: Elsevier Academic Press; 2005.

[11] S. Virtanen et al., Acta Biomaterialia 4 (2008) 468–476

[12] Schmuki P. From bacon to barriers: a review on the passivity of metals and alloys. J Solid State Electrochem 2002;6:145–64.

[13] Virtanen S, Milošev I, Gomez-Barrena E, Trebše R, Salo J, Konttinen YT, Special modes of corrosion under physiological and simulated physiological conditions. Acta Biomaterial 2008;4:468–76.

[14] Jones DA, Principles and prevention of corrosion. 2nd ed. New Jersey: Prentice Hall 1996; vol 5: pp. 75-115.

[15] Yu J, Zhao ZJ, Li LX., Corrosion fatigue resistances of surgical implant SSs and titanium alloy. Corrosion Sci 1993; 35: 587-97.

[16] F. Zivic et al., Influence of loose PMMA bone cement particles on the corrosion assisted wear of the orthopedic AISI 316LVM stainless steel during reciprocating sliding, Wear 300 (2013) 65-77.

[17] Sivakumar M, Kumar S, Dhanadurai K, Rajeswari S, ThulasiramanV, Failures in SS orthopaedic implant devices: A survey. J Mater Sci Lett 1995; 14: 351-4.

[18] R.A. Antunes, M.C.L. de Oliveira, Acta Biomaterialia 8 (2012) 937–962.

[19] Mudali KU, Sridhar TM, Raj B. Corrosion of bio implants, Sadhama 2003; 28(3-4): 601-37.

[20] Geetha et al., Biomedical Implants: Corrosion and its Prevention, Recent Patents on Corrosion Science, 2010, Volume 2 40-54.

[21] Kurella A, Dahotre NB, Surface modification for bioimplants: the role of laser surface engineering. J. Biomater. Appl. 2005; 20: 5-50.

[22] E. Frutos, Acta Materialia 61 (2013) 1886–1894.

[23] Rey C., Biomaterials 1990; 11:13–15.

[24] Jarcho M., Calcium-phosphate ceramics as hard tissue prosthetics. Clin Orthopaed Relat Res 1981:259–78.

[25] de Groot K, Wolke JGC, Jansen JA., Calcium phosphate coatings for medical implants. Proc Inst Mech Eng Part H – J Eng Med 1998;212:137–47.

[26] F.-H. Lin et al., Biomaterials 23 (2002) 4029–4038.

[27] D. Gopi et al., Corrosion Science 53 (2011) 2328–2334.

[28] J. Tavares et al., Surface & Coatings Technology 203 (2009) 2278–2287.

[29] V. Muthukumaran et al., Materials and Design 31 (2010) 2813–2817.

[30] A. Kuhn: Passivation SS, Metal Finishing Information Services Ltd., June, 1998, 100–105.
[31] S. Nagarajan, V. Raman and N. Rajendran, Mater. Chem. Phys., 2010, 119, 363.
[32] Malihe Omrani et al., International journal of hydrogen energy 37 (2012) 1467–1486.
[33] A.P. Piedade, J. Nanes, M.T. Vieira, Thin films with chemically graded functionality based on fluorine polymers and SS, Acta Biomater. 4 (2008) 1073–1080.
[34] M. Fedel, M. Olivier, M. Poelman, F. Deflorian, S. Rossi, M.-E. Druart, Corrosion protection properties of silane pre-treated powder coated galvanized steel, Prog. Org. Coat. 66 (2009) 118–128.
[35] M. Cieślik et al., Corrosion Science 53 (2011) 296–301.
[36] Li. J. and Zhitomirsky I., Electrophoretic deposition of manganese dioxide-carbon nanotube composites. J. Mater. Proc. Technol., 2009, 209, 3452–3459.
[37] Y. Liu et al. The antimicrobial and osteoinductive properties of silver nanoparticle/poly (DL-lactic-co-glycolic acid) coated stainless steel, Biomaterials 33, 2012, 8745-8756.
[38] Y. Dong, Acta Biomaterialia 7 (2011) 447–457.
[39] A. Madhan Kumar, N. Rajendran, Ceramics International 39 (2013) 5639–5650.
[40] Surface engineering of light alloys: Aluminium, magnesium and titanium alloys, Edited by Hanshan Dong, CRC Press Boca Raton Boston New York Washington, 2010.
[41] Patel J. L. and Saka N. (2001), 'Microplasmic coatings', Am Ceram Soc Bull, 80(4), 27–29.
[42] X. Nie, C. Tsotsos, A. Wilson, A.L. Yerokhin, A. Leyland, A. Matthews, Surf. Coat. Technol. 139 (2001) 135–142.
[43] A.L. Yerokhin, A. Leyland, C. Tsotsos, A. Wilson, X. Nie, A. Matthews, Surf. Coat. Technol. 142–144 (2001) 1129.
[44] A.L. Yerokhin, X. Nie, A. Leyland, A. Matthews, S.J. Dowey, Surf. Coat. Technol. 122 (1999) 73–93.
[45] X. Nie, A. Wilson, A. Leyland, A. Matthews, Surf. Coat. Technol. 121 (2000) 506–513.
[46] C. Tsotsos et al., Wear 253 (2002) 986–993.
[47] X. Jin, et al., Surf. Coat. Technol. (2013), http://dx.doi.org/10.1016/j.surfcoat.2013.04.056.

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35th INTERNATIONAL CONFERENCE ON PRODUCTION ENGINEERING

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SOUND INSULATION OF PLYWOOD TRANSPORTER

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Abstract: *The paper presents a procedure for design of noise protection system for an industrial plywood transporter. It is noticed in exploitation that the transporter occasionally emits high frequency sound, which is detected as a distinct tone at a measurement point in nearby residential area. A technical solution of a light revetment is presented, and its insulation properties are calculated.*

***Key words**: noise, plywood transporter, sound insulation*

1. INTRODUCTION

The paper presents a technical solution of noise protection for a wood chip conveyor at a plywood factory bordering on the urban city area. Machines and equipment that generate high levels of noise are used in the plywood production process. In this case, the dominant sound sources such as fans are sound-isolated [1]. In addition, toward the residential area two sound barrier 6 m high and 110 m long in total were built [2]. Thanks to protection, noise level is significantly reduced. In the current situation, it shows noise coming from some wood chip conveyors with height exceeding the sound barrier height.
For calculation and the insulation in this case a conveyor closest to residential area was selected. The measurement finds that during such conveyor operation mode pulse and tonal properties of the noise appear. On the basis of frequency analysis of noise, and acoustic calculation [4] and possibilities of technical realization, a light acoustic barrier armoring the conveyor along the entire length was selected. The light acoustic barrier should reduce noise emission and, while doing it, not burden the wood chips conveyor structure by its weight.

2. SOURCES OF NOISE

Equipment and machinery used in the production of plywood are a group of stationary sources that generate high levels of noise.
Raw wood chip is delivered by the chain conveyor from silo to the dryer. Chain conveyor for wood chip, which is analyzed in this paper, transports the wood chip from the silo of the raw wood chip to the dryer. It is 19.7 m long. In addition to the aforementioned carriers in a factory, there are several conveyors of similar purpose and noise levels. The dry wood chips conveyor is the closest to residential area, so the level of noise that it generates is a dominant compared to other conveyors.
Chain conveyors at the plant are used to transport dry and raw chip. These conveyors achieve the highest capacity if they are in the horizontal position. They can also transport under deflection, however, their capacity is reduced. In comparison with other conveyors they take up less space and can be used for the transport of various bulk materials. Conveyor bed is made of steel plates with reinforcements of steel profiles, and drive and tensile sprocket wheel are of the wear-resistant cast. Transport is enabled by an endless chain with vanes that while sliding at the bottom of the bed take the material up and carry it in the direction of the drive sprocket wheel. Input and output necks can be placed along the entire length of the conveyor. The drive is provided by an electric motor with reduction gear via chains and sprockets.

Fig. 1. Chain conveyor for raw wood chip

The conveyor chain is lubricated by oil that falling free from the tank placed at the top of the conveyor. If there is a blockage of oil pipelines or shortage of oil, squeaking of a chain is drastically increased. If the conveyor works with reduced capacity or "in neutral", that also leads to the squeaking of a chain and blades.

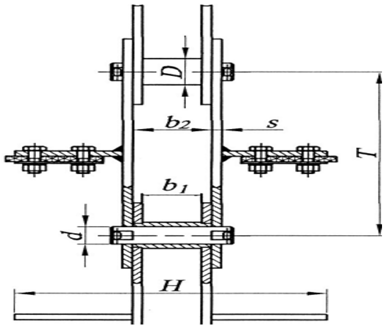


Fig. 2. Chain with blades

2.1 The level of noise at the source

Factory works all day without any interruptions. The conveyor noise levels were measured at a very close distance (up to 0.5 m), in order to eliminate the influence of other sources. As the conveyor bed has a prismatic shape, measuring of noise levels was carried out on all four sides in order to more reliably determine the level of noise emitted by each surface of conveyor (Figure 3).

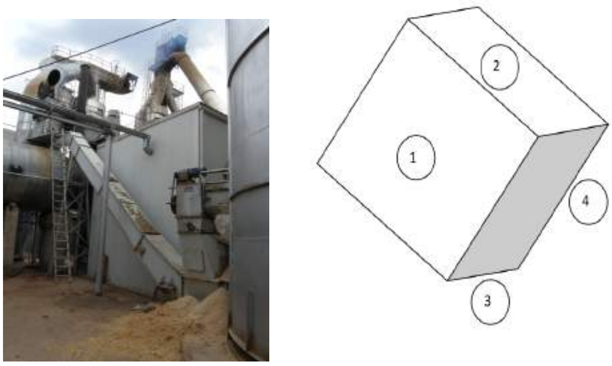


Fig. 3. Conveyor and measuring points in all sides

Measurement of noise levels was carried out in the middle of the conveyor, on the all sides. The reason for such a measurement is because discernible squeaking and beeping of conveyor chain is heard occasionally.

Table 1. Noise levels on all sides of conveyor

Pos.	L_{Aeq} [dB(A)]	L_{AImax} [dB(A)]	L_{AFmax} [dB(A)]	ΔL_i [dB(A)]
1	84.3	99.9	97.2	2.7
2	80.5	93.5	89.4	4.1
3	82.2	95.8	93.8	2
4	82.3	97.5	95.0	2.5

Beside the equivalent noise level with A weighting (L_{Aeq}), also the maximum noise levels with the pace of showing IMPULSE and FAST (L_{AImax}; L_{AFmax}).
In order to determine the impulse in noise the measurements were carried out and their results are shown in Table 1. The difference in noise level is determined according to the formula (1) defined by the standard [4]:

$$\Delta L_I = L_{AImax} - L_{AFmax} \left[dB(A) \right] \quad (1)$$

If the difference ΔL_I less than 2 dB, source noise at the measuring point has no impulses.
Difference: L_{AImax} – L_{AFmax} is determined for each individual measurement (Table 1). The measurement results show that the impulse character of the noise is present in all four measuring positions.

2.2 Noise level at the measuring point

Za ocenu buke fabrike u stambenom naselju, odabrano je merno mesto koje se nalazi između dve stambene jedinice (u nivou fasada) na rastojanju od 40 m od transportera. Na osnovu akustičkih proračuna i ranijih merenja [2], [1] , odabrano merno mesto ima najviši nivo buke u stambenoj zoni koja je ugrožena bukom fabrike iverice. U daljim analizama ova merna tačka je označena sa MT_1. Prilikom merenja buke, mikrofon je postavljen na stalak visine 150 cm.

Table 2. Noise levels at measuring point MT_1

Pos.	L_{Aeq} [dB(A)]	L_{AImax} [dB(A)]	L_{AFmax} [dB(A)]	ΔL_i [dB(A)]
MT_1	64.7	74.1	71.3	2.8

At the measuring point MT1 measurements of noise levels are performed, and the results are shown in Table 2. According to equation (1) at the measuring point a noise impulse character is determined.
The total equivalent noise level of 65 dB (A) at the measuring point comes from the operation of all plant and machinery in the factory.

$$L_R = L_{Aeq} + K \left[dB(A) \right] \quad (2)$$

The relevant noise level LR is defined as the sum of A-equivalent noise level and correction of the noise level (K). The correction factor K is defined by standard [5]. This factor includes, among other things, the correction of the noise level for normal impulse noise (KI) of 5 dB. Other correction factors of the noise level in this case have a zero value. In that way a reference level of noise in the measurement point of 70 dB (A) is determined.
Measuring point is located along the regional road, and as such, classified in V acoustic zone [7], with the limit values of noise indicators in the open space of 65 dB (A) for day and evening and 55 dB (A) for the night. The relevant noise level at the measuring point exceeds the limit values of indicators of environmental noise during the referent daytime and night-time.
As the occasional conveyor creaking is clearly recognized at the measuring point, it can be concluded that impulsive character of noise mostly comes from the work of the conveyor.

2.3 Frequency analysis of noise

Beside the measurement of the equivalent noise level on the conveyor itself and at the measuring point in the residential area, the frequency analysis of the noise was carried out, too. At the same measuring points frequency characteristics of noise were measured with 1/3 octave filters. Noise is a wide area type, because there is an approximately even distribution of sound energy in a wider frequency range. Figure 4 presents the 1/3 octave frequency spectrum measured from the front side of the conveyor (item 1), the modes with and without chain creaking.

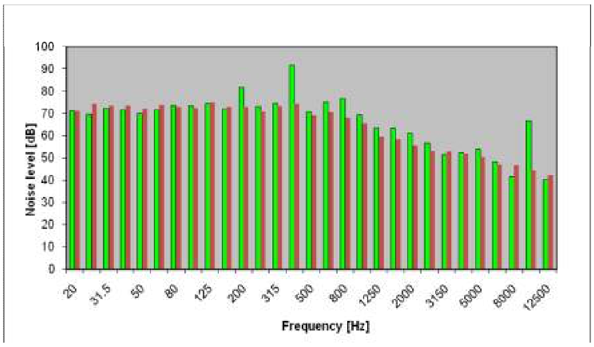


Fig. 4. Frequency analysis of conveyors noise

Figure 4 shows noise level in the frequency range from 20 Hz to 12500 Hz.

The noise is tonal [4], if the difference between the adjacent tierce in the low, mid and high frequencies is higher than:

- 15 dB at the low frequency range (25 Hz - 125 Hz)
- 8 dB at the mid frequency range (160 Hz - 400 Hz)
- 5 dB at the higher frequency range (500 Hz - 10000 Hz)

According to a simplified method for the evaluation of tonality, frequencies that give tonality to noise are shown in Table 3.

Table 3. Frequency with emphasized tone

	Frequency [Hz]			
	200	400	800	10000
Level difference ΔL [dB]	8.7	17.3	8.8	22

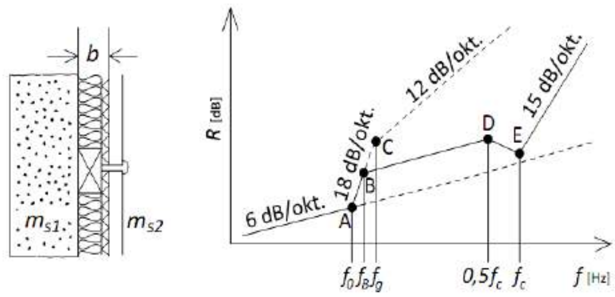
The results of frequency analysis show that the source noise has tonal character, because at frequencies of 200 Hz, 400 Hz, 800 Hz and 10,000 Hz, the difference in noise level between the adjacent tierce exceed the limit values that are defined by a simplified method.

3. TECHNICAL SOLUTION OF NOISE PROTECTION

To achieve a successful model for noise management, assessment of the state of the noise level and taking the appropriate measures and methods for noise reduction, it is necessary to have as accurate as possible information about the characteristics of the noise itself. This information is determined by measuring the characteristic size of the noise in the frequency, amplitude and time domain.

3.1 Contribution of light lining to insulating power of solid wall

Light coating or thin barrier added to a solid wall to increase its insulating power is joined to it in some places very fixed. A flexible way of joining is adopted (Fig. 5 a). As a result of such attachment, acoustic bridges are formed and over them part of the sound energy is transferred from the solid wall to the light coating. Therefore, the insulating power of this structure is much lower than it would be an ideally accomplished double barrier. However, this added light barrier increases the insulating power of a solid wall in the frequency range between the resonance frequency f_0 of the complex wall and the coincidence frequency fc of the light lining. For this case, the frequency of the onset of action of a rigid connection, that is, the start of operation of the acoustic bridge f_B is characteristic too.



a) b)

Fig. 5. a) Solid wall with flexibley joined light lining b)Diagram of insulating power in a function of frequency

The frequency of resonance is defined according to the same formula as for a double barrier:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1{,}8\cdot\rho\cdot c^2}{b}\left(\frac{1}{m_{s1}}+\frac{1}{m_{s2}}\right)} = 80{,}23\sqrt{\frac{m_{s1}+m_{s2}}{b\cdot m_{s1}\cdot m_{s2}}}\;[Hz] \quad (3)$$

where m_{s1} and m_{s2} are surface masses of solid wall and light lining, respectively, and b distance between lining and wall. In these cases the surface mass of solid wall is significantly higher than the mass of the lining ($m_{s1} >> m_{s2}$) so practically a resonance frequency f_0 depends only on a surface mass of lining m_{s2} and its distance from the wall - b.

The frequency of onset of action of acoustic bridges for flexible connection is given by (4)

$$f_{BL} = f_0\sqrt{\frac{e\cdot f_c}{c}}\;[Hz] \quad (4)$$

In the formula (4): c – speed of sound, f_c – coincidence frequency of lining, e – distance between joining spots.

Increasing of insulating power within the frequency range from f_b to $f_{c/2}$ is in the case of flexible joining:

$$\Delta L_{BD} \approx 20\log\left(f_c\cdot e\right) - 45\,[dB] \quad (5)$$

The frequency of coincidence is calculated according to the formula:

$$f_c = \frac{c}{2\cdot\pi\cdot b} \approx \frac{55}{b}\;[dB] \quad (6)$$

The surface mass of conveyor wall and light lining is calculated according to the formula (7).

$$m_s = d \cdot m_t \left[kg/m^2 \right] \qquad (7)$$

Where is: d – barrier thickness in cm; m_t – surface mass of materials $\left[kg/m^2, cm \right]$ (Table value).

Improvement of insulating power of the light lining is shown in the Fig, (5 b)) by the ABDE curve. On the frequency of coincidences insulating power is weakening, depending on the muffling value of light lining, and above this frequency is growing by the speed of 15 dB/okt.

3.1 Technical Solution of light lining of wood chip conveyor

In order to enable an efficient design of protection system against conveyor noise, it is started from the theoretical model of light acoustic lining. Understanding the possibilities of technical implementation, a final solution of chip conveyors noise protection is adopted in the factory of plywood.

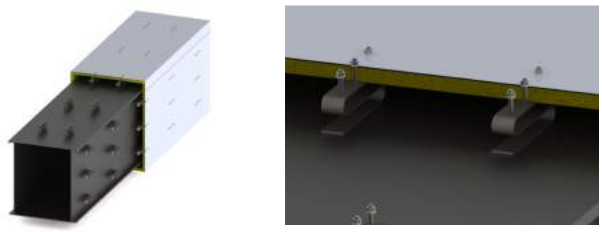


Fig. 6. Technical solution of conveyor light lining

First, the supporting structure of the lining consisting of flexible spacers in the form of the letter S are made then welded to the entire body of the conveyor. Before bending the spacers, the holes are drilled and bolts are welded for joining with lining. Lining consists of an insulating material (Azmafon A) and thin aluminum sheet protecting the absorbing material against weathering.

Conveyor body is made of steel plate 5 mm thick. The absorbing coating layer has a thickness of 20 mm, and the aluminum sheet is 0.7 mm thick. Distance between spacers is 500 mm. Surface mass of steel m_{s1} is 76,84 kg/m^2, and surface mass of aluminum 27,6 kg/m^2. Distance between the conveyor body and aluminum sheet is b = 70 mm.

Based on the adopted constructive dimensions and the formula 3÷7, the characteristic frequency of light lining put on the solid wall (body of the conveyor) can be calculated, as shown in Figure 5 b).

Values of the characteristic frequencies of light lining and the expected effect of reducing the level of noise are:

$f_o \approx 25\,Hz$, $f_c \approx 786\,Hz$, $f_{BL} \approx 27\,Hz$, $\Delta f_{BP} \approx 6.9\,dB$.

4. EFFECTS OF NOISE PROTECTION SOLUTION

For evaluation of performed technical solution, measurements of the noise level were made after making of conveyor light lining.

Measurements were performed at the same measuring points on which noise measurement had already been done before the sound protection.

Equivalent noise level around conveyor, on the average, is decreased by 8 dB (A). None of the measuring point is determined by the impulse character of noise.

Equivalent noise level at the measuring point in a residential area is reduced by 2.5 dB (A).

Table 4Noise levels in a settlement, after sound protection

Pos.	L_{Aeq} [dB(A)]	L_{AImax} [dB(A)]	L_{AFmax} [dB(A)]	ΔL_i [dB(A)]
MT_1	62.2	68.9	67.7	1.2

Another important result is the loss of the pulse at the measuring point in a residential area so that the referent noise level is reduced by another 5 dB (A). A total effect in protecting the conveyor is a reduction of noise level at the measuring point of 7.5 dB (A).

5. CONCLUSION

An expected effect of reducing the noise level in a residential area is achieved by the noise protection measures. Actual noise reduction enabled plywood factory work during the reference day time. Technical solution for the noise protection of the chain conveyor may be used to protect other conveyors in the factory, as well as in other similar cases.

Acknowledgement: The paper is a part of the research done within the project TR37020. The authors would like to thank to the Ministry of Education and Science of the Republic of Serbia for supporting this research.

REFERENCES

[1] Radičević B., Petrović Z., Todosijević S., Petrović Zv., „Design of noise protection of industrial plants – case study of a plywood factory “, 23rd National Conference & 4th International Conference “Noise and vibration”, Niš, 2012, pages 71-75

[2] Petrović, Z., Radičević, B.,Šoškić Z., Bjelić, M. - Zaštita od buke industrijski postrojenja - Buka i vibracije, XXI konferencija sa međunarodnim učešćem, Tara 2008

[3] Petrović Z., Radičević B., Bjelić M., „Designing main fan noise protection system in mine “Jarando“ – Baljevac“, Podzemni radovi, br.15, (133-138), Rudarsko geološki fakultet, Beograd, 2006

[4] Drinčić D., Pravica P., ”*Akustika – zbirka rešenih zadataka”*, Visoka škola elektrotehnike i računarstva strukovnih studija, Beograd, 2011

[5] Standard: SRPS ISO 1996-1: 2010

[6] Standard: SRPS ISO 1996-2: 2010

[7] Uredba o indikatorima buke, graničnim vrednostima, metodama za ocenjivanje indikatora buke, uznemiravanja i štetnih efekata buke u životnoj sredini ("Sl. glasnik RS" br. 75/2010)

35th INTERNATIONAL CONFERENCE
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NOISE PROTECTION IN MANUFACTURING PLANTS

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Abstract: *The production facility is limited and confined space whose dimensions of significantly higher compared to the wavelength of the spectral components of the emitted sound pressure level (sound power) noise sources that are widespread in the area. During operation of sound sources in the plant comes to complex phenomena in the sound field (reflection, interference, diffraction, attenuation) that are more or less successfully explain existing theories. Acoustics manufacturing plants is of great importance in solving noise protection.*
Noise sources can be any machines and mechanisms, the flow of gases and liquids in pipelines, devices, and in the atmosphere, variable electromagnetic fields in electric devices, speech, music etc. The protection system design methods can be divided into two groups: active methods and passive methods. Active methods involve the intervention of the noise source in decreasing while passive methods related to specific interventions along the main routes of transmission of the noise source to the receiving stations. This paper analyzes the noise sources, their characteristics, the physical phenomena that occur and ways to reduce noise and increase the comfort and safety of the workplace.

Key words*: Noise sources, workplace, noise protection*

1. INTRODUCTION

The rapid development of modern society, since the beginning of the twentieth century, the construction of new roads, industrialization, have led to a new environmental problem – *noise.*
The European Noise Directive 2003/10/EC defines the minimum health and safety requirements regarding the exposure of workers to the risks arising from noise. Under this Directive the employer is required to investigate whether “workers are or are likely to be exposed to risks from noise as a result of their work” [1].
Noise level has been increasing in human living and working environment. This is supported by the following facts:

- Noise is the third environment polluter (after air and water pollution),
- Over 40% of the adult population feel some kind of discomfort caused by the influence of noise and vibration
- In industry and at workplace, noise level often exceeds acceptable level.
- Product development and productivity growth lead to increase of the installed power capacity, speed increasing, automation of the operations and processes.
- As consequence, vibrations are increased leading to enhancement of the overall noise levels.

Table 1. Maximum measured noise level in industrial plants

Industrial plants	**The noise level**
Shipbuilding	135 db
Metal industry	130 db
Metallurgy-Forge	130 db
Metallurgy of non-ferrous metals	122 db
Electrical Industry	122 db
Paper industry	122 db
Textile industry	121 db
Printing Industry	120 db
Wood industry	120 db
Leather industry, rubber and customs	120 db
Food industry	115 db
Chemical industry	115 db
Oil processing	112 db
Energy production and distribution	111 db

2. THE DIVISION OF NOISE

The basic classificaton of nose is: noise in worplace and environmental noise.
a) Noise in the workplace include:

- Noise generated by the device on which the employee works directly
- Noise from other devices
- Noise from the so-called. non-production sources - eg. ventilation units and air and sounds from the environment (eg. traffic)

b) Environmental noise include:

- Traffic noise
- Noise is heard from industry
- Street noise of various origins (cafes, playgrounds, etc.).
- Noise in households (from electrical and electronic devices, from neighboring apartments, etc.).

In addition to direct harmful effects on human health, noise indirectly affects the results of work, and all the more visible and more significant if it is stronger. Decline in labor productivity, an increase in the number of errors and injuries at work is evident in all sectors. In industrial plants, where this noise, change of machines or changes in the technological process, noted as significant improvements in product quality and productivity achieved.

There are very different types of noise. Most noise is classified by duration and spectrum. For partition its duration is taken as the criterion time form of the noise level. Thus we have:

- constant noise level when the source radiates sound always the same strength
- varying levels of noise, which is characteristic of traffic
- impact noise, which occurs in a crash two solid bodies and the beats or irregular.

The degree of interference depends very much on how to change the time format of the noise level. At least interferes with noise whose level is constant in time, while varying levels of noise and impact noise have a greater adverse effect on humans.

Therefore, the measurement and valorization of harmfulness introduced specific procedures to the impact of noise can be properly assessed [2].

Fig.1. The correlation of the phenomenon of noise and environment

Figure 1 shows the correlation of the phenomenon of noise and vibration and the environment in which they are manifested.

Vibrations caused by any of the above causes, through rigid or flexible connections between certain mechanisms or assemblies, shall be transferred to the entire machine or plant, generating a noise level emitted to the workspace to the workplaces.

The overall noise levels in the workplace greatly affect closed industrial space, starting with the construction of the facility and its size, the choice of materials for the interior of the facility. Solutions in construction of buildings (walls, roofs, openings for volume lighting and ventilation based machines) have the greatest impact on the transmission of noise and vibration in the open space outside the industrial plant, where the noise is still spreading in the environment.

Research shows that the criteria of efficiency and costs of noise protection can be decisive in the choice of technical equipment and the design of the technological process. Better quality and more expensive equipment with lower levels of noise and vibration, which is due to the quality characteristics expensive, often resulting in lower total cost of investment. By choosing less expensive technological equipment necessary to design and carry out a set of protections.

Mechanical oscillations occur due to:

- collision of machine elements,
- their friction,
- excitation forces,
- magnetic fields,
- changes in fluid pressure and
- other factors.

Industrial space (the construction of the facility, its size, the choice of materials) affects on overall noise level.

The main causes of noise (Fig. 2) can be categorized into four groups: structural parameters, production technology, workflow and maintenance technologies.

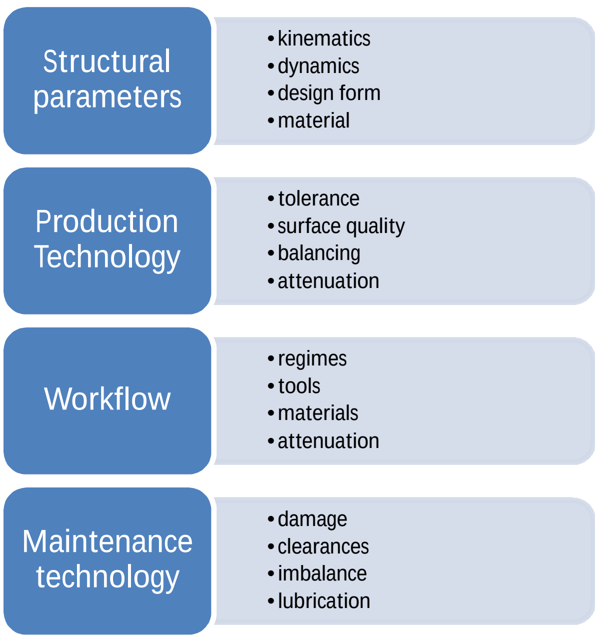

Fig.2. The main causes of vibration and noise sources

These four groups represent research and development areas in which it is necessary to actively influence the agents noise and vibration to equipment was reduced to that value which corresponds to the level of development of technology.

Machines and mechanical equipment used in the industry are a group of stationary noise sources that generate noise in the workplace but also can generate significant levels of noise in the factory halls and environment space. Generated noise is mainly dependent on the machine power [3].

Mechanical equipment includes machinery used in industrial applications such as motors, compressors, boilers, pumps, transformers, generators, cooling towers and ventilation equipment. The main mechanisms of noise generation can be divided into three groups:

- mechanical (gear transmission, bearings, belt drive, fans and other rotating components)
- aerodynamic (fluid flow-air or some liquid) and
- magnetic (periodic force between the stator and rotor).

Is necessary a constant active attitude towards the problem in the product lifecycle, starting from the origin of the idea of the research and development stage of structural parametars, through development production technology parts and components, proper operation, to maintenance of appropriate technology products and systems.

There are two basic types of the vibration and noise effects:

- Effects on technological equipment and
- Medical effects (biological effects on human and living organisms) Fig. 3.

These two groups cause large number of adverse events and changes that are located in the general areas: human-machine-workspace-environment.

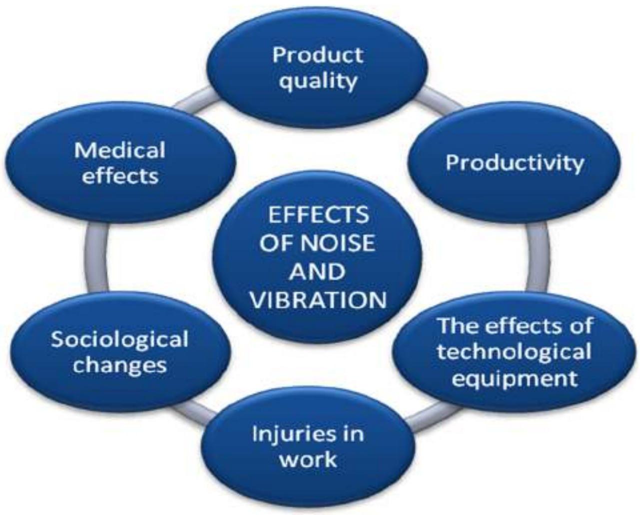

Fig.3. The effects of noise and vibration

3. ACOUSTICS OF INDUSTRIAL PLANTS

In industrial plants is a major source of noise and the jobs assigned to the requirements of the technological processes in the whole space. In relation to the demands of classical architectural acoustics, acoustics main tasks of industrial plants can be defined with the main objectives:

- Noise in the workplace must not interfere with the performance of certain types of jobs, or to be ahead of the prescribed limit values and total levels of spectra, and
- Existing optimal balance between direct and reflected sound to total (minimal) costs necessary to meet the objectives of the previous and the expected positive effects psychoacustic.

Obviously, the only method of acoustics can not meet the requirements of protection, but can significantly contribute to their implementation in other passive and active methods of noise protection in industrial facilities. This requires, in addition to knowledge of the acoustics of the rooms, good knowledge of technology and technological equipment, construction machinery components and assemblies, methods of measurement and analysis of vibration noise, maintenance methods, as well as special materials and equipment for protection against noise and vibration. For this reason it is necessary to supplement and specialist knowledge in this field gained in mechanical engineering.

Increased noise levels at workplaces in industrial plants occurs for two reasons:

- due to a distribution of a large number of noise sources and plant
- due to the negative effects of indoor space.

Types and selection of process equipment is connected to the design of manufacturing technology. More favorable distribution can be influenced by matching requires noise protection with the demands of technology and equipment selection, given the acoustics.

The second reason was never fully be eliminated regardless of the acoustic processing plant, which closed space uizvesnoj much closer to the open air [3].

4. DESIGN METHODS FOR NOISE PROTECTION

Design methods of protection from vibration and noise are developed based on the study of the process of their generation and transmission. Transmission of noise and vibration by air and the conductive space.

The methods of designing the protection system can be divided into two main groups:

- Active methods, which include interventions at the source of noise and vibrations in decreasing and
- Passive methods, related to the particular requirements along the main routes of transmission of the noise source to the receiving stations.

5. ROUTES OF TRANSMISSION OF NOISE AND VIBRATION

The main objective in the design of the protection system is to broadcast the level of vibration and noise of appropriate technical solutions lead to limits on specific workplace or part of the plant. To such devices need every source analyzed from this perspective.

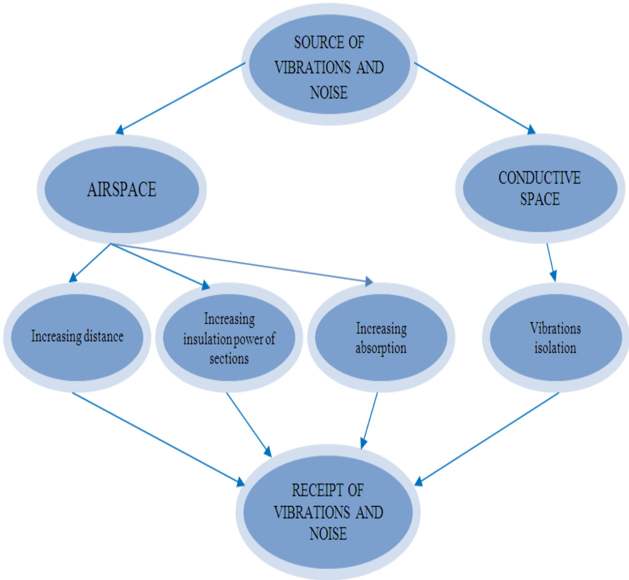

Fig. 4. Routes of transmission and methods protection vibration and noise

Figure 4 shows the two main routes of transmission vibration and noise from the source to the observed point in space. These routes of transmission point to both primary care practices (reduce) noise and vibration.

Noise transmission by air is achieved in an open or closed space. During the translation of the main open space protection procedures are increasing the distance between the source of admission ii, and also increase the insulation of partition in active and passive safety. In enclosed spaces, such as industrial plants, a very important process to protect and increase the absorption of enclosed space [4].

6. CONCLUSION

Under the European Directive 2003/10/EC on noise at work employers are required to investigate whether “workers are or are likely to be exposed to risks from noise as a result of their work” [5].

Solve the problems of working and the environment from noise and vibration protection system design, implementation and verification of projects can be successfully implemented if the following conditions are met:

- Won the necessary knowledge and methods of calculation for vibration and noise, which requires knowledge of the physics of the process of their generation and transmission, as well as the method of designing the protection system.
- Achieved methods of determining the characteristics of the source of noise and vibration in the laboratory and in real terms, and won verification methods designed and executed security solution;
- Developed the necessary materials and equipment renowned mechanical/acoustic characteristics for the execution of projects, including their production and availability in the market under known conditions of purchase and delivery;
- Establishment of specialized firms for execution of projects;
- Adopted the legal and technical regulations, and established the necessary inspection authorities.

The main objective in the design of production systems should be to reduce the noise level. Measures for noise protection must be provided for in the works of major projects in the planning of factories and office schedule. Noisiest facilities to deploy in separate complexes. The conclusion is that noise should be reduced by all available means, wherever and however possible.

Acknowledgement: The authors would like to express their gratitude to the Ministry of Education and Science of the Republic of Serbia for their support to this research through the project TR37020.

REFERENCES

[1] Directive 2003/10/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise)

[2] Uzunović, R., „*Noise and Vibration control”*, LOLA Institut, Beograd,1997

[3] Praščević M., „Environmental noise“, Univerzitet u Nišu, Fakultet zaštite na radu 2005

[4] Radičević B., *Design of noise protection of industrial plants-case study of a plywood factory*, 23rd National Conference and 4th International Conference NOISE AND VIBRATION, Niš 2012, pp 71-75

[5] Jürgen H. Maue, *Application of measurement uncertainties for comparing measuring results with the action values of European Directive 2003/10/EC*, AIA-DAGA 2013, Conference on Acoustic, Merano

35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013, Kraljevo, Serbia
University of Kragujevac,
Faculty of Mechanical and Civil Engineering Kraljevo

NOISE MAPPING IN AREA OF AN URBAN OVERPASS

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Abstract: *The paper presents the concept of noise mapping in an urban area around major overpass in city of Kraljevo. The overpass is used by road traffic and is built over a railroad track. The height of the overpass is variable, with one end in the foot, and with the other end at the top of a hill. On one side of the overpass is the hill, which is covered by vegetation. On the other side of the overpass is residential area with houses and multi-floor buildings. The dominant source of the noise is the road traffic on the overpass, and the railroad traffic represents secondary source of the noise. Uneven terrain and presence of complex concrete structure of the overpass represent a challenge for the calculation of the noise field. The concept of calculation is performed according ISO 9613:2, using both commercial and proprietary software tools.*

Key words*: Environment protection, Noise protection, Noise mapping*

1. INTRODUCTION

In June 2002, the European Directive on the Assessment and Management of Environmental Noise or Environmental Noise Directive 2002/49/EC [1], was accepted and came into force. The document represents the legal basis for implementation of strategy for combating noise in European Union. Under this directive, as a first step in the strategy, member states were obliged to produce noise maps of the major roads, railways, airports and industrial activity sites as well as of large agglomerations by 30th of June, 2007. Noise maps are intended to describe the environmental noise levels caused by the previously mentioned sources in terms of the harmonized noise indicators L_{den} and L_{night}. From these noise levels, other indicators such as the total number of seriously annoyed residents may be derived. This information was to be submitted to the European Commission and made public. The next step of the strategy is drafting of Noise Action Plans, sets of measures for managing the noise issues and effects, including the reduction of noise if necessary. The Noise Action Plans are to be based on the noise−mapping results, drawn by competent authorities, with consultation of public on matters of priorities. One of important aspects of the strategy is harmonization of European noise legislation. The technical basis for the strategy is established through FP5 project "Harmonoise" [2], FP6 project "Imagine" [3], and FP7 project "Silence" [4].

While not a member of European Union, Republic of Serbia followed the developments of noise management strategy defined by the European Noise Directive. Government of Republic of Serbia passed in 2009 Law on environment noise protection [5] that addresses subjects in charge for environment noise protection, means and conditions for environment noise protection, measurement of environmental noise, access to information about noise, surveillance and other topics of relevance for environment and health protection. Further directions are defined by respective regulations, guidelines and standards that are relevant to environment noise protection and are in line with the European Noise Directive. The regulations determine the principles of assessment of noise impact, noise mapping and drawing of Noise Action Plans [6][7][8]. Overview of the valid regulations and standards relevant for environment noise protection is given in [9].

Majority of the measures prescribed by the regulations is still not supported by existence of a relevant accredited institutions and research groups, noise protection means available at market and adequate software support. The project "Development of methodologies and means for noise protection of urban environment" (acronym "UrbaNoise") [10] is a project financed by Serbian Ministry of Education and Science, aimed to facilitate solution of the present problems and deficiencies. The project is realized by three major Serbian state universities, University of Kragujevac, represented by Faculty of Mechanical and Civil Engineering in Kraljevo, University of Niš, represented by Faculty of Occupational Safety and University of Belgrade, represented by the Faculty of Traffic Engineering. The project goals are:

- development of national noise assessment methodologies harmonized with EU;
- development of national database of noise sources;
- development of software tools for local noise mappings;
- construction of laboratory facilities for testing of acoustic materials;
- design of modular noise barriers from waste materials.

This paper presents current phase in the development of software tool for drawing of local noise maps. The concept of the software is developed based on experiences in work with similar noise mapping tools and tested on the problems from practice of noise protection. In this paper is described problem of the drawing of noise map in vicinity of an urban overpass in city of Kraljevo. The noise mapping was intended to be performed based on international standard ISO-9613:2 [11], and it turned out that the mapping represents a demanding task from the point of view of the standard, because the surroundings of the overpass contains all features that are considered within the standard.

The structure of the paper is the following: after this introductory paper follows the second chapter, where the object of the study, the surroundings of the overpass in city of Kraljevo, is described with the sufficient details to show the complexity of the task from the point of view of the standard ISO-9613:2. In the third chapter are presented measurements of the noise level at selected measurement points in vicinity of the overpass and the results of calculation of noise levels at the same points by application of various software packages. In the fourth chapter are presented analyses of the obtained results. Finally, the last chapter summarizes conclusions drawn from the described work and directions for the future actions.

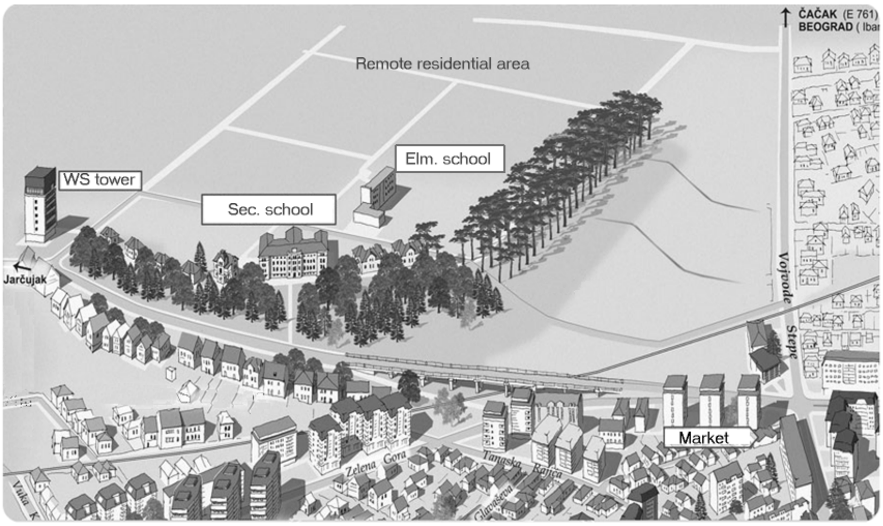

Figure 1: A drawing of the surroundings of the overpass studied in this paper

2. OBJECT OF THE STUDY

Kraljevo is a city in Central Serbia that represents an important crossing between North-South and West-East national roads and railroads. During 1980s, close to the large residential area near central part of the city was constructed major overpass that enabled passage of the road transport above the railroad line. In the Figure 1 is presented the overpass and elements of its surroundings. The overpass is pictured at the center of the figure, and it is shown that its left end is at a middle of a hill, while the right end is at the foot of the hill. The length of the overpass is 410 m, and the vertical difference between it ends is 8.33 m. The slope of the road varies from 1.5% to 5.2%. In the lower part of the figure is pictured a residential zone, with row of houses built along the higher part of the road that lead to the overpass. Along the lower part of the road is row of multistorey buildings. The rows of houses and buildings act as artificial barrier to noise propagation. In the higher part of the figure is shown hill above the road that is covered by vegetation that acts as a natural barrier to noise propagation. The foliage and the slope of the hill are providing a certain noise protection to houses and schools at the top of the hill and to remote residential area. Almost the whole surroundings is used as residential area and there are very few objects of other types, as it is the case with the elementary school and secondary school at the hill, water supply tower close to the upper part of the road, and a market close to the lower part of the road.

The elimination of the previous crossing between the railroad and the road made the overpass an attractive option for the truck, bus and car transport that is passing through the city. The increased traffic load led to significant increase of noise emission, and the nearby densely populated residential area soon became acoustically endangered zone. The main source of the noise was the traffic on the overpass, but important noise sources are also a wide street and the railroad line, both passing below the overpass. “Local ecology action movement” - municipal agency that deals with environment protection issues - is developing plans for noise protection of the surrounding of the overpass by a barrier constructed along the overpass. According to the practice prescribed by the law, as mentioned in the introduction, the first step in noise protection of a certain zone is drawing of the noise map of the endangered area. The concept of the noise mapping was to perform a series of measurements of noise levels, and then to draw noise maps by noise field calculations, using the various available commercial software packages that will be compared to the results of noise field measurements, in order to determine the best available noise map.

3. RESULTS

The experimental measurements were performed at ten measurement points. Noise level was measured using phonometer Bruel & Kjaer 2238 Mediator that has accuracy 0.1 dB. The measurement points were selected as shown in the Figure 2, with the aim to represent different configurations of surrounding objects around measurements points. The measured quantity was the A-pondered equivalent continuous sound level L_{eqA}, as defined by ISO-1996:1 [12]. Measurements were performed during the morning, day and evening. The results of the measurements are presented in the Table 1. With the aim to characterize the road as a noise source were performed measurements of noise level in points along the road, with distance between the two measurement points equal to 6 meters. Simultaneously with the noise measurements along the road was performed traffic counting, so the frequencies of light and heavy vehicles were determined in both directions.

In general, noise field calculations may be performed by the exact (so-called reference) and the approximate (so-called engineering) models. The exact methods are based on solving of differential equations of wave propagation, require considerable computer resources and time, and are suitable for accurate calculations of sound fields in acoustics, as it is the case with halls and theatres. The engineering models are much faster in implementation, but are considerably less accurate. They are suitable for noise mapping because noise maps essentially represent an estimation of the influence of the estimated noise sources in some longer period.

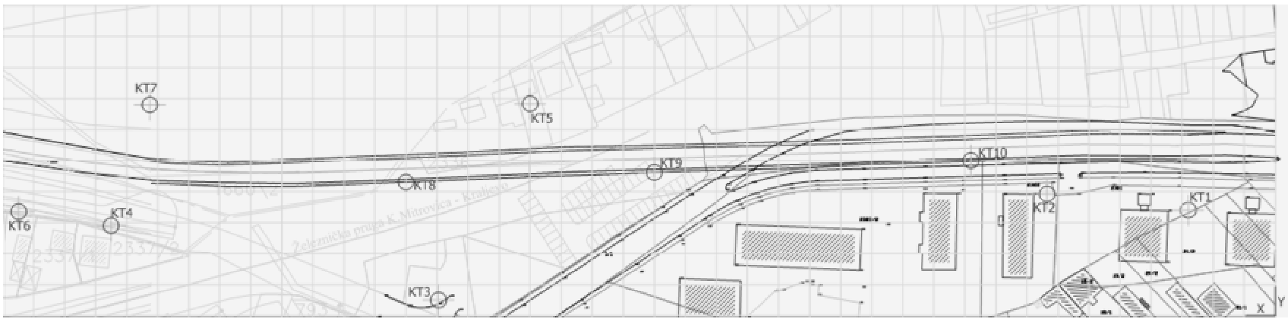

Figure 2: Positioning of the measurement points, marked by circles and numbered KT1-KT10

International standard ISO-9613:2 is adopted for the purposes of calculation of outdoor noise fields. The standard enables calculation of average downwind sound pressure level L_{AT}(DW) and long-time average sound pressure level L_{AT}(LT) at a receiver that is exposed to noise from multiple point-like sound emitters on uneven ground with varying hardness, in environment that consists of housings, industrial sites, foliage and noise-protection barriers. While the standard cannot describe many practical cases, and despite the presence of improved noise emission and propagation models, it remains the only internationally adopted standard.

At the market of commercial software are present several software packages for noise mapping, ranging from integrated software packages for strategic noise mapping to software for low-scale noise-field calculations intended as support tools for design of noise protection systems. The software packages differ in the models of sound propagation they use, ability to present various objects in noise maps and in the extent of the area that can be presented and processed.

Table 1: Results of the experimental measurements of the noise level at measurement points [dBA]

Measurement point	KT1	KT2	KT3	KT4	KT5	KT6	KT7	KT8	KT9	KT10
Morning	69.2	62.5	60.4	67.0	61.2	68.4	69.2	74.8	74.8	73.8
Day	69.3	65.4	60.8	66.2	59.2	67.8	69.0	76.5	72.6	74.5
Evening	63.7	58.9	55.3	60.0	55.8	63.3	61.7	70.8	69.5	65.3

As explained in the introduction, within the framework of the project “UrbaNoise” research team at the Faculty of Mechanical and Civil Engineering Kraljevo has been developing a proprietary methodology for noise mapping. Besides, for the calculations of the noise fields in surroundings of the overpass were used two evaluation versions of the software packages for noise mapping, SPM9613 [13] and OTL-Terrain [14].

Using the software SPM9613, the terrain in vicinity of the overpass was modeled as a mesh with 11x11 nodes and dimensions 410x100 meters. Each point of the terrain was described by its elevation and hardness of the ground. The noise of the traffic on the overpass was modelled by 42 point-like sources with noise power level of 76 dB over all third-octaves, uniformly distributed over the middle of the road at the overpass, with distance 10 meters. The park between the road and the secondary school was modelled as foliage. The buildings within the map were modelled as six horizontal barriers. However, the horizontal surface of the overpass was not modelled as a barrier to noise propagation, because the software package SPM9613 does not provide possibility for the modelling of horizontal surfaces. For that reason, the overpass was modelled as a hard terrain, without the free space below it. The results of the calculations are presented in the Table 2.

The software package OTL-Terrain has advanced capabilities for calculation of noise maps, including: Hadden & Pierce Diffraction 3D model implemented with finite impedances faces using Salomons semi-analytical method including ground effects; calculation of multiple barrier diffraction in a recursive way at any diffraction order; in-house sound path detection methods; incorporating of ground effect using the One Parameter Theory of Chessell based on Delany and Bazley; inclusion of reflections from finite surfaces based on Clay–Medwin's work to include Fresnel zones contribution at any order level; atmospheric absorption based on ISO-9613:1 and inclusion of turbulence coherence factor based on WP3 of the project "Harmonoise". Besides, the software package also enables much simpler calculation of the noise fields according to the ISO-9613:2 standard, and this was exactly the option that was used for calculation of the noise field in the vicinity of the overpass, for the sake of comparison with the results of other software packages.

Table 2: Results of the calculations of the noise level at measurement points [dBA]

Measurement point	KT1	KT2	KT3	KT4	KT5	KT6	KT7	KT8	KT9	KT10
Experiment	70.7	65.7	62.1	68.0	62.0	69.7	70.4	77.3	75.5	75.3
SPM 9613	68.3	70.4	74.9	68.7	69.3	67.8	67.3	66.1	65.9	76.2
OTL Terrain	67.0	69.2	73.6	65.5	67.0	65.6	67.0	73.3	74.9	76.7
BelCho	72.0	74.1	64.3	68.8	69.2	70.2	70.0	73.0	72.9	75.9

The basis for the model was the imported 2D image from the Google Earth web-based application, but the 3D modelling of the terrain was not available. For that sake, the hill above the overpass was modelled as Δ-barrier, and the overpass was modelled as a set of interconnected I-barriers. The buildings along the road were modelled as 18 structures with four walls and a flat roof. However, the remaining terrain was modelled as a flat ground with the appropriate acoustic hardness expressed by airflow resistivity. The results of the calculations performed using OTL-Terrain software are presented in the Table 2.

Besides the two trial versions of the commercial packages, noise field was also calculated by application of the software modules developed within the project "UrbaNoise". The software modules implement noise field calculations based on ISO-9613:2, with the basic objects being point-like sources, ground, foliage, housing, industrial sites and vertical barriers, but also proprietary objects like individual buildings and horizontal barriers which are suitable for modelling of bridges, platforms and various types of ceilings. The software has three main components: geometric library, ISO-9613 library and model implementation library. The geometric library implements geometric objects and geometric operations, the ISO-9613 library implements spectra, spectral operations and the effects of sound propagation, and the model implementation library implements the acoustic field and the objects within it, and performs calculations of noise levels in the acoustic field. The results of the calculation of the noise field by the software modules (in the development phase referred as "BelCho"), are also shown in the Table 2 for the sake of comparison.

4. ANALYSIS

The results listed in the Table 2 are shown in the Figure 3. The presented results will be considered from the point of view of predicted trends and magnitudes.

Before any other analysis, it is important to stress that noise mapping is essentially has statistical nature, and it requires acquisition of data in statistically meaningful amounts and periods. Both statistical requests are not satisfied with the experimental data provided in this paper, because they represent just a beginning of a planned systematic measurement of noise in the studied area. Therefore, the results of the provided analysis, as well as the derived conclusions, have only limited validity, and represent just directions for the future actions.

It can be observed that the results obtained by SPM9613 do not agree in trends with experimental observations in points KT5, KT6, KT7, KT8 and KT9, predicting also approximately 5 dB lower values than the other software packages for noise field calculations. Being that the distance to the overpass decreases from KT5 to KT9, the result obtained by SPM9613 raises suspicions and demands further study of the model applied with the software package.

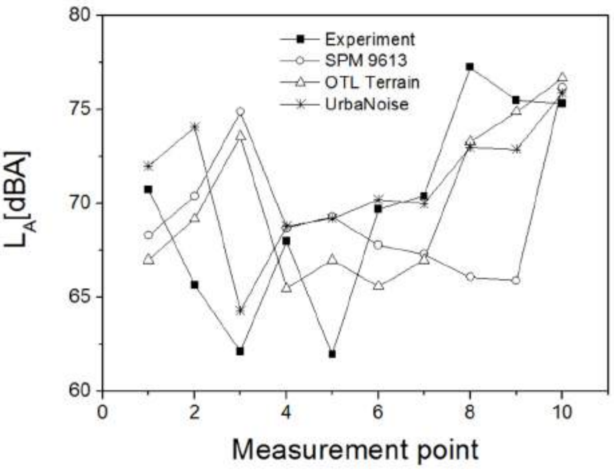

Figure 3: Graphical presentation of the experimental data and results of numerical calculations

The predictions of both SPM 9613 and OTL-Terrain disagree with the observed trend in the measurement point KT3, predicting also almost 10 dB lower values than those estimated by the experiment. The point KT3 is located between the buildings behind the first row of houses; it seems that the simple model, which includes just limited number of buildings besides the road, is not sufficient for description of the noise field at the measurement point KT3. The conclusion is further facilitated by the fact that the surrounding of the KT3 is modeled with more details in the model used with software modules developed within the project "UrbaNoise".

The most striking difference between the observed and the calculated trends is in the point 5, where all three software packages predicted higher values then in the points 4 and 6, and the experimental measurements indicated lower values. Considering that the measurement point KT5 is also between houses, the observed behaviour may be as well attributed to the insufficient description of the surroundings used for calculations.

The statistical analysis of the difference between the experimental and numerical estimations of the noise field is shown in the Table 3. It is obvious that the best agreement with experimental results show results obtained by the modules developed within the project “UrbaNoise”. However, it should be stressed again that the results do not have enough statistical reliability, especially considering that the models of the studied area that were used in calculations were not the same for the three software packages used.

Table 3: Statistical analysis of differences between the experimental and numerical estimations [dBA]

Model	Mean	Dev.	Min.	Med.	Max.
SPM9613	5.5	4.5	0.7	3.9	12.8
OTL-T	4.0	3.0	0.6	3.6	11.4
UrbaNoise	2.8	2.9	0.4	1.7	8.4

The noise map obtained by the application of the software modules developed within the project “UrbaNoise is presented at the Figure 4.

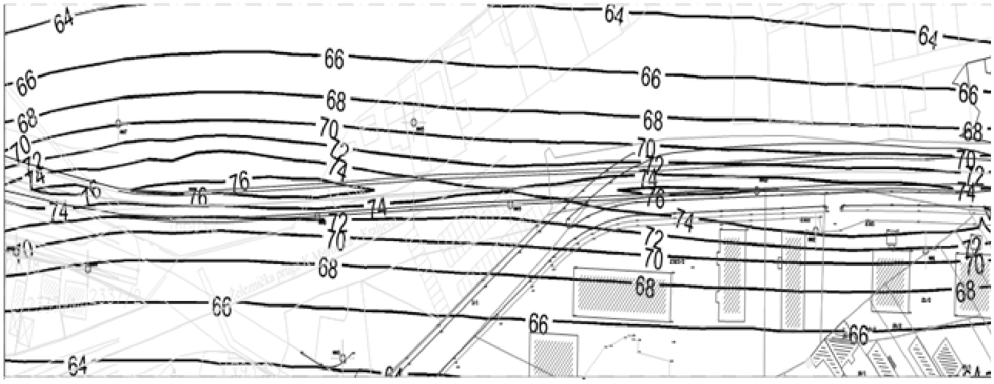

Figure 4: Noise map obtained by the application of the software modules developed within the project “UrbaNoise”

5. CONCLUSIONS

Two commercial software tools and software modules developed within the project “UrbaNoise” were used for drawing of the noise maps of the surroundings of the overpass. Each of the software tools has different set of limitations from the point of view of modelling the objects and space where the sound propagates and the noise levels are calculated. Therefore, the models of the object of the study area where not the same, but depended on the limitations of the respective software package. The software package SPM 9613 was not capable of modelling of the structure of the overpass, because it cannot describe horizontal barriers to sound propagation. The software package OTL-Terrain was not used up to its full potential because it was used in ISO-9613 mode, and the terrain was modelled by Δ-barriers, which did not allow for accurate modelling of the hilly terrain around the overpass. The software modules developed during the project “UrbaNoise” did not take into account influence of the reflections.

The obtained results were compared to the experimental measurements of noise taken at selected points near the overpass. The experimental results were taken at sufficient number of points that represent well the structure of the noise field that was studied. However, the measurements were taken during just one day and cannot be considered representative for noise level, because they do not represent variations of traffic intensity and weather conditions during seasons. Therefore, the derived conclusions may be only recommendations for future actions.

The obtained results have shown rather good agreement between the magnitudes of experimental and numerical estimations of the noise level fields, as evidenced by the Table 3. However, the trend analysis shows that the details of the model can significantly influence the obtained results.

The results suggest that the exact shape of the terrain is not of crucial importance for good agreement between experimental and numerical estimations of the noise level, because rough modeling of the terrain by Δ-barriers in OTL-Terrain model does not seem to have large influence on the results. On the other hand, inability to represent the overpass as a structure with openings seemed to have negative impact on ability of SPM 9613 model to comply with results of other models and experimental results.

Finally, all the models showed large discrepancy in comparison to the experimental results at the measurements points that were between buildings and houses. Due to the importance of residential areas for noise mapping, noise control and environment protection as whole, appropriate attention has to be devoted to the calculation of noise fields in spaces between buildings and houses. Therefore, such areas have to be described with as much details as possible, and further attention should be devoted to development of models of sound propagation in limited open space.

Acknowledgements: The authors from Serbia wish to express their gratitude to Ministry for education, science and technology of Republic of Serbia for support through research grant TR37020.

REFERENCES

[1] "Directive 2002/49/EC of the European Parliament and the Council of June 2002", Official Journal of the European Communities, 2002.
[2] http://cordis.europa.eu/fetch?ACTION=D&CALLER=PROJ_IST&QM_EP_RCN_A=57829
[3] http://www.imagine-project.org
[4] http://www.silence-ip.org
[5] "Law on environmental noise protection of Republic of Serbia", Official Gazette of Republic of Serbia, No. 36/2009
[6] "Regulation on noise indicators, limiting values and methods for estimation of noise indicators, annoyance and detrimental effects of noise", Official Gazette of Republic of Serbia, No. 75/2010
[7] ”Guidelines on contents and methods of strategic noise mapping and their public presentation", Official Gazette of Republic of Serbia, No. 80/2010
[8] "Guidelines on methodology for design of action plans", Official Gazette of Republic of Serbia, No. 72/2010
[9] M. Kolarević, Z. Šoškić, Z. Petrović, B. Radičević, “Noise Protection in Urban Environment-Description of a Project”, Mechanics, Transport, Communications, No. 3, p. IV-69/IV-77 (2011)
[10] http://www.mfkv.rs/urbaNoise
[11] ISO 9613-2:1996, Acoustics -- Attenuation of sound during propagation outdoors -- Part 2: General method of calculation
[12] ISO 1996-1:2003, Acoustics -- Description, measurement and assessment of environmental noise -- Part 1: Basic quantities and assessment procedures
[13] http://poweracoustics.com/Software.html
[14] http://www.otlterrain.com

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THE METHODS FORANALYSIS AND SYNTHESISOF CONTROLLED TIME DELAY SYSTEM WITH REQUIRED DAMPING FACTOR

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Abstract:*D-decomposition method in the area of relative stability, developed from Loo [7] in order to separate constant time settling area in parametric space, ensures the system have predefined settling time [4]. This paper develops the methods for synthesis and analysis of controlled-loop system with proportional regulator with pre-defined damping factor. Here we presents and investigates the further expansion of last obtained results. Now it would be possible to separate the region in three-dimensional space (frequency ω (Hz), gain K=1/α and time delay constant τ), so that adjustable parameters guarantee damping factor ξ of controlled system will have a priori defined value. Useful of this researches is that checking of obtained results can be made with MATLAB software package and the simulation of dynamic behavior will be done with this package .The verification of the system model could be done with this method in order the system will have as much as possible accuracy of working.*

Key words*: Time Delay System, Relative Stability, Parametric Plane, Damping Factor*

1. INTRODUCTION

The method for extracting region in parameter plane, which enables closed-loop system will have pre-defined damping factor was also particularly developed and explained in [1], [2] and this paper will continue extend last mentioned results and their application.

The basis of mathematical equations and rules for shading parametric curves remain the same as in the case of system without delay. We will discuss the case of closed-loop system with a single delay, when the adjustable parameters are non-linearly related to polynomial coefficients of characteristic equation [8].

$$W_{ok} = \frac{N(s)}{\alpha D(s)} e^{-\tau s} \tag{1}$$

so that characteristic equation has the following form:

$$f\left(s, e^{-\tau s}\right) = \propto D(s) + N(s) e^{-\tau s} = 0 \tag{2}$$

where $K = 1/\alpha$ is proportional regulator gain, where α is a regulator parameter linearly related to polynomial coefficients of characteristic polynomial of time delay system and adjustable time for transport delay is realized by the moving velocity of the belt.

2. EXTRACTION THE AREA OF PRE-DEFINED DAMPING FACTOR

The system will possess an appropriate damping factor only if the all roots of characteristic equation are within this contour shown on Fig. 1.

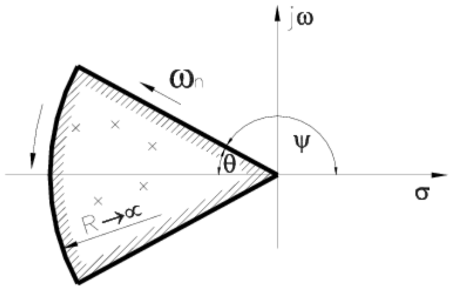

Fig. 1. The method is transforming this contour from complex plane to parametric plane τ-α

2.1. Decomposition curves

For ω_n-undamped frequency and ξ – damping factor, complex variable s has the form:

$$s = \omega_n e^{j\theta} = -\omega_n \xi + j\omega_n \sqrt{1-\xi^2}, \quad \xi = \cos\theta \tag{3}$$

and for T_k and U_k, which are Chebishev's polynomials, its degrees are given in the form:

$$s^k = \omega_n^k T_k(-\xi) + j\omega_n^k \sqrt{1-\xi^2} U_k(-\xi) \tag{4}$$

By substituting (4) in (2), characteristic equation will also have real and imaginary part, i.e. in polar coordinates:

$$D(\omega_n, \xi) = r_D(\omega_n, \xi) e^{j\Phi_D}; \quad N(\omega_n, \xi) = r_N(\omega_n, \xi) e^{j\Phi_N} \tag{5}$$

and then substituting (5) in (1) from (2) are followed next decomposition curves:

$$\alpha = \pm \frac{r_N(\omega_n, \xi)}{r_D(\omega_n, \xi)} e^{\tau \omega_n \xi} \tag{6}$$

$$\tau = \frac{1}{\omega_n\sqrt{1-\xi^2}}\left[\Phi_N(\omega_n,\xi) - \Phi_D(\omega_n,\xi) + 2k\pi + \frac{\pi}{2} \pm \frac{\pi}{2}\right] \quad (7)$$

$k \in Z, \omega_n \in [0,+\infty)$

Note: The upper sign of (6) correspondents to the upper sign of (7) and the lower sign of (6) correspondents to the lower sign of (7).

2.2. Curve shading

The shading of decomposed curves is determined by the sign of Jacobean (as in systems without delays). For complex s (3) characteristic equation is going to be:

$$f(\omega_n,\xi) = R_F(\omega_n,\xi,\tau,\alpha) + jI_F(\omega_n,\xi,\tau,\alpha)$$

$$R_F(\omega_n,\xi) = R_N(\omega_n,\xi) + \alpha e^{-\tau\omega_n\xi}\begin{bmatrix} R_D(\omega_n,\xi)\cdot\cos\left(\tau\omega_n\sqrt{1-\xi^2}\right) - \\ -I_D(\omega_n,\xi)\cdot\sin\left(\tau\omega_n\sqrt{1-\xi^2}\right)\end{bmatrix} \quad (8)$$

$$I_F(\omega_n,\xi) = I_N(\omega_n,\xi) + \alpha e^{-\tau\omega_n\xi}\cdot\begin{bmatrix} I_D(\omega_n,\xi)\cdot\cos\left(\tau\omega_n\sqrt{1-\xi^2}\right) + \\ +R_D(\omega_n,\xi)\cdot\sin\left(\tau\omega_n\sqrt{1-\xi^2}\right)\end{bmatrix} \quad (9)$$

Jacobean of the system as follows:

$$J = \begin{vmatrix} \frac{\partial R_F}{\partial \tau} & \frac{\partial R_F}{\partial \alpha} \\ \frac{\partial I_F}{\partial \tau} & \frac{\partial I_F}{\partial \alpha} \end{vmatrix} = \alpha\cdot\omega_n\sqrt{1-\xi^2}\cdot e^{-2\tau\omega_n\xi}\cdot r_D^2(\omega_n,\xi) \quad (10)$$

2.3. Singular lines

Singular lines, in the case of extracting area of pre-defined damping factor, is defined for boundary cases $\omega_n \to 0^+$ and $\omega_n \to +\infty$, in (2), (6) and (7):

$$\alpha = \pm\lim_{\omega_n\to 0}\frac{r_N(\omega_n,\xi)}{r_D(\omega_n,\xi)}e^{\tau\omega_n\xi} \quad (11)$$

$$\tau = \lim_{\omega_n\to 0}\frac{1}{\omega_n\sqrt{1-\xi^2}}\left[\Phi_N(\omega_n,\xi) - \Phi_D(\omega_n,\xi) + 2k\pi + \frac{\pi}{2} \pm \frac{\pi}{2}\right]$$

$$\alpha = \pm\lim_{\omega_n\to +\infty}\frac{r_N(\omega_n,\xi)}{r_D(\omega_n,\xi)}e^{\tau\omega_n\xi} \quad (12)$$

$$\tau = \lim_{\omega_n\to +\infty}\frac{1}{\omega_n\sqrt{1-\xi^2}}\left[\Phi_N(\omega_n,\xi) - \Phi_D(\omega_n,\xi) + 2k\pi + \frac{\pi}{2} \pm \frac{\pi}{2}\right]$$

$$\alpha = \pm\lim_{\omega_n\to a}\frac{r_N(\omega_n,\xi)}{r_D(\omega_n,\xi)}e^{\tau\omega_n\xi} \quad (13)$$

$$\tau = \lim_{\omega_n\to a}\frac{1}{\omega_n\sqrt{1-\xi^2}}\left[\Phi_N(\omega_n,\xi) - \Phi_D(\omega_n,\xi) + 2k\pi + \frac{\pi}{2} \pm \frac{\pi}{2}\right]$$

where a is every value of ω where (9) and (10) are not defined.

A special case boundaries of region is for $\xi = 1$ and $\omega_n \to \infty$ the curve of constant damping factor in that case becomes:

$$\alpha = \pm\lim_{\substack{\omega_n\to +\infty \\ \xi\to 1}}\frac{r_N(\omega_n,\xi)}{r_D(\omega_n,\xi)}e^{\frac{\xi}{\sqrt{1-\xi^2}}\left[\Phi_N(\omega_n,\xi)-\Phi_D(\omega_n,\xi)+(2k+1)\pi\right]} \quad (14)$$

$$\tau = \lim_{\substack{\omega_n\to +\infty \\ \xi\to 1}}\frac{1}{\omega_n\sqrt{1-\xi^2}}\left[\Phi_N(\omega_n,\xi) - \Phi_D(\omega_n,\xi) + 2k\pi + \frac{\pi}{2} \pm \frac{\pi}{2}\right]$$

The equations (14) are the singular lines in that case also. It could be emphasized that the method of shading singular lines is the same as for systems without delay. The procedure of selection area of constant damping factor is defined by the procedure of selection area of absolute stability for required automatic control system [2]. Area of pre-define damping factor is obtained from the section of area of required damping factor according to decomposition curves (6) and (7) in parametric space (α,τ,ω), according to rules of shading and area of absolute stability. Parametric plane $\alpha-\tau$ is top view of that figure.

$$S = \bigcap_{k\to 0}^{k\to +\infty} S_k \bigcap S \quad \textit{absolute stability} \quad (15)$$

3. APPLICATION THE METHOD

Application of the methods described here will be illustrated on the two examples: transport and dosing device and circulating reservoir for mixing liquids. A mathematical model is developed for control systems with proportional controller which gain is $K = 1/\alpha$ and given object (Figure 2 and Figure 7) for some nominal parameter values, with time delay in the nature of objects and pre-defined damping factor $\xi = 0.5$. The open loop transfer function of feedback system is:

$$W_{ok} = \frac{N(s)}{\alpha D(s)}e^{-\tau s} \quad (16)$$

3.1 Transport and dosing device

Pure time delay is τ , which in the case of transport and dosing device is ratio between the length of transport belt and the moving velocity of belt, as described in the system modeling [1]. This system belongs to the class of time delay system, where adjustable time of transport delay ischosen by the moving velocity of the belt.

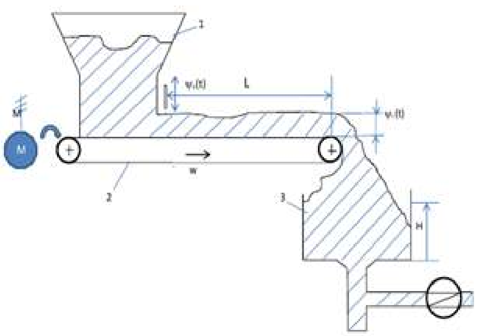

Fig.2.Functional sheme of transport and dosing device

<u>**Synthesis of controlled-loop system**</u>

We can approach the synthesis by comparing (17) and (1) according to the methods described in chapter 2. Then equations (6), (7) and (10) become:

$$\alpha = \pm \frac{0.11}{\omega_n} e^{0.5\tau\omega_n} \tag{17}$$

$$\tau = \frac{1.778}{\omega_n}\left[\frac{\pi}{3} + 2k\pi + \frac{\pi}{2} \pm \frac{\pi}{2}\right] \tag{18}$$

$$J = -\alpha\omega_n^3 \sqrt{1-\xi^2} e^{-2\tau\omega_n\xi} \tag{19}$$

Singular lines are determined from (11), (12) and (13) and (14) according to the rules of calculating boundary values, equations are:

$\tau \to \infty$ and $\alpha \to \infty$,
$\tau = 0$ and $\alpha = 0$

For the sign of α we take plus, because it is nominal sign of value for gain of proportional regulator.
Areas given from extraction curves (17), (18) and (19) by rules of shading which define that values of parameters for system with damping factor ξ = 0.5 are not exist , as it show on Fig. 3, Fig.4, Fig. 5 and Fig. 6.

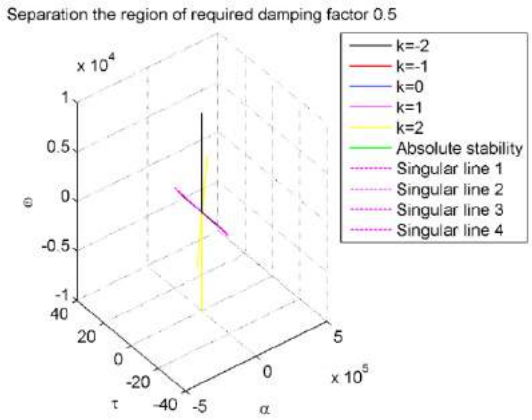

Fig. 3. Separation the region of constant damping factor ξ=0.5

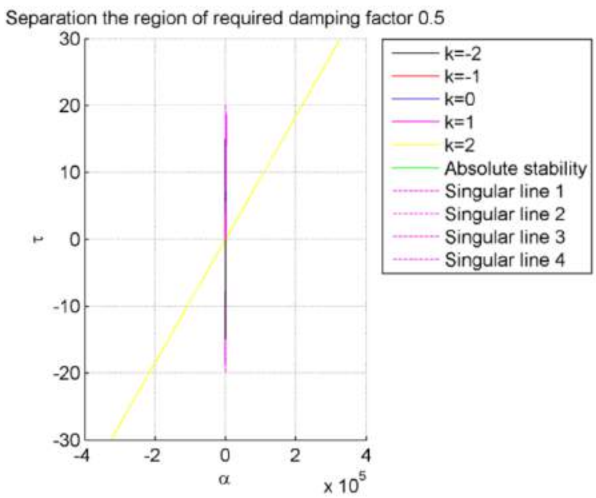

Fig. 4. Top view of Fig. 3

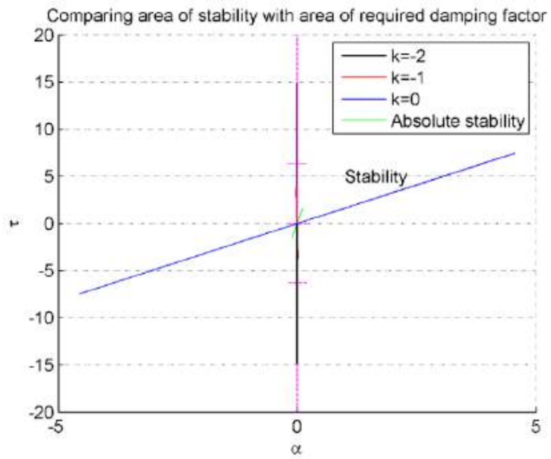

Fig. 5. Comparing with region of absolute stability

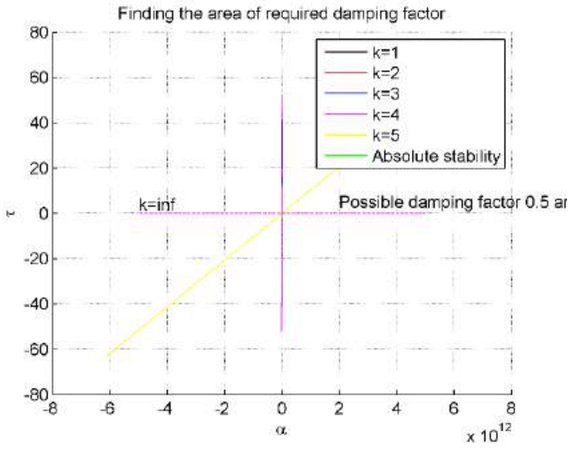

Fig. 6. Top view of Fig. 3

So for this system it is not capable to separate the region of damping factor ξ=0.5. If k→-∞ than the decomposition curve separate region which is one line α=0. If k→-∞ than the decomposition curve separate region which is one line τ=0.

3.2 Circulating reservoir for mixing liquids

$$W_{ok} = \frac{\left(2.31\cdot 10^{-4} s + 1.34\cdot 10^{-7}\right)\cdot e^{-\tau s}}{\alpha \cdot \left(s^2 + 17.3\cdot 10^{-4} s + 61.5\cdot 10^{-8}\right)}$$

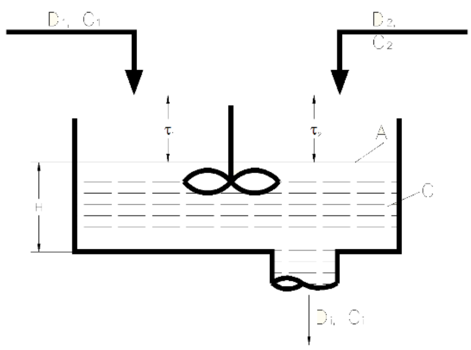

Fig. 7. Functional shame for circulating reservoir for mixing

$$J = -\alpha\omega_n\sqrt{1-\xi^2}\,e^{-2\tau\omega_n\xi}\cdot\left\{\begin{array}{l}\left(2\omega_n^2\xi^2-\omega_n^2-17{,}3\cdot10^{-4}\omega_n\xi+61{,}5\cdot10^{-8}\right)^2+\\ +(17{,}3\cdot10^{-4}\omega_n\sqrt{1-\xi^2}-\\ -2\omega_n^2\xi\sqrt{1-\xi^2})^2\end{array}\right\}$$

$$\alpha = \pm\sqrt{\frac{5{,}34\cdot10^{-8}\omega_n^2-6{,}205\cdot10^{-11}\omega_n\xi+1{,}80\cdot10^{-14}}{(2\cdot\omega_n^2\xi^2-\omega_n^2-17{,}3\cdot10^{-4}\omega_n\xi+61{,}5\cdot10^{-8})^2+ +(17{,}3\cdot10^{-4}\cdot\omega_n\sqrt{1-\xi^2}-2\cdot\omega_n^2\xi\sqrt{1-\xi^2})^2}}\,e^{\tau\omega_n\xi} \quad (21)$$

$$\tau = \frac{1}{\omega_n\sqrt{1-\xi^2}}\left[\begin{array}{l} arctg\dfrac{2{,}31\cdot10^{-4}\omega_n\sqrt{1-\xi^2}}{-2{,}31\cdot10^{-4}\omega_n\xi+1{,}34\cdot10^{-7}}-\\ -arctg\dfrac{17{,}3\cdot10^{-4}\omega_n\sqrt{1-\xi^2}-2\omega_n^2\sqrt{1-\xi^2}}{2\omega_n^2\xi^2-\omega_n^2-17{,}3\cdot10^{-4}\omega_n\sqrt{1-\xi^2}+61{,}5\cdot10^{-8}}\\ +2k\pi+\dfrac{\pi}{2}\pm\dfrac{\pi}{2}\end{array}\right]$$

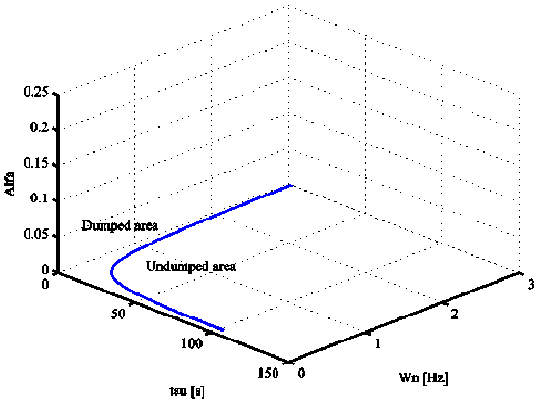

Fig. 8. Dumped area for α> 0

__Dynamic analysis of synthesized system__

From the ξ = 0.5 we highlight the point which determines the controller parameters α = 1/120 and τ = 25s, and on the basis of (20) receives the open loop transfer function of the system. Simulation of the system behavior is done with MATLAB software with step response.

Simulation result of the step response is shown on Figure 9.

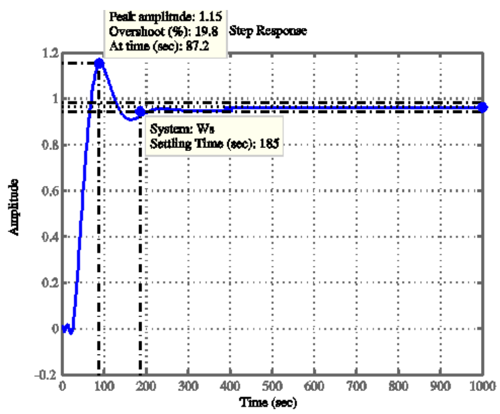

Fig. 9. Step response for feedback system (circulating reservoir for mixing liquids)

4. CONCLUSION

Software package MATLAB enables to obtain more precocious D-decomposition method applied to adoption new principle of separation the field of pre-specified damping factor in the parametric plane of α-τ [1]. The results presenting here together overview variation and dependences of parameters in three-dimensional form(α, τ, ω_n) where could be possible to choose from the given area the values of parameters which guarantee absolute and relative stability for specific class of time–delay systems [1], [2].

REFERENCES

[1] Debeljković D., Brašić V., Milinković S., Jovanović M., On relative stability of linear stationary feedback control systems with time delay, IMA Journal of Mathematical Control & Information, Oxford University Press, pp. 13-17, 1994.

[2] Brašić V., Analysis and synthesis of feedback contol systems with transport lag, Report, Department of Control Engineering, Faculty of Mechanical Engineering, Belgrade, 1994

[3] Chu Y., Trans. Am. Inst. Elec. Eng. 71 (2)

[4] Eisenberg L., Stability of linear systems with transport lag, IEEE Trans AC 11, 247, 1966.

[5] Loo S., Stability of linear stationary systems with time delay, Int. J. Control 9, 103, 1969

[6] Mikić O., Some extensions of Mitrovicev's method in analysis and synthesis of feedback control systems with time delay, Proc USAUM, Belgrade, pp. 52-67, 1982

[7] Neimark Yu., O Opredelenii Značenii Parametrov, prikatorih SAR ustoičava, Avt. Telem, 3, 190, 1949.

[8] Neimark Yu.,

[9] Šiljak D., Generalization of Mitrović's method, IEEE Trans. Ind. Appl. 314, 1964

[10]Šiljak D., Analysis and synthesis of feedback control systems in the parametic plane – Parts I, II, III, IEEE Trans. Ind. Appl. 449, 1964

[11]Šiljak D., Generalization of the parametric plane method, IEEE TransAC 11, 63, 1966

Acknowledgement: In the paper are presented some of the results from the project No. TR33026 which is partly funded be Serbian ministry of education and sciences.

35th INTERNATIONAL CONFERENCE
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Kraljevo - Kopaonik
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DETERMINATION OF THE DESCRIBING FUNCTION OF NOZZLE-FLAPPER TYPE PNEUMATIC VALVE WITH TWO PORTS

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Abstract: *In many pneumatic systems with a wider bandwidth, nozzle-flapper type valves are usually used for flow rate control. Because of their inherently nonlinear behavior and parameters variation, modelling of the servo valve is important for analysis and design purpose. The describing function was used for modelling of the mass flow rate characteristic of the servo valve. The paper presents two describing functions. One is for the fixed orifice with the subsonic flow regime, and the other is for the nozzle with the sonic flow regime. In the first case, the mass flow rate function is approximated by a polynomial.*

Key words*: nozzle-flapper type pneumatic valve, nonlinear model, describing function, mass flow rate*

1. INTRODUCTION

Pneumatic servosystems are widely used in industrial applications because of the favourable performances/price ratio. However, high precision control of such systems is difficult due to their complex physical nature. The main causes of that complexity are: air compressibility, friction between the contact surfaces, nonlinear flow-pressure characteristics of the orifice type restriction and parameter variations [1-3]. In order to solve the problem of design and control of such systems, it is necessary to have better understanding of their nonlinear characteristics. A mathematical model which should clarify the most relevant dynamic and nonlinear behavior in the pneumatic system is used for that purpose.

Nozzle-flapper type valves are frequently used in pneumatic systems because of their simple structure, high sensitivity and a broad bandwidth [4-6]. As the nonlinear characteristics of the valve reflect in the operation of the whole pneumatic system, it is observed and modelled as a separate subsystem. The paper presents and analyzes the characteristics of the nonlinear mass flow rate-pressure ratio of a 2-port nozzle-flapper type pneumatic servo valve with one fixed orifice and one nozzle (Fig.1).

One of the methods of analysis of nonlinear-systems is the quasi-linearization method [7, 8]. Linearization in the ordinary sense is not valuable in the case when nonlinearity inputs exceed the limits of acceptable linear approximation or when there is discontinuity at the nominal operating point. The advantages of true linearization are kept in the case of quasi-linearization but there is no limit to the range of input signal magnitudes or to the selection of the operating point. The constraint is that linear description of the system depends on some properties of the input signal. The system description thus depends not only on the system itself, but also on the signals passing through the system (which is a property of nonlinear systems). In other words, quasi-linearization is performed for a certain form of input signal. The problem with nonlinear systems with feedback configurations is in difficult determination of the signal form which occurs on entering the nonlinearity. This is the main constraint of the method. It is not always possible to reduce the nonlinearity input signal to a simple form. The practical solution of the problem is to assume the form of the input signal in advance. In practice, three forms of input signals are used in quasi-linearization [7, 8]: bias, sinusoid and Gaussian process.

The quasi-linear function which approximatively describes nonlinearity is called the describing function (DF). As the design of control systems is frequently realized in the frequency domain, the Sinusoidal Input Describing Function (SIDF) is used in this paper. Assuming that the linear part of the system filters high order harmonics (low-pass filter), every periodic signal is reduced to a basic periodic function on entering the nonlinearity. In the case of memoryless nonlinearity, the SIDF represents the gain which is changed depending on the amplitude of the input signal.

The paper determines the SIDF of the nonlinear mass flow rate characteristic of the nozzle-flapper type pneumatic valve with two ports.

2. MASS FLOW RATE CHARACTERISTIC OF NOZZLE - FLAPPER TYPE PNEUMATIC VALVE

Figure Fig.1 presents the functional scheme of the nozzle-flapper type pneumatic valve with two ports. The valve consists of a fixed orifice-type restriction (*Or*) and a nozzle (*Nz*). Moving of the flapper (*Fl*) changes its distance from the nozzle, i.e. the mass flow rate $\dot{M}_n$. As a result, there occurs a change of the pressure P at the control port. A detailed mathematical description of the nozzle-flapper type pneumatic servo valve with four ports can be found in [4-6]. This paper deals primarily with the flow-rate characteristic of the valve. Since the flow-rate through the valve depends on the pressure at the control port, the figure also shows the chamber (*Ch I*) which is not a part of the valve but acts as a load.

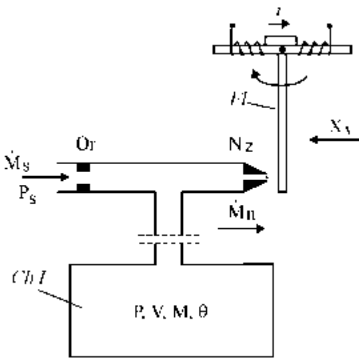


Fig. 1. The nozzle-flapper type pneumatic valve with the load chamber

The mass flow rate through the restriction can be in sonic or subsonic conditions depending upon the ratio of upstream-downstream pressure. According to the standard theory, mass flow rate can be presented in the form [9]:

$$\dot{M} = A_e \varphi(P_u, P_d, \theta_u) \tag{1a}$$

where the function φ is defined as:

$$\varphi(P_u, P_d, \theta_u) = \begin{cases} C_1 \dfrac{P_u}{\sqrt{\theta_u}} & if \quad \dfrac{P_d}{P_u} \le P_{cr} \\ C_2 \dfrac{P_u}{\theta_u} \left(\dfrac{P_d}{P_u}\right)^{\frac{1}{\kappa}} \sqrt{1 - \left(\dfrac{P_d}{P_u}\right)^{\frac{\kappa-1}{\kappa}}} & if \quad P_{cr} < \dfrac{P_d}{P_u} \le 1 \end{cases} \tag{1b}$$

while the parameters C_1, C_2 and P_{cr} are determined by:

$$C_1 = \sqrt{\frac{\kappa}{R}\left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}}, \; C_2 = \sqrt{\frac{2\kappa}{R(\kappa-1)}}$$
$$P_{cr} = \left(\frac{2}{\kappa+1}\right)^{\frac{\kappa}{\kappa-1}} \tag{1c}$$

If the downstream/upstream pressure ratio is smaller than a critical value P_{cr} (0.528 for air), the flow is sonic and the function of upstream pressure is linear. If the pressure ratio is higher than P_{cr}, the flow is subsonic and depends nonlinearly on both pressures. In order to determine the flow regimes at the valve orifices, it is necessary to analyze the flow in the nominal regime for which it holds that:

$$\dot{M}_{sN} = \dot{M}_{nN} \tag{2}$$

If it is assumed that the air temperature in the chamber is constant (isothermal chamber) and equal to the ambient temperature:

$$\theta = \theta_a = const. \tag{3}$$

then, based on (1) and (2), it can be written that:

$$A_{es}\varphi(P_s, P_N, \theta_a) = A_{en}\varphi(P_N, P_a, \theta_a) \tag{4}$$

Numerical solution of Equations (1) and (4) results in the static characteristic (steady state characteristic) of the valve which shows dependence of the load pressure (P_N) on the supply pressure (P_S) for different ratios of effective flow areas (A_{enN} / A_{es}).

The flow regime which is established depends on the supply pressure and the ratio between the effective flow areas. It is assumed that the flow at the fixed orifice (*Or*) is in the subsonic regime and that the flow has sonic velocity at the nozzle. In other words, for the fixed orifice it can be written that:

$$\dot{M}_S = \dot{M}_S(P) = A_{es} C_2 \frac{P_S}{\theta_a}\left(\frac{P}{P_S}\right)^{\frac{1}{\kappa}} \sqrt{1 - \left(\frac{P}{P_S}\right)^{\frac{\kappa-1}{\kappa}}} \tag{5}$$

The flow through the nozzle is determined by the following expression:

$$\dot{M}_n = \dot{M}_n(A_{en}, P) = A_{en} C_1 \frac{P}{\sqrt{\theta_a}} \tag{6}$$

and it is the function of two values, the effective area of restriction A_e and the working pressure P.

If it is assumed that the area is a linear function of the distance between the flapper and the nozzle, it can be written that [4-6]:

$$A_{en} = \frac{X_{vN} - X_v}{X_{vN}} A_{enN} \tag{7}$$

Now, based on (6) and (7), it can be written that:

$$\dot{M}_n = \dot{M}_n(X_v, P) = \frac{X_{vN} - \tilde{X}_v}{X_{vN}} A_{enN} C_1 \frac{P}{\sqrt{\theta_a}} \tag{8}$$

It should be noted that the effective area of the nozzle in the nominal regime depends on the nominal working pressure P_N. Namely, from (5) and (6) in the nominal regime:

$$\frac{A_{enN}}{A_{es}} = A_{es}\frac{C_2}{C_1}\sqrt{\left(\frac{P_N}{P_S}\right)^{\frac{1-\kappa}{\kappa}} - 1} \tag{9}$$

It means that the position of the nominal point is determined by the working pressure in the nominal regime.

3. DESCRIBING FUNCTION OF THE VALVE

Behavior of the system from Fig.1 is described by the block diagram in Fig.2.

It was assumed that the load behavior was described by the linear dynamics (W(s)), while the valve was described by the static nonlinearities $\dot{M}_n(X_v, P)$ and

$\dot{M}_s(P)$. Describing functions of those nonlinearities will now be determined.

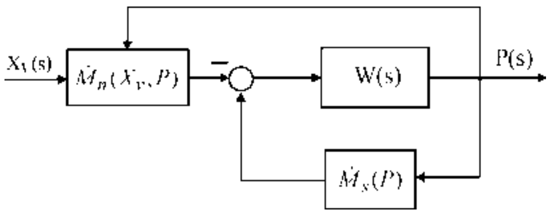


Fig.2. Block diagram of the pneumatic system

Let $\dot{m}_n$, x_v, p be relative changes of the values $\dot{M}_n$, X_v, P, respectively. Then, based on (8), it can be obtained that:

$$\dot{m}_n = p - x_v - x_v p \qquad (10)$$

Let us now assume that the following holds:

$$x_v = x_{vA}\sin(\omega t) \qquad (11a)$$

$$p = p_A \sin(\omega t + \alpha) \qquad (11b)$$

In other words, relative changes of input values have the character of basic periodic oscillations with the amplitudes x_{vA} and p_A, and the frequency ω. The values are phase shifted for α.

Let us now introduce the assumption that for inputs (11) the relative change of flow $\dot{m}_n$ is also a periodic function which can be represented by the Fourier series:

$$\dot{m}_n = \frac{a_o}{2} + \sum_1^{\infty} a_n \cos(n\omega t) + b_n \sin(n\omega t) \qquad (12a)$$

where:

$$a_o = \frac{1}{\pi}\int_{-\pi}^{\pi} \dot{m}_n \, d\psi \qquad (12b)$$

$$a_n = \frac{1}{\pi}\int_{-\pi}^{\pi} \dot{m}_n \cos(n\psi)\, d\psi \qquad (12c)$$

$$b_n = \frac{1}{\pi}\int_{-\pi}^{\pi} \dot{m}_n \sin(n\psi)\, d\psi \qquad (12d)$$

Fourier coefficients can be obtained based on the expressions (10), (11) and (11). Table 1 gives the values for the first nine members of the series.

Table 1. Fourier coefficients for the mass flow rate approximation $\dot{m}_n$

$a_o/2$	$-\frac{1}{2}x_{vA}p_A\cos(\alpha)$		
a_1	$p_A\sin(\alpha)$	b_1	$p_A\cos(\alpha) - x_{vA}$
a_2	$\frac{1}{2}x_{vA}p_A\cos(\alpha)$	b_2	$-\frac{1}{2}x_{vA}p_A\sin(\alpha)$
a_3	0	b_3	0
a_4	0	b_4	0

It can be seen from the table that the values of Fourier coefficients depend on the amplitudes of input signals and the phase shifts between them.

It can be seen that the value of coefficients, i.e. phase delay, depends on load dynamics. However, if:

$$\alpha \neq 2k\pi, \; k = 0,1,... \qquad (13a)$$

and if

$$x_{vA} < 1 \text{ and } p_A < 1 \qquad (13b)$$

then

$$\begin{aligned}\dot{m}_n &\approx a_1\cos(\omega t) + b_1 \sin(\omega t) \\ &= p_A\sin(\alpha)\cos(\omega t) + (p_A\cos(\alpha) - x_{vA})\sin(\omega t) \qquad (14) \\ &= p_A \sin(\omega t + \alpha) - x_{vA}\sin(\omega t) = p - x_v\end{aligned}$$

which means that the nonlinearity defined by (10) for the case of inputs defined by (11) can be represented as a linear element with the unit gain. In other words, the describing function for both inputs has the value one if the conditions (13) are fulfilled.

Equation (5) can be the basis for determination of dependence of the relative change of flow through the fixed orifice on the relative change of pressure p:

$$\dot{m}_s = (1+p)^{\frac{1}{\kappa}}\left(1 - \left(P_N(1+p)/P_S\right)^{\frac{\kappa-1}{\kappa}}\right)^{\frac{1}{2}} \left(1 - \left(P_N/P_S\right)^{\frac{\kappa-1}{\kappa}}\right)^{-\frac{1}{2}} \qquad (15)$$

Depending on the desired accuracy and the range of changes for p, the relative change of flow $\dot{m}_s$ (16) can be approximated by the polynomial:

$$\dot{m}_s = c_1 p + c_2 p^2 + c_3 p^3 \qquad (16)$$

In Fig.3, the dashed line shows the value of the mass flow rate $\dot{m}_s$ approximated by the polynomial of the third degree (16).

If it is assumed that the value p is changed in the manner defined by Equation (11b) and that the relative change of flow $\dot{m}_s$ has the form defined by (12a), then, by using Equations (12b), (12c) and (12d) (the index *s* is used instead of the index *n*) as well as Equation (16), the Fourier coefficients given in Table T4 can be determined.

It is seen that the value of coefficients depends both on the input signal (amplitude and phase) and the nominal point around which harmonic linearization (coefficients c_1, c_2, c_3) is performed.

Table 2. Fourier coefficients for mass flow rate aproximation $\dot{m}_s$.

a_1	$\left(c_1 + \frac{3}{4}c_3 p_A^2\right)p_A\sin(\alpha)$
a_2	$\frac{1}{2}\left[2\sin^2(\alpha) - 1\right]p_A^2 c_2$
a_3	$-\frac{1}{4}p_A^3\sin(3\alpha)c_3$

b_1	$\left(c_1 + \frac{3}{4}c_3 p_A^2\right) p_A \cos(\alpha)$
b_2	$\frac{1}{2}\sin(2\alpha) p_A^2 c_2$
b_3	$-\frac{1}{4} p_A^3 \cos(3\alpha) c_3$
a_4, b_4	0

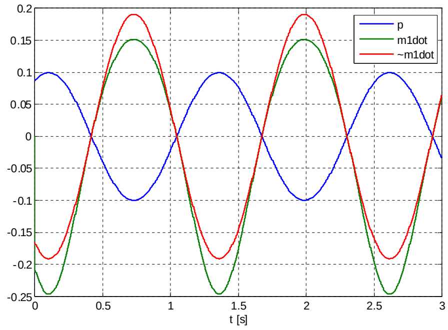
If the mass flow rate is approximated by the fundamental harmonics, then:

$$\dot{m}_s \approx \left(c_1 + \frac{3}{4}c_3 p_A^2\right) p_A \sin(\alpha) \qquad (17)$$

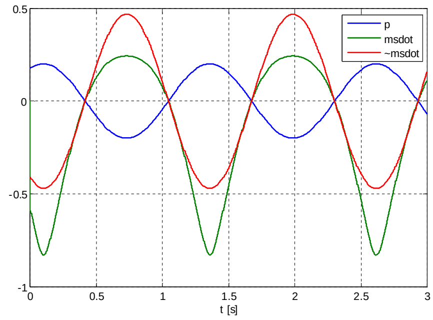
and hence the describing function of the nonlinear function (15) is:

$$N_s = \left(c_1 + \frac{3}{4}c_3 p_A^2\right) \qquad (18)$$

The results of simulation show that the accuracy of approximation (17) is most influenced by the amplitude of the input signal. Fig.3 (a, b) presents the exact values of relative changes of the mass flow rate $\dot{m}_s$ (15) and their approximations (17) for two different values of the amplitude of the input signal $p_A = \{0.1, 0.2\}$ (11b).



(a)



(b)

Fig.3. Exact and approximated values of the mass flow rate for two values of the amplitude of the input signal

4. CONCLUSION

At the orifices of the nozzle flapper type valve all four combinations of flow regimes (sonic/subsonic) are possible. However, for standard working conditions, with the constant volume chamber load type, the flow regime through the fixed orifice is subsonic while the flow state through the nozzle is sonic.

If the changes of pressure and position of the flapper have a periodic character and the same frequency but are phase shifted, the mass flow rate of the nozzle can be approximated by a constant, unit gain for both values. In other words, the mass flow rate of the nozzle can be approximated by true linearization. Nonlinearity of the mass flow rate becomes more pronounced at the fixed orifice. The describing function can be determined analytically with the previous determination of the mass flow rate by a polynomial. The value of the describing function depends on the selection of the nominal operating point and the amplitude of the input signal.

REFERENCES

[1] Antonio Carlos Valdiero, Carla Silvane Ritter, Cláudio Fernando Rios, and Marat Rafikov, (2011) *Nonlinear Mathematical Modeling in Pneumatic Servo Position Applications*, Mathematical Problems in Engineering, Volume, Article ID 472903,16pages

[2] João Falcão Carneiro, Fernando Gomes De Almeida, (2011) *Undesired Oscillations in Pneumatic Systems*, Nonlinear Science and Complexity, Editors Machado, J.A.T., Luo, A.C.J., Barbosa, R.S., Silva, M.F., Figueiredo, L.B., Springer, pp 229-243

[3] N. A. Daw, J. Wang, Q. H. Wu, J. Chen, Y. Zhao, (2003) *Parameter identification for nonlinear pneumatic cylinder actuators*, Nonlinear and Adaptive Control, LNCIS 281, Editors A. Zinober and D. Owens, Springer-Verlag Berlin Heidelberg , pp. 77-88

[4] Tao Wang, Kenji Kawashima, Toshiharu Kagawa, (2007) *Modelling of a 4-port Nozzle-flapper Type Pneumatic Servo Valve*, Systems Modeling and Simulation, Editors K. Koyamada, S. Tamura, O. Ono, Springer, pp 248-252

[5] Tao Wang, Maolin Cai, Kenji Kawashima and Toshiharu Kagawa, (2005) *Model of a nozzle-flapper type pneumatic servo valve and differential pressure control system design*, Proceedings of the 6th JFPS International Symposium on Fluid Power, TSUKUBA 2005, Nov. 7-10, pp. 322-327.

[6] Tao Wang, Maolin Cai, Kenji Kawashima and Toshiharu Kagawa, (2005) *Modelling Of A Nozzle-Flapper Type Pneumatic Servo Valve Including The Influence Of Flow Force*, International Journal of Fluid Power 6, No. 3, pp.33-43

[7] Arthur Gelb, Wallace E. Vander Velde, (1969) *Multiple-Input Describing Functions And Nonlinear System Design*, McGraw-Hill.

[8] D.P. Atherton, (1975) *Nonlinear Control Engineering*, van Nostrand Reinhold Co. , London.

[9] Anderson, B. W., (1967) *The Analysis and Design of Pneumatic Systems*, Wiley, New York.

35th INTERNATIONAL CONFERENCE ON PRODUCTION ENGINEERING
25. - 28. September 2013, Kraljevo, Serbia
University of Kragujevac,
Faculty of Mechanical and Civil Engineering Kraljevo

POSITION CONTROL OF X-Y TABLE FOR A CNC MACHINE BY DIGITAL SLIDING MODE

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Abstract: *Nowadays, the DC servo motors are used to power X-Y tables of some CNC machines. Accuracy and positioning of X-Y tables of CNC machine is directly conditioned by the good and exact control of servo motors. There are many different control algorithms. This paper presents a new algorithm for X-Y table servo motor control that uses the theory of variable structure system with sliding working mode. In this paper, all the advantages of the proposed control algorithm are presented by computer simulation.*

Key words: *CNC, Digital control, X-Y table, Sliding mode*

1. INTRODUCTION

Machine tools are an important part of many manufacturing processes with a growing demand of part quality and cost reduction. To achieve these objectives, machine tools have incorporated technology to automatize the process. The introduction of the first Computer Numerical Control (CNC) machine was in the early 1970's, when most of the digital hardware from the Numerical Controlled (NC) machine was replaced by a dedicated computer [1].
The advantages of using CNC machines are:

- Increased productivity by reducing the total time,
- High-accuracy processing and slight control of the
- workpiece,
- Parts processing complex contour that is difficult to achieve in a conventional,
- Increase in efficiency of time machines,
- Reduction of the number and duration of preparatory operations, labeling, etc.,
- Simplified management of the production process.

One of the main parts of some CNC machines is the X-Y table, Fig. 1.

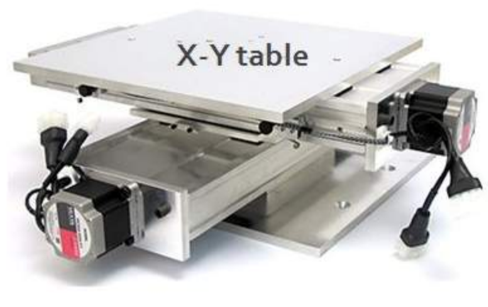

Fig. 1. CNC X-Y table.

The development of a compact and high performance servo controller system for a precision CNC X-Y table is a popular research work in literature [2, 3, 4, 5].
The control architecture of a modern machine tool can be divided in three levels as Fig. 2 shows [6, 7].
Adaptive control sets the programmed parameters (feeds and speeds) in order to pursue a given criterion or to minimize a given cost function using measured or predicted output process variables.

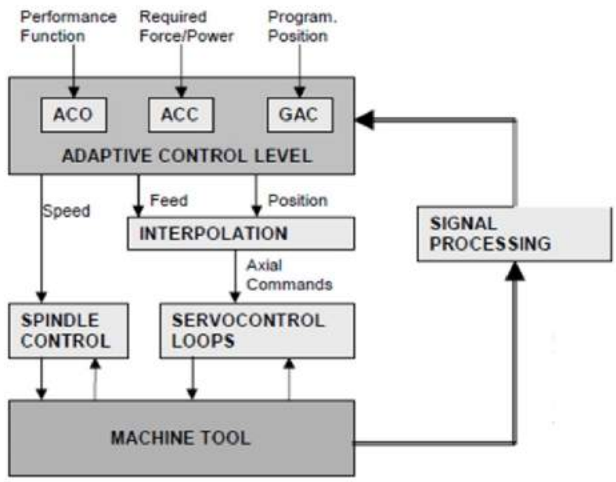

Fig.2. CNC control architecture.

The interpolator level sets the coordinated movements among the axes of motion in order to achieve the tool trajectory. The interpolation level can be classified as:

- linear interpolation,
- circular interpolation, and
- complex surface interpolation.

Servo control loops control the axes of the machine (in some cases X-Y table) based on requirements of velocity, position and acceleration. Traditionally, the dynamics of each axis in a machine tool is represented as a second order system for which well-known techniques are applied, such as PID (Proportional-Integral-Derivative) controllers [6]. However, the action of these simple controllers can be degraded by process perturbations, model uncertainties and non-linearities, which require sophisticated techniques and innovative hardware to achieve higher control requirements.

The main goal of this paper is exploration of the possibility of applying the algorithm of control of the variable structure with sliding working mode to the problem of CNC machine axes (X-Y table) control by DC servo motors control. The motives for this paper are to be found in numerous publications dedicated to the application of sliding modes to various control tasks [7], which confirm the superiority of such systems over classic solutions.

The basic features of sliding modes, known to a small circle of experts in the field of automatic control, are:

- theoretical invariance to the external load and internal perturbations (parameters uncertainty) if maching conditions are satisfied [9] and practical robustness;
- the character of the system's movement is known in advance;
- the movement does not depend on the object's parameters and control, but only on control parameters;
- what is necessary is not exact knowledge of the object's parameters, but only of the range of their possible change;
- it is easier to ensure the system's stability by decomposing the problem of stability into two simpler sub-problems;
- lowering the order of the differential equation which describes movement.

This paper makes use of a digital algorithm of control of the variable structure, which was applied for the first time to the problem of controlling the generator of waveforms [10] and detailed explained in [11].

The paper is organized in the following way: the second part presents the description of X-Y table of CNC machines. The third part presents an outline of the digital control algorithm with sliding mode on the basis of [11]. The fourth part presents the mathematical model of CNC X-Y table. The fifth part presents the effects of the application of the above-mentioned algorithm of control by means of computer simulation.

2. CNC X-Y TABLE DESCRIPTION

The typical architecture of the conventional motion control system for the X-Y table is shown in Fig. 3, and it consists of a central controller, two controllers (Controller 1 and Controller 2) for each axes and an X-Y table [7]. The central controller performs the function of motion trajectory and data communication with separate controllers and with an external device. Each separate controller performs the functions of position/ speed/current control at each single axis of the X-Y table and establishes data communication with the central controller.

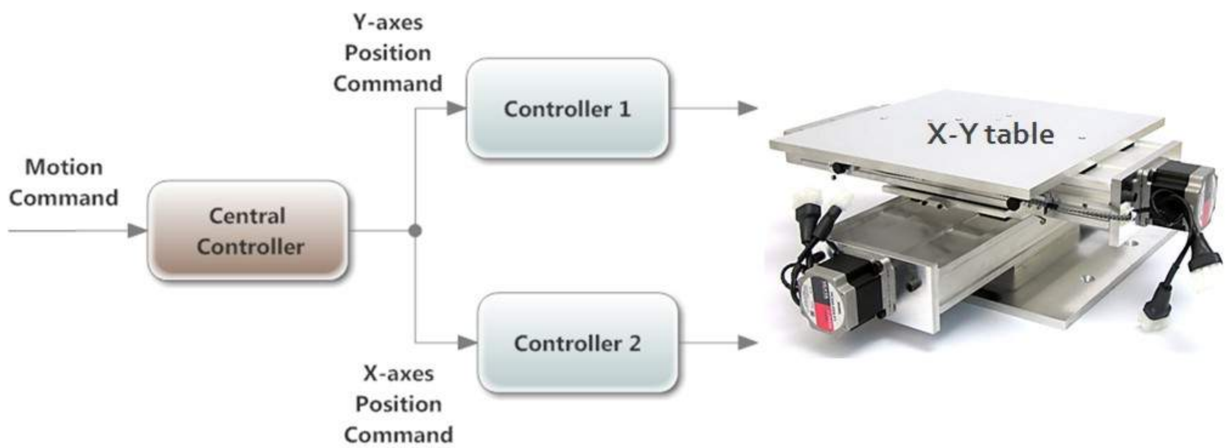

Fig.3. X-Y table control system

3. ALGORITHM OF DIGITAL CONTROL WITH SLIDING MODE

The algorithm of control, for application to the problem of CNC X-Y table control is examined in this paper, belongs to the group of digital algorithms of control of variable structure. The goal of synthesis of control is to achieve movement of the system in the space of state on a pre-given hyper-surface, in systems of the higher order, i.e. on a line (most frequently a straight line), in systems of the second order.

To summarize, the movement of these system has three phases [11, 12, 13]:

I. the phase of reaching the hyper-surface;
II. the phase of the sliding regime;
III. the phase of steady state.

The system movement is shown in Fig.4.

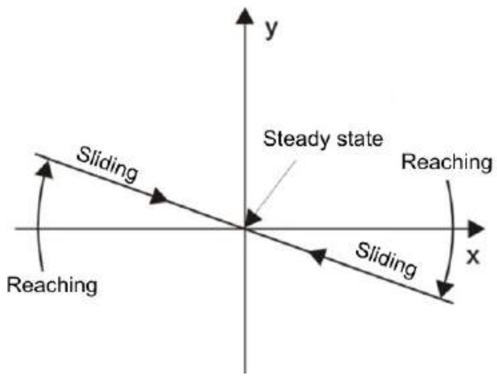

Fig.4. System movement.

If the sliding hyper-surface is marked as s(x), the conditions are met by satisfying the inequality.

$$s(\mathbf{x})\dot{s}(\mathbf{x}) < 0 \,. \tag{1}$$

This condition can be satisfied by applying various algorithms of control.
The algorithm applied in this paper has two components:
a relay component, which ensures safe and quick transfer of the system's state near the sliding hyper-surface without intersecting it, and
a linear component, which brings the system's state into *s(x)*=0 in the following step (during one discretization period).
In shortest, the applied algorithm, which is described in [11] in detailed, can be represented in the following way.
For a given controllable and observable dynamic system

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{b}u, \quad \mathbf{x} \in R^n, \quad u = R^1, \quad \mathbf{A}_{nxn}, \quad \mathbf{b}_{nx1} \,. \tag{2}$$

Since the control will be digitally implemented, it is necessary to perform time-discretization of the model (2). If T denotes the discretization period and

$$\mathbf{A}_{\boldsymbol{\delta}}(T) = \frac{e^{\mathbf{A}T} - \mathbf{I_n}}{T}, \quad \mathbf{b}_{\boldsymbol{\delta}}(T) = \frac{1}{T}\int_0^T e^{\mathbf{A}\tau}\mathbf{b}\,d\tau, \tag{3}$$

the discrete-time state-space model of the nominal system, by using δ-transform, can be expressed in the form:

$$\boldsymbol{\delta}\mathbf{x}(kT) = \mathbf{A}_{\boldsymbol{\delta}}(T)\mathbf{x}(kT) + \mathbf{b}_{\boldsymbol{\delta}}(T)\mathbf{u}(kT) \,. \tag{4}$$

The well known scalar switching function $s(\mathbf{x})$ in sliding mode control systems that defines a sliding surface in the state space (s=0), along which the sliding mode is organized, is chosen as

$$s = \mathbf{c}_{\boldsymbol{\delta}}(T)\mathbf{x} \,, \tag{5}$$

where $\mathbf{c}_{\boldsymbol{\delta}}(T)$ is the switching function vector of appropriate dimension.
The positioning control law is obtained as:

$$u = -\mathbf{c}_{\boldsymbol{\delta}}(T)\mathbf{A}_{\boldsymbol{\delta}}(T)\mathbf{x}(k) - \boldsymbol{\Phi}(s(k), \mathbf{X}(k)) \,. \tag{6}$$

The switching function vector $\mathbf{c}_{\boldsymbol{\delta}}(T)$, which exclusively defines system dynamics in sliding mode, is selected according to the relation:

$$\mathbf{c}_{\boldsymbol{\delta}}(T) = [\mathbf{c_1}(T) \mid 1]\mathbf{P}_1^{-1}(T) \,, \tag{7}$$

where:

$$\mathbf{P}_1(T) = \mathbf{A}_A\mathbf{A}_B;$$

$$\mathbf{A}_A = \left[\mathbf{b}_\delta(T) \ldots \mathbf{A}_\delta^{n-1}(T)\mathbf{b}_\delta(T)\right]$$

$$\mathbf{A}_B = \begin{bmatrix} a_1(T) \ldots a_{n-1}(T) & 1 \\ a_2(T) \ldots \quad 1 & 0 \\ \vdots \quad \ddots \quad \vdots & \vdots \\ 1 \quad \ldots \quad 0 & 0 \end{bmatrix} , \tag{8}$$

$$\delta_i(T) = \frac{e^{-\alpha_i T} - 1}{T}, \quad \begin{matrix} \alpha_i > 0, i \neq j \Rightarrow \alpha_i \neq \alpha_j \\ i, j = 1, \ldots, n-1 \end{matrix} , \tag{9}$$

$$c_i(T) = \frac{1}{(i-1)!} \frac{d^{i-1}\prod_{j=1}^{n}\left(\delta - \delta_j(T)\right)}{d\delta^{i-1}}\Big|_{\delta=0} \,. \tag{10}$$

Function $\Phi(s,X)$ is defined as:

$$\boldsymbol{\Phi}(s,\mathbf{X}) = \boldsymbol{\Phi}(s) = \min\left(\frac{|s|}{T}, \sigma + \rho|s|\right)\mathrm{sgn}(s); \quad \begin{matrix} 0 \le \rho T < 1, \\ \sigma > 0 \end{matrix} \tag{11}$$

Parameters σ and ρ defines sliding mode reaching dynamics and should be chosen to provide as short as possible reaching phase [11, 12, 14].

4. CNC X-Y TABLE MATHEMATICAL MODEL

The X-Y table consists of two linear motors, for the X-axis and Y-axis [15]. These motors are the same, this paper describes only the mathematical model for the X-axis in detail.
The servo DC motor is used in CNC X-Y table control systems, for analytical purpose, it is necessary to establish its mathematical model. The DC servo motor circuit diagram [7, 16, 17] is presented in Fig. 5.

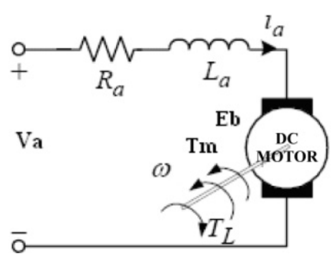

Fig.5. DC servo motor circuit diagram

The velocity and position of the DC servo motor, is controlled by changing the supply voltage. According to this theory if rewrites voltage and moment equations:

$$V_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + E_b(t) \,, \tag{12}$$

(13)

$$T_m = j\frac{d\omega_m(t)}{dt} + B\omega(t) + T_L(t)\,,$$

where $i_a(t)$ is armature current, L_a is armature inductance, R_a is armature resistance, $V_a(t)$ is input voltage, $E_b(t)$ is back emf., T_L is load moment, T_m is motor moment, ω is motor angular velocity, B is friction constant, j is motor moment inertia.

For the simplicity of the model, the movement of each axes of X-Y table is given as a function of angular position of the rotor shaft (θ_x - for x axes and θ_y - for y axes):

$$x = K_L\theta_x \quad \text{and} \quad y = K_L\theta_y\,, \tag{14}$$

where K_L is relation parameter of angular and linear position.

5. SIMULATION RESULTS

In order to verify the theoretically obtained results, a simulation is carried out. The control plant is a DC servo motor, and its state space model for these purposes is (i=x,y for each axes):

$$\begin{bmatrix} \dot{x}_{1i} \\ \dot{x}_{2i} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -15 \end{bmatrix}\begin{bmatrix} x_{1i} \\ x_{2i} \end{bmatrix} + \begin{bmatrix} 0 \\ -710 \end{bmatrix}u_i\,, \tag{15}$$

$$x_{1i} = \theta_{di} - \theta_i, \quad x_{2i} = -\omega_i\,, \tag{16}$$

and X-Y table positions are:

$$x = K_L x_{1x} \quad \text{and} \quad y = K_L x_{1y}\,, \tag{17}$$

where θ_d and θ are desired and actual angular position of the rotor shaft and u is the control signal by input voltage V_a.

The simulink model of X-Y table is shown in Fig. 6.

The X coordinate subsystem and Y coordinate subsystem are the same because they are consisted from the same parts. The X coordinate subsystem is shown in Fig.7.

The test was performed with T=0.4ms and α=15s^{-1}. The controller parameters have been selected as:

$\sigma = 7$,

$\rho = 0$,

$\mathbf{c}_\delta(T) = [-0.028141 \quad -0.001407]$,

$\mathbf{c}_\delta(T)\mathbf{A}_\delta(T) = [0 \quad -0.007014]$.

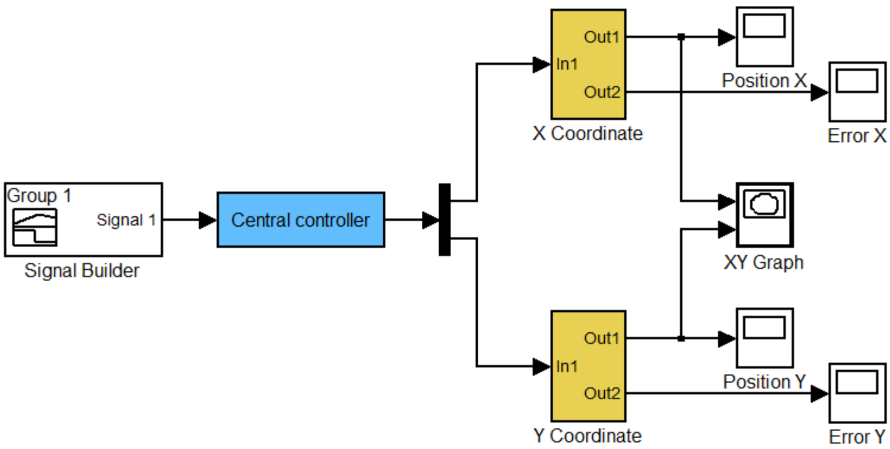

Fig.6. Simulink model of the hole system

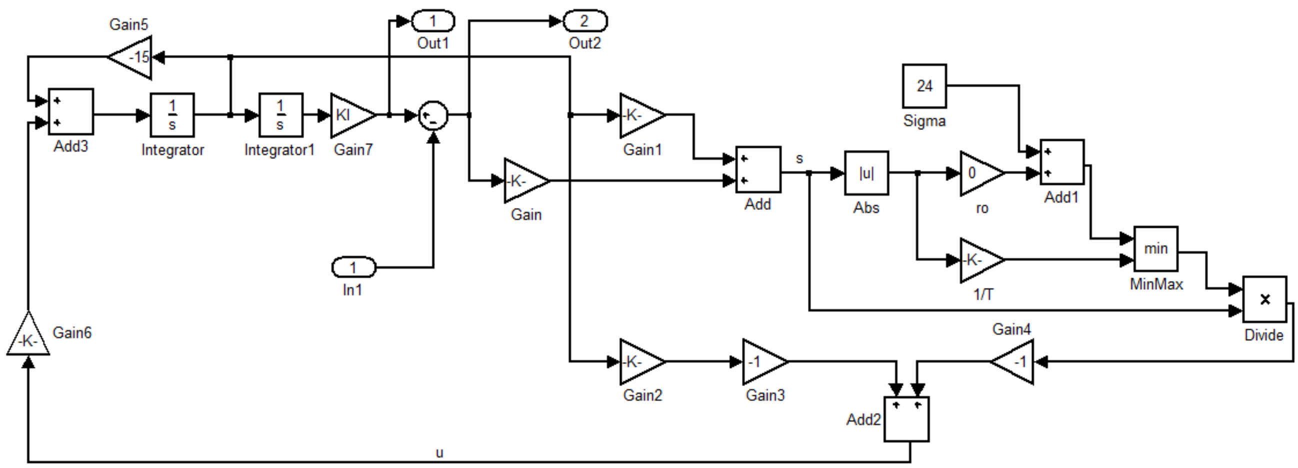

Fig.7. Simulink model of the X coordinate subsystem

In Fig. 8, the positioning results of the X-Y table, for separate axes, when digital control with sliding mode is used, are shown.
In Fig. 9, the positioning result of X-Y table is shown.

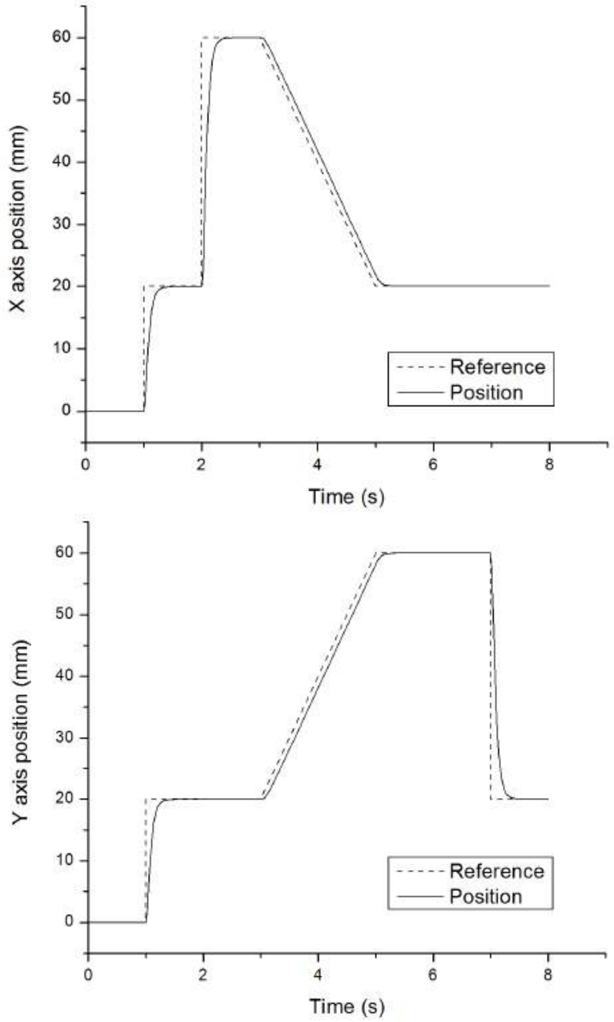

Fig.8. Diagram of the X and Y axes position

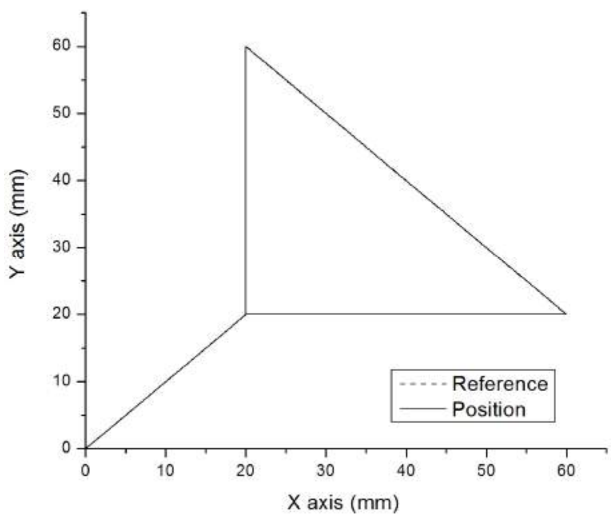

Fig.9. Diagram of the X-Y table position

In Fig. 10, the magnified positioning result of X-Y table from Fig.9, in region from 19.5 mm to 20.5 mm for X axe and from 30mm to 50mm for Y axe, is shown.

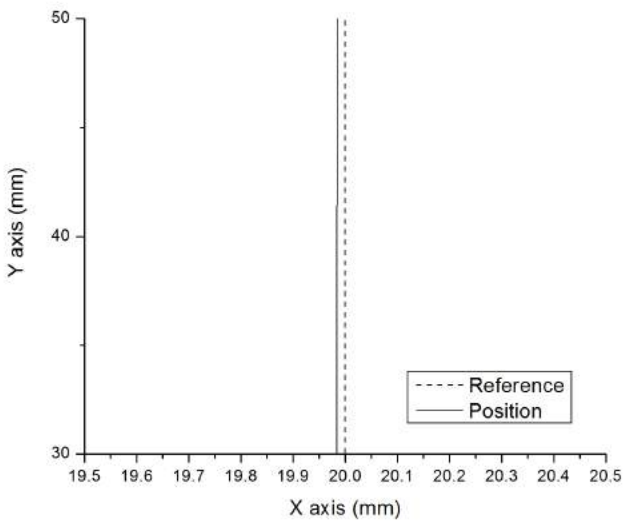

Fig.10. Magnified part of the diagram on Fig.9.

The results of position show that digital control with sliding mode of the CNC X-Y table exhibits superior performance. The digital control with sliding mode approach successfully achieves the desired positions of the axes.

6. CONCLUSION

The paper discusses the positioning problem of the X-Y table in CNC machines. In order to represent a real physical model as best as possible, the mathematical and simulink models of the X-Y table for a CNC machine are designed. Mathematical and simulink models of CNC X-Y table offer a possibility for designing and testing a wide range of positioning control algorithms.
Digital control with sliding mode is employed in solving the positioning problem. The designed digital sliding mode controller performs its task successfully, since it ensures robustness and quick reaching of the desired position without oscillation. The position error when digital control with sliding mode is used is nearly equal to zero.

Acknowledgement: This paper is part of project TR35034, The research of modern non-conventional technologies application in manufacturing companies with the aim of increase efficiency of use, product quality, reduce of costs and save energy and materials, funded by the Ministry of Education and Science of Republic of Serbia.

REFERENCES

[1] KOREN, Y., (1983) *Computer Control of Manufacturing Systems*, McGraw Hill
[2] PARK, E. C., LIM, H., CHOI, C. H. (2003) *Position control of XY table at velocity reversal using presliding friction characteristics*, IEEE Trans. Control Systems Technology, vol. 11(1), pp. 24-31
[3] HANAFI, D., TORDON, M., KATUPITIYA, J. (2003) *An active axis control system for a conventional CNC machine*, Proceedings of

IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pp. 1188-1193
[4] HOUK, L., SEO, J.W., CHOI, C.H. (2000) *Position control of XY table in CNC machining center with non-rigid ballscrew*, Proceedings of the American Control Conference, Chicago, USA, Vol. 3, pp.1542-1546
[5] HOUK, L., SEO, J.W., CHOI, C.H. (2001) *Torsional displacement compensation in position control for machining centers*, ELSEVIER Control Engineering Practice, Vol. 9, No. 1, pp.79-87
[6] KOREN,Y. (1997) *Control of Machine Tool*, Journal of Manufacturing Science and Engineering, Vol. 119, pp 749-755
[7] MARINKOVIĆ, I., BLAGOJEVIĆ, V., PETKOVIĆ, D. (2013) *Mathematical and Simulink Model of the X-Y Table for a CNC Machine*, Proceedings of The 2nd International Conference Mechanical Engineering in XXI century, Niš, Serbia, pp. 99-102
[8] UTKIN, V. I. (1992), *Sliding Modes in Control and Optimization*, Springer Verlag
[9] DRAZENOVIC, B. (1969) *The Invariance Condition in Variable Structure Systems*, Automatica, Vol. 5, pp 287-295
[10] GOLO, G., MILOSAVLJEVIĆ, Č. (1997) *Two-phase Triangular Wave Oscillator Based on Discrete-time Sliding Mode Control*, Electron. Lett., Vol. 33, pp 1838-1839
[11] GOLO, G., MILOSAVLJEVIĆ, Č (2000) *Robust discrete-time chattering free sliding mode control*, ELSEVIER Systems & Control Letters, pp. 19-28
[12] BLAGOJEVIĆ, V., (2010), *Contribution to the Development of Efficient Control of Pneumatic Executive Organs*, Ph D Thesis, Faculty of Technical Sciences, Novi Sad
[13] BLAGOJEVIĆ, V. (2004) *Synchronization of the Work of Pneumatic Executive Organs in Technological Processes*, Master's Thesis, Faculty of Mechanical Engineering, University of Nis
[14] BLAGOJEVIĆ, V., ŠEŠLIJA, D., STOJILJKOVIĆ, M., DUDIĆ, S. (2013) *Efficient control of servo pneumatic actuator system utilizing by-pass valve and digital sliding mode*, Sadhana, Indian Academy of Sciences, Vol 38, N^{0}2, pp. 187-197
[15] KUNG, Y.S., HUANG, C.C., HUANG, L.C. (2012) *FPGA-Based Motion Control IC for Linear Motor Drive X-Y Table Using Adaptive Fuzzy Control*, Fuzzy Controllers – Recent Advances in Theory and Applications, pp.181-200
[16] MEHMET, A., İSMAİL, T. (2007) *Motion Controller Design for the Speed Control of DC Servo Motor*, International journal of applied mathematics and informatics, Vol. 1, pp 131-137
[17] BLAGOJEVIĆ, V., STOJILJKOVIĆ, M., RANČIĆ, M. (2011) *DC servo motors cntrol of CNC machines by sliding mode*", 34th International Conference on Production Engineering, Proceedings, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia, pp. 3

35th INTERNATIONAL CONFERENCE
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DETECTION OF PLANAR SEGMENTS IN POINT CLOUD USING WAVELET TRANSFORM

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Abstract: *In this paper we propose a new method for 3D plane segmentation and fitting from point cloud. The method is based on discrete wavelet transform. In particular, we exploit the sensitivity of certain wavelets to abrupt changes in the signal, as well as their orthonormality to linear functions to effectively recognize planar regions. The application of the proposed method is evaluated using two examples. The first example refers to a synthesized signal, and the second, real world example deals with the detection of the welding seam pose within adaptive control of robotized continuous welding.*

Keywords: point cloud, plane segmentation, reverse engineering

1. INTRODUCTION

The performances of the state of the art scanning devices [6] gave additional élan for research in the area of implementation of originally reverse engineering (RE) methods in on line manufacturing processes control. An example is the adaptive control of robotized continuous welding [5] in unstructured environment. The hardware of contemporary scanning devices is characterized by high speed and accuracy, giving usually more than sufficient raw data. However, the bottleneck for on line application of RE techniques in the process control is the data processing [1]. There are a number of very successful methods for raw 3D data registration, integration and meshing [1], and the generation of dimensionally correct polygonal mesh [7] from point cloud is standard feature of CAD systems. Nevertheless, point cloud segmentation, simplification and surface fitting still remain the most critical elements of RE software.

Segmentation and fitting of planes in point cloud attracts more research efforts than other types of primary geometry. Besides the simplicity of the planar surface, there are other mainly application driven reasons. In addition to robotized continuous welding, typical examples are: 1) on line navigation of mobile robots in unstructured environment using sensory informa-tion from laser radars [2], 2) plane recognition in architectural reconstruction [8]. Another very important outcome is that identification of planar regions in point cloud leads to significant reduction of necessary vertices making further processing of resulting mesh more efficient. There are three main streams for recognition of planar features in point cloud. They are based on 3D Hough transform, RANSAC (Random Sample Consensus) method, and region growing [2].

In this paper we propose a novel method for segmentation of planar regions from point cloud based on discrete wavelet transform.

2. DISCRETE WAVELET TRANSFORM

Wavelet transform represents one dimensional signal as a linear superposition of atomic functions - wavelets. The wavelets are obtained by translation and dilatation of a single non-periodic function - mother wavelet. In discrete wavelet transform (DWT) dilatation and translation are carried out with discrete steps. Discretization is non-uniform in time-frequency space and it provides higher time resolution for low and better frequency resolution for high frequencies. To make the DWT unique and inverse DWT feasible, the wavelets should form an orthonormal basis [3].

Multiresolution analysis (MRA) [4] had very significant impact on DWT. Besides subband filtering scheme – a fast hierarchical algorithm for execution of DWT, MRA gave efficient methods for creation of orthonormal wavelet bases. Basic MRA algorithm for DWT application can be briefly stated as follows. If a sequence of resolutions 2^{-j}, $j \in (0, -\infty)$ is taken, then each signal can be represented as the sum of its approximation at resolution J – $A_J f$ and details $D_j f$, $j \in [1, J]$ taken from it during passing from higher to the lower level of approximation:

$$f = A_J f + \sum_{j=1}^{J} D_j f = \sum_n a_n^J \phi_{J,n} + \sum_{j=1}^{J} \sum_n d_n^j f \psi_{j,n} \qquad (1)$$

In relation (1) orthonormal bases $\{\phi_{j,n}, n \in Z\}$ and $\{\psi_{j,n}, n \in Z\}$ represent family of wavelets and corresponding scalling functions, a_n^J are the approximation and d_n^j the detail coefficients, computed by above-mentioned subband filtering scheme [4]. J represents the level of transform.

There are a number of families of wavelets (Daubechies wavelets, coiflets, symmlets [3]) that form othonormal bases. All of them are compactly supported thus providing excellent time localization properties to the transform. In addition some of them have asymmetric shape and can be employed for detection of abrupt changes in signal such as edges.

Besides application in time series analysis, DWT can be performed on two dimensional signal represented by matrix **S** with dimensions $m \times n$, using the following procedure:

Step 1: One-dimensional DWT of each row of matrix **S**

Step 2: One-dimensional DWT of columns computed in step 1

Two dimensional DWT inherits all the properties of one dimensional DWT including real time applicability and sensitivity to abrupt changes.

2. APPLICATION OF DWT IN RECOGNITION OF PLANAR REGIONS

Besides suitability for detection of abrupt changes (e.g., edges) in signal, there is another property of some wavelets that is crucial for the application at hand. Namely, the wavelet db2 from Daubechies family (db wavelets) has 2 vanishing moments:

$$\int x^2 \psi(x) dx = 0, \quad n = 0,1,...N-1 \qquad (2)$$

where ψ denotes the wavelet. This means that the db2 wavelet is orthogonal to the first degree polynomials 1, x and that the signal after DWT application will be approximated by linear function. Consequently the detail coefficients in the areas of the signal that are well approximated by first degree polynomial will be close to zero. On the other hand, in all nonlinear areas, the detail coefficients will be high. Besides, on the transition between two linear segments with different inclination there will be abrupt change in signal. Since db2 is highly asymmetric wavelet, it will be sensitive to this change and the level of detail coefficients at the connection of two linear segments will be high.

For the illustration of the given observations, Fig. 1 presents one level decomposition of a synthesized signal using db2 wavelet. Signal (Fig. 1a) consists of four linear and one conic section segment. The details of the signal at the first level of DWT using db2 wavelet are presented in Fig. 1b. It can be seen that details equal zero in all areas in which signal is constant or linear, while it differs from zero in areas that correspond to circular segment. The boundaries between segments represent abrupt changes in the signal and DWT detects them - detail coefficients differ from zero. This information is very useful for segmentation of adjacent linear segments. Besides sensitivity to abrupt changes, 2D DWT inherits the orthonormality to polynomial surfaces from one dimensional DWT, as well.

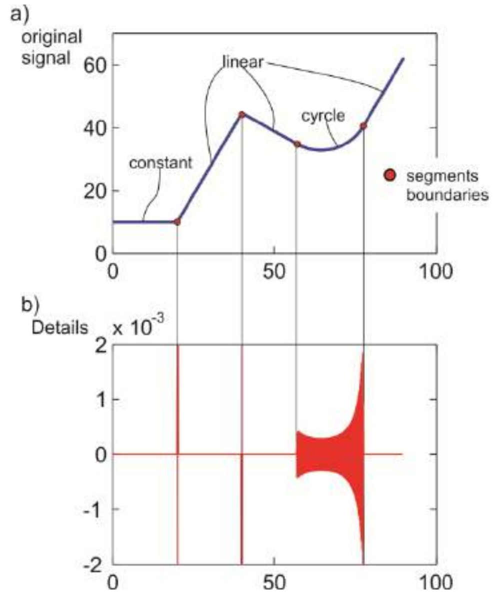

Fig. 1. Sensitivity of db2 DWT to abrupt changesand higher order polynomials – 1st level details

For the illustration of application of 2D db2 DWT in segmentation of planar regions, we used a synthesized surface that consists of four planar and one cylindrical segment (Fig. 2a). The detail coefficients of 2D db2 DWT at the first level of transformation of the selected surface is given in Fig. 2b. As expected, the details equal zero in points that belong to planar segments. The only exceptions are the points at the surface edges - this information will be used for the segmentation of adjacent planar regions (Fig. 2c). Simple tresholding of the details (Fig. 2b) leads to generation of binary 2D matrix (binary image) which contains one connected object for each planar segment in processed surface (Fig. 3a). Using well known procedure for detection of connected components in 2D binary image, the planar segments are recognized and segmented (Fig. 3b). After segmentation, since all data that belong to one segment are sampled from single plane, we can apply least squares regression for computation of plane parameters. The detected planar segments are shown in Fig. 2d.

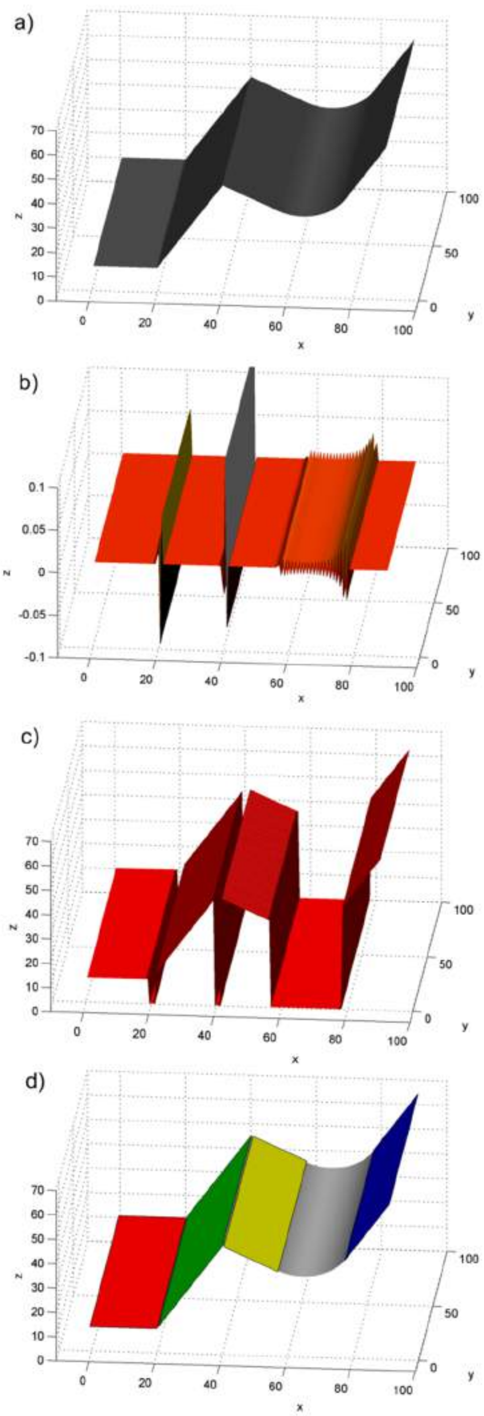

Fig. 3. a) 2D binary image; b) recognition of connected regions

3. A REAL WORLD EXAMPLE

In the scope of diversified manufacturing, adaptive control of robotized continuous welding in unstructured environment represents a significant issue. During continuous welding of the assemblies, there exists a significant discrepancy between assumed/ predefined and real pose of the seem due to the different errors that come from imperfections in semi-finished products dimensions, errors in assembly part's positioning, thermal deformations introduced during previous phases of welding, etc. Existing contact systems for detection of seem position are time expensive and have poor influence on production system's efficiency. Introduction of alternative, fast methods based on scanning devices (e.g., structured light sensors) is more than welcome. Nevertheless, the online application of scanning devices in this area demands a fast algorithm for plane segmentation and fitting. For the given reason, we have chosen the detection of the seam in corner joint as a real world example in this paper.

During experiments (Fig. 4), two metal sheets were placed in the fixture in such a way to create a corner joint. The digitization of the sheets is carried out using ATOS Compact Scan 3D scanner, and unstructured 3D mesh is generated (Fig. 5a). To employ described procedure for detection of planes, we had to create a regular point cloud from scattered points. We used an algorithm similar to z buffer algorithm along with the representation of mesh triangles in barycentric coordinates. The resulting regular point cloud is shown in Fig. 5b. After the application of wavelet based procedure, the planar regions shown in Fig. 5c are recognized. Since dealing with real world data, the threshold applied to DWT details was set to 0.002 The seam is detected as planar segments cross-section. As can be observed from Fig. 5, our procedure is insensitive to the missing data in point cloud.

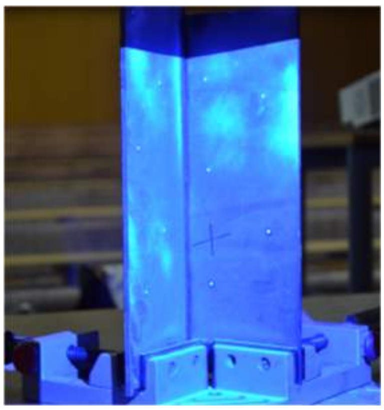

Fig. 4. Expermental setup

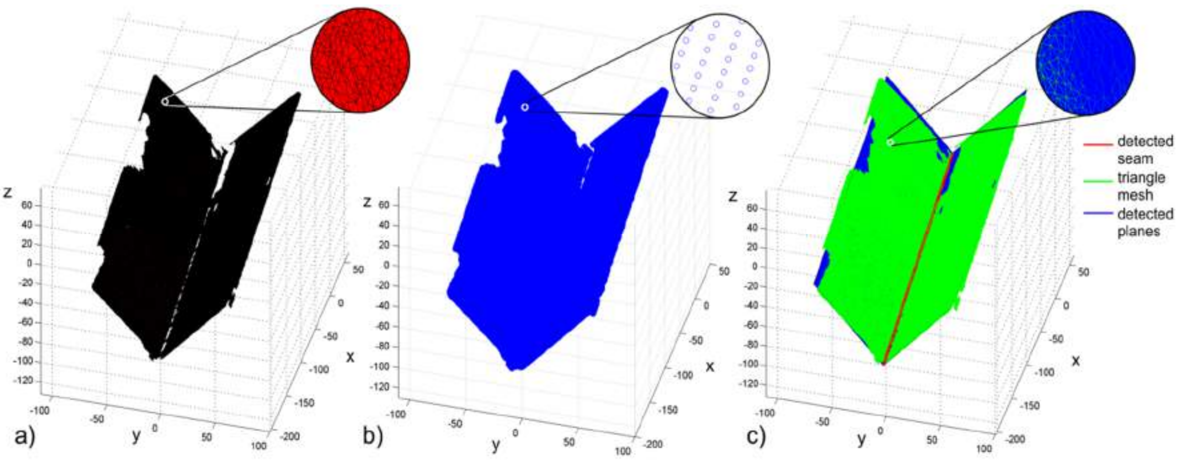

Fig. 5. Real world example – welding seam detection from scanned point cloud

4. CONCLUSION

In this paper we have introduced the method for segmentation of planar regions from point cloud using DWT. The presented method gives fast, one-pass algorithm that is suitable for detection of multiple planar regions in the cloud[1]. It is not subject to the trade off between execution velocity and the accuracy of the plane parameters present in Hough transform. In addition, our method is insensitive to missing data.

The main drawback of the algorithm is that it requires regular point cloud at input. For overcoming this issue, we have used the derivative of z buffer algorithm for scattered point cloud structuring. However, it should be noted that a large number of scanning devices outputs regular point sets.

The future work will address the segmentation of other, more complex surfaces (e.g., quadrics).

Acknowledgement: We express the gratitude to the Serbian Ministry of Education, Science and Technological Development, research grants TR35007, TR35020, TR35022, and company Topomatika Zagreb for scanning service

REFERENCES

[1] Bi Z. M., Wang L., Advances in 3D data acquisition and processing for industrial applications, *Robotics and CIM*, Vol. 26, pp. 403-413, 2010

[2] Borrmann D., Elseberg J., Lingemann K., Nuechter A., The 3D Hough transform for plane detection in point clouds: a review and a new accumulator design, *3DR Expresss*, Vol. 2, Art. 32, 2011

[3] Daubechies, I., Ten Lectures on Wavelets, *CBMS-NSF regional conference series in applied mathematics*, Vol. 61, SIAM, Philadelphia, Pennsylvania, 1992

[4] Mallat, S., G., A Theory for Multiresolution Signal Decomposition: The Wavelet Representation, *IEEE Transaction on Pattern Analysis and Machine Intelligence*, Vol II, pp. 674-693, 1989

[5] Petrović P. B., Hodolič J., et al., Intelligent robotic systems for extremely diversified production–TR35007, *38. JUPITER Conf.*, Belgrade, pp. UR.49-UR.66, 2012 (In Ser.)

[6] Savio, E., De Chiffre, L., Schmitt, R., Metrology of freeform shaped parts, *Annals of the CIRP*, 56/2, pp. 810-834, 2007

[7] Schall O., Samozino, M., Surface from Scattered Points: A Brief Survey of Recent Developments, *1st International Workshop towards Semantic Virtual Environments*, Villars, Switzerland pp. 138-147, 2005

[8] Tarsha-Kurdi, F., Landes, T., Grussenmeyer, P., Hough transform and extended RANSAC algorithms for automatic detection of 3d building roof planes from lidar data, *IAPRS*, Vol. 36, pp. 407-412, 2007

[1] Note that RANSAC algorithm demands a significant number of iterations in presence of multiple planes, while region growing methods are very sensitive to seed selection.

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VARIABLE STIFFNESS ACTUATOR DESIGN FOR INTRINSICALLY COMPLIANT AND BACKDRIVABLE INDUSTRIAL HUMANOID ROBOT

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This paper presents the concept of a variable stiffness actuator (VSA), which is the basic building block of the industrial humanoid robots. It includes VSA design of the mechanical and control system, as well as formulation of the VSA dynamic model. Special focus is paid on control law synthesis, that possess a number of various functional modes, spanning from conventional position control to a more sophisticated compliant motion control, generally based on adapted impedance/admittance control. This also includes some aspects of physical and cognitive interaction of the VSA and its environment. Besides the theoretical aspects, the paper also presents early experimental results obtained through extensive experimentations performed on a dedicated laboratory VSA prototype.

Keywords: *Industrial humanoid robots, compliant behaviour, soft joint.*

1. INTRODUCTION

New manufacturing paradigm of mass customization imposes close cooperation between human and robot, [1]. In this context, human and robot share the same work space through collaboratively performing tasks, including physical and cognitive interaction. To enable work in cooperative manner, the robot should behave like a human, and thus leads to the concept of industrial humanoid robots, [2]. Starting point for human-robot collaborative work, including physical interaction, is safety. Robotic systems safety is covered by specifications that are defined by the new series of ISO and ANSI standards which guides the design of industrial humanoids for true collaborative work without fences.

The basic building block for the concept of industrial humanoid robot is variable stiffness actuator (VSA), or more general, soft joint. Soft joint design should provide two key features: compliance and backdrivability. In fact, it is necessary to enable simultaneous control both, joint position / velocity and torque, i.e., the soft joint mechanical impedance / admittance.

In general, physical realization of the soft joint is classified into two driving configurations [3, 4]. The first of these is based on use of a single servo motor which is controlled in that way to simultaneously generates given angular position and compliance function of the soft joint, [5]. The second driving configuration is based on actuation redundancy, [6]. In this case two servo motors are used, first of which controls joint position, while compliance / stiffness of the actuator is controlled by the second servo motor. Besides the driving configuration of the VSA, the control system is of paramount importance, because the control system finally shapes the soft joint behavior and performance. Although a lot of research work is conducted in this field, design of the soft joints for industrial humanoids is still an open research area.

This paper presents results of the research activities we have conducted in the field of VSA design. Section 2 presents general framework of industrial humanoid soft joint, including generalized stiffness concept of anthropomorphic robot arm, VSA model based control laws with position and force feedback, and variant VSA design architectures. Section 3 presents basic information about the VSA laboratory prototype which is developed at the Cyber-Manufacturing Systems Laboratory, Faculty of Mechanical Engineering, as well as early experimental results in implementation of various control laws for shaping compliant and backdrive behavior of VSA laboratory prototype.

2. INDUSTRIAL HUMANOID SOFT JOINT

2.1 Generalized stiffness

Generalized stiffness of robot joint mechanism in world coordinate system Q_R, which determines relationship between the excitation force F, applied to the robot tip H, and the robot tip displacement vector δX, (Fig. 1), is defined by the following analytical relation, [7]:

$$F = K_x\left(X - X_0\right) = K_x \delta \mathrm{X}\,. \tag{1}$$

The robot tip displacement is dominantly influenced by compliance of the robot servo actuating system (joint compliance). Displacement which is induced by the robot mechanical structure is in general of secondary importance and can be neglected.

Using congruent transformation, generalized stiffness matrix K_X can be expressed in robot joint coordinates, thus leads to the actuating system stiffness matrix of the robot, [7]:

$$K_X \to K_q = J^T(q) K_X J(q),\;\; K_q \in R^{n\times n} \tag{2}$$

According to the relation (2), stiffness matrix of the actuating system K_q can be generated for virtually arbitrary generalized stiffness matrix K_X. To make this transformation physically feasible it is necessary to provide variable stiffness of the joint actuating system. This is why the VSA is required. In general, the stiffness matrix K_q is non-diagonal and nonlinear, and obviously positive definite.

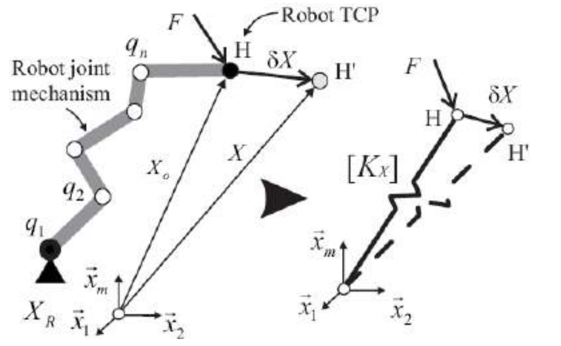

Fig. 1.General concept of the soft industrial robot

2.2 Dynamic model and control system

In our study, the soft joint which is driven by the VSA is considered as a manipulator with one controlled degree of freedom□□Fig. 2. Its approximate dynamic model is given by following relation:

$$\tau = ml^2\ddot{\theta} + v\dot{\theta} + \mu \operatorname{sgn}\dot{\theta} + mgl\cos\theta + \tau_E \,. \qquad (3)$$

Equation (3) defines the relation between the torque τ as the control variable and the set of dynamic members that influence robot joint behavior: inertial member $ml^2\ddot{\theta}$, viscous dissipative member $v\dot{\theta}$, dissipative nonlinear member of Coulomb type friction $\mu \operatorname{sgn}\dot{\theta}$, gravitational member $mgl\cos\theta$, and torque τ_E that is generated through interaction with the environment.

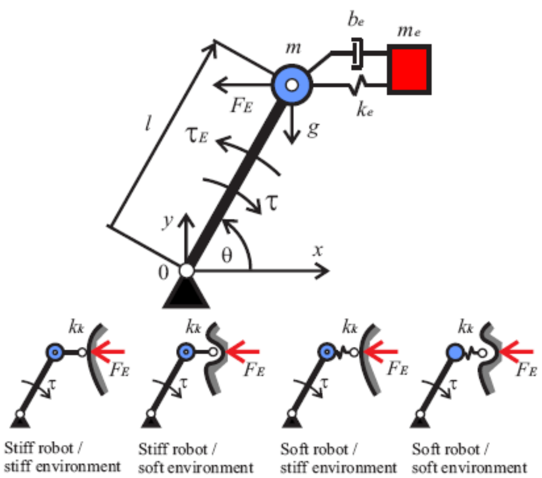

Fig. 2. Dynamic model of soft joint and typical cases of interaction with environment

The control system should provide two basic control modes: 1) position control and 2) force control that is to shape the interaction with the environment. In multi-degree of freedom robot arms, variation and combination of these basic control modes leads to a complex multi-layer control system (Fig. 3.), which should be capable of changing and controlling the behavior of the industrial humanoid, including autonomous trajectory and interaction planner in real time. To cope with unknown mechanical properties of environment, this control system should incorporate stiffness observer module as its integral part. In order to provide adaptive interaction with the environment, the high level of the robot control system sets the sets the optimal values of the stiffness, i.e., the stiffness matrix Kq that must be achieved in real-time.

Position control law for the nonlinear system (3) can be created by using the method of control law partition into a model based portion and an error based portion, [8]:

$$\tau = \alpha\tau' + \beta \,. \qquad (4)$$

where error based portion, is defined by the relation:

$$\tau' = \ddot{\theta}_0 + k_v\dot{e} + k_p e \qquad (5)$$

whereby the $e = (\theta_0 - \theta)$ is the joint angular error.

The components of the model-based portion, which encounters estimated components of the soft joint dynamic model in control law (4), including the torque τ_E generated through interaction with the environment (directly measured by appropriate force sensor), is defined as follows:

$$\begin{aligned} \alpha &= \hat{m}l^2 \\ \beta &= \hat{v}\dot{\theta} + \hat{\mu}\operatorname{sgn}\dot{\theta} + \hat{m}gl\cos\theta + \tau_E \end{aligned} \qquad (6)$$

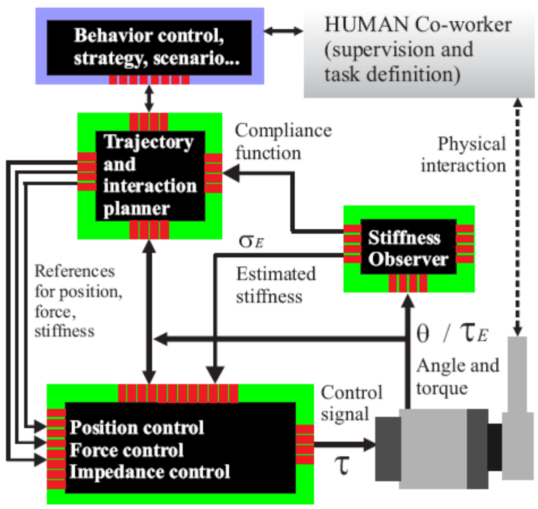

Fig. 3. Architecture of soft joint control system

Synthesis of the force control law that governs behavior of the soft joint during its physical contact with the environment requires definition of the relationship between the robot tip displacement and the corresponding contact force. This relation is defined by equivalent static stiffness of the robot-environment contact point and can be analytically determined by superposition of the robot generalized stiffness k_X and the environment stiffness k_E, which are serially coupled. Accordingly, equivalent stiffness of the robot – environment system is:

$$k_K = \frac{k_X k_E}{k_X + k_E}. \tag{7}$$

Further, the relation (7) leads to:

$$\tau_E = k_K \theta. \tag{8}$$

Relation (8) is very important, because it shows the essence of physical inseparability of the contact force and corresponding robot tip displacement. It means that in the physical domain is impossible to control the interaction force without controlling the robot displacement and opposite. By substituting equation (8) into (3), the actuator drive torque can be expressed as a function of the contact force only:

$$\begin{aligned} \tau = ml^2 k_K^{-1} \ddot{\tau}_E + h(\dot{\tau}_E, \tau_E, k_K^{-1}, \phi) + \\ + mgl\cos(k_K^{-1}\tau_E) + \tau_E \end{aligned}. \tag{9}$$

Same as for the position control law (4), the force control law can be derived using the control law partitioning method, which leads to:

$$\tau_f = \alpha_f \tau_f' + \beta_f \tag{10}$$

$$\tau_f' = \ddot{\tau}_0 + k_{vf}\dot{e}_f + k_{pf}\ddot{e}_f \tag{11}$$

$$\begin{aligned} \alpha_f &= \hat{m}l^2 \hat{k}_K^{-1} \\ \beta_f &= h(\dot{\tau}_E, \tau_E, \hat{k}_K^{-1}, \hat{\varphi}) + \hat{m}gl\cos(k_K^{-1}\tau_E) \\ &+ \tau_E \end{aligned} \tag{12}$$

whereby the error in servo portion part is defined by relation $e_f = (\tau_{E0} - \tau_E)$.

Behavior control of the industrial humanoid robot during its contact with the environment can be achieved within the trajectory and interaction planner module, whose functionality is based on the simultaneous use of both, position and force control laws (4) and (10), as well as relations (7) and (8) that analytically define physical coupling between the position and the force domain.

Control law partitioning method, used for derivation of (4) and (10), is based on feedback linearization concept [9, 10], which makes possible cancellation of nonlinearities on formally systematic manner. The essence of feedback linearization lies in the assumption that is possible to find the transition of variables *z=T(x)* such that transforms the nonlinear system into an equivalent linear system, or induces linear behavior in nonlinear system:

$$z = T(x) = \begin{bmatrix} z_1(x) \\ z_2(x) \\ \vdots \\ z_n(x) \end{bmatrix} = \begin{bmatrix} y \\ \dot{y} \\ \vdots \\ y^{n-1} \end{bmatrix}. \tag{13}$$

where: x is the state vector, y is an output vector, and n is the relative order of the system. In parallel to the feedback linearization, real-time transition between various VSA control modes during its interaction with the environment can be formally handled by the sliding mode control approach. By satisfying the various parameter sets, the VSA control system can smoothly slides within the set of specific modes of behavior.

2.3 Variable stiffness actuator architecture

Despites it design simplicity, VSA which is based on a single servo motor, that simultaneously satisfies given angular position and compliance behavior of the soft joint, has an inherent problem of stiffness observation in real-time [3]. Complexity of the control system presents major limiting factor. This problem relaxed by functional decupling which can be achieved using actuation redundancy.

As shown in Figure 4, there are two possibilities to introduce actuation redundancy in VSA design. The first one is based on mimic of nature and use two motors as an antagonistic driving pair in combination of with mechanical compliant member which is introduced in driving chain.

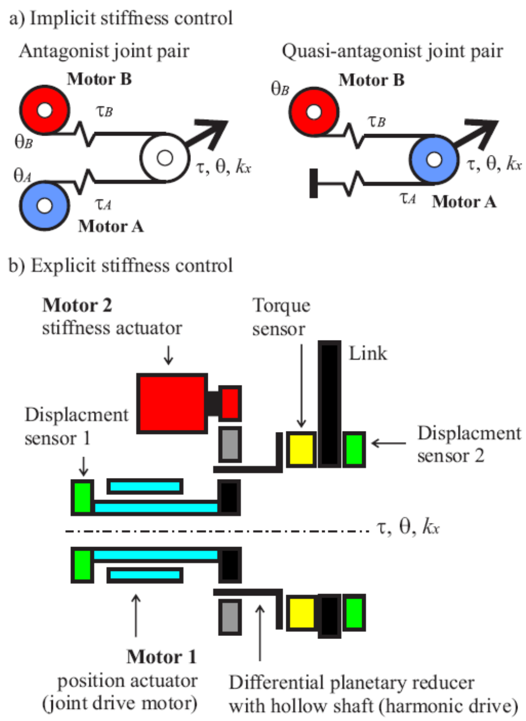

Fig. 4. Soft joint redundant actuator design

The essence of antagonistic driving approach is in combination of compliance which is generated by the servo-controlled motors and the compliance which is embedded in the mechanical structure of VSA. The VSA of this type, consists of two pre-stressed linear elastic elements (spring in generic sense), A and B, of equivalent stiffness

$k = k_A = k_B$ that take simultaneous action on the central segment, S, Fig. 5. The equation of static equilibrium is:

$$F = -F_A + F_B = -k(x - x_{0A}) + \\ +k(x_{0B} - x) = -2kx + k(x_{0B} - x_{0A}) \quad (14)$$

where: x_{0A} and x_{0B} are internal coordinates of actuating pair A and B, and x is internal coordinate of equilibrium position of the central segment S, i.e., the output of the VSA. Differentiation of (14) by the coordinate. x leads to:

$$k_X = -\frac{dF}{dx} = -2k \quad (15)$$

which shows that the VSA stiffness is constant, and therefore not depend of the internal coordinates of the actuator A and B. This is not the case for actuators with non-linear stiffness [3, 8]. For example, if the actuator stiffness is second order polynomial, then equation (14) becomes:

$$F = -k(x - x_{0A})^2 + k(x_{0B} - x)^2 = \\ = -2kx(x_{0A} - x_{0B}) + k(x_{0A}{}^2 - x_{0B}{}^2) \quad (16)$$

and consequently:

$$k_X = \frac{dF}{dx} = 2k(x_{0A} - x_{0B}) \quad (17)$$

In this case, stiffness of VSA (17) is a linear function of the internal coordinates of the actuator, and therefore it is controllable. It is clear that two internal degrees of freedom, allow simultaneous control of VSA stiffness and position. The output position of the VSA is:

$$2kx(x_{0A} - x_{0B}) + k(x_{0A}{}^2 - x_{0B}{}^2) = 0 \\ \Rightarrow x = \frac{x_{0A}{}^2 - x_{0B}{}^2}{2(x_{0A} - x_{0B})} = \frac{x_{0A} + x_{0B}}{2} \quad (18)$$

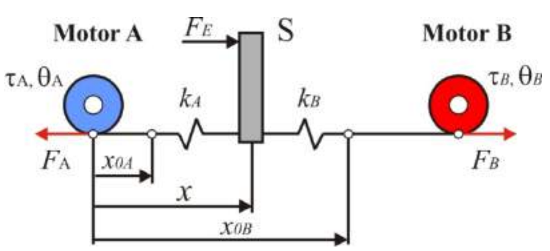

Fig. 5. Actuation redundancy concept of antagonistic couple type

Control of the VSA stiffness k_X, which can be generally an arbitrary function of the joint position, $k_{X0} = k_{X0}(x)$, and consequently control of the interaction with the environment, can be achieved by using (4), (10), (17) and (18).

Actuation redundancy concept of this type allows realization of many design solutions of the soft joint. Generally, various solutions of this type can be divided into two basic classes [3, 4, and 8]: actuators with explicit and implicit stiffness control, as shown in Fig. 4.

3. EXPERIMENTS

A dedicated experimental platform was developed at CMSysLab in order to test derived control laws and to gain practical experience with the soft joints.

Developed VSA is based on design with a single servo motor (SEW WAF10), equipped with the systems for angular position and driving torque measurement. The control system is based on networked microcontroller units (PIC18F45K22) for control the basic functional modules in real-time. Photo of the developed system in whole is shown in Fig. 6.

In Fig. 6 are shown graphs of the developed soft joint behavior for three specific cases: 1) linear spring, 2) constant force spring, and 3) passive, backdrive behavior.

The graphs in Fig. 7a) shows the soft joint behavior in interaction with soft environment (human hand) when the VSA is programmed to behave as a hard linear spring. Under an action of an external force, the soft joint generates compliant motion and moves back for 13°. After a time delay which has occurred during the presence of a stationary external force, the actuator goes back like mechanical spring to the initial position.

The graphs in Fig. 7b) show the soft joint behavior in case when the VSA is set to behaves\ as a constant force spring (like a pneumatic cylinder or counterweight mechanism). As the graph clearly shows, the soft joint interacts with the environment (again the human hand) with constant torque along the total angular movement of 13°. Joint displacment function has a pronounced hysteresis loop, which comes from a preset threshold level of allowed torque value. The threshold value should be set because the static components and internal friction of actuator reducer bring significant disturbance. The graphs show that the control system maintains stable contact torque with slight variations around the given value of 5 Nm.

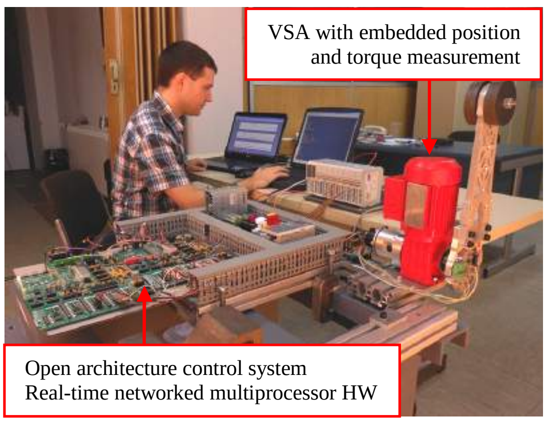

Fig. 6. Developed soft joint actuator with controllable and variable stiffness-prototype No.1

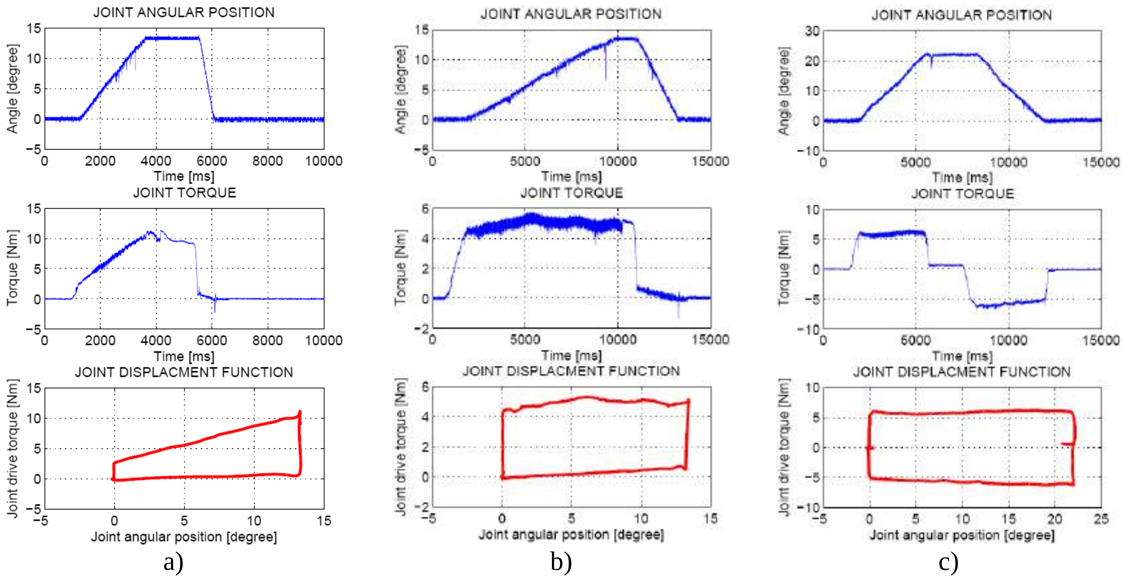

Fig. 7. Three typical cases of soft joint behavior

The backdrive behavior is shown in Fig. 7c. The actuator passively moves in the direction of the external torque, while maintaining constant force. Return to the initial state is only possible by external force acting in the opposite direction.

4. CONCLUSION

This paper presents the basic framework for design concept of the variable stiffness actuator (soft joint), which is the key component of the mechanical and control system of industrial humanoid robot. Dynamic model of one degree of freedom robotic arm, control system architecture and variant design solutions of soft joint actuator mechanical design are presented and discussed. Practical results which are obtained by experimentations with laboratory soft joint prototype developed in CMSysLab at Faculty of Mechanical Engineering, Belgrade University, clearly show the practical value of the developed theoretical models and ability of the physical system to realize human-like compliant and backdrive behavior. Further research will be directed towards improving the experimental system in sense of stability and better controllability in interaction with the rigid environment, non-stationary environment, as well tracking the desired contact force patterns. Also, further activities will be focused in the field of cognitive aspects of robot-environment interaction.

Acknowldgement: This research is carried out the Cyber-Manufacturing Laboratory - CMSysLab, Faculty of Mechanical Engineering, within the project: Smart Robotics for Customized Manufacturing, grant No.: TR35007, supported by the Serbian Ministry for education, science and technology development.

REFERENCES

[1] Jovane, F., Koren, Y., Boër, C.R., "Present and Future of Flexible Automation - Towards New Paradigms", *CIRP Annals - Manufacturing Techn.*, Volume 52, Issue 2, pp. 543–560, 2003.

[2] Petrović, P., Lukić, N., Danilov, I., "Industrijski humanoidi - novi koncept robota za kolaborativni rad čovek-mašina u sistemima za robotsku montažu", *Zbornik radova* 38. *JUPITER konferencija*, Beograd 2012, str. 3.126-3.139, ISBN: 978-86-7083-757-7.

[3] Grioli, G., Bicchi, A., "A real-time parametric stiffness observer for VSA devices", *Proceedings - IEEE International Conference on Robotics and Automation*,06/2011;DOI:10.1109/ICRA.2011.5980165 pp.5535 – 40.

[4] Sugar, T. G., Vanderborht, B., Hollander, K. W., and Lefeber, D., "Compliant Actuator Design", *IEEE Robotics & Automation Magazine*, Sept 2009, 81-94.

[5] Albu-Schäffer, A., Eiberger, O.,Grebenstein, M., Haddadin, S., Ott, C., Wimböck, T., Wolf, S., Hirzinger, G., "From Torque Feedback-Controlled Lightweight Robots to Intrinsically Compliant Systems", *IEEE Robotics & Automation Magazine*, September 2008, 20-30.

[6] Schiavi, R., Grioli, G., Sen, S., Bicchi A., "VSA-II: A Novel Prototype of Variable Stiffness Actuator for Safe and Performing Robots Interacting with Humans", *IEEE International Conference on Robotics and Automation*, USA, 19-23 May, 2008., 2171-6.

[7] Petrović, P., Lukić, N., Danilov, I., Miković, V., "Pseudoinverzija Jakobijana dijagonalizacijom aktuacione matrice krutosti kinematski redundantnog industrijskog humanoida", *Zbornik radova 56. ETRAN konferencije*, Zlatibor, 11-14. jun 2012., RO1.5.

[8] Petrović, P., Lukić, N., Danilov, I., "Eksperimenti sa mekim zglobom" *Zbornik radova 57. ETRAN konferencije*, Zlatibor, 3-6. jun 2013., RO1.2.

[9] Palli, G., Melchiorri, C., Wimböck, T., Grebenstein, M., Hirzinger, G., "Feedback linearization and simultaneous stiffness-position control of robots with antagonistic actuated joints", *IEEE Int. Conference on Robotics and Automation*, Italy, 10-14 April, 2007, 4367-72.

[10] Palli, G., Melchiorri, C., De Luca, A., "On the Feedback Linearization of Robots with Variable Joint Stiffness", *IEEE Int. Conf. on Robotics and Automation*, USA, 19-23 May, 2008, 1753-9.

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CODED STRUCTURED LIGHT TRIANGULATION FOR AGILE ROBOT – ENVIRONMENT INTERACTION IN ARC WELDING

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Abstract: *Triangulation of coded structured light is a machine vision method which enables extremely fast acquisition of object or environment geometrical data. Digitalization efficiency is primarily based on massively parallelized triangulation process and inherent robustness to various types of disturbance. Robust and agile sensory feedback in robotic welding is of high technological importance, because it enables robot to effectively communicate with its environment and cope with geometrical imperfections of parts and assembly that should be welded. It is worth to mention that structured light triangulation is in general much more complex then point or line triangulation in laser proximity sensors which are commonly used in adaptive welding applications. This paper presents the basics of the concept of coded structured light machine vision, which is adapted for robotic welding application. Besides the conceptual and theoretical aspects, this paper presents the first laboratory findings carried on dedicated experimental installation which is developed at the Cyber Manufacturing Systems Laboratory / CMSysLab at Faculty of Mechanical Engineering, Belgrade University, within the project: Smart Robotics for Customized Manufacturing, supported by Serbian Ministry for education, science and technology development, under the grant No.: TR35007.*

Key words*: Robotic Welding, Adaptive behaviour, Triangulation, Structured light.*

1. INTRODUCTION

Robotic welding is by its share in industrial practice dominant field of application of industrial robots [1, 2]. However typical robotic welding cell works as an open system, with or without a rudimentary interactions with the environment. Programming a robot to perform a specific task requires a long period of time and the system's ability to react to deviations from nominal conditions is almost non-existent. The key sensor technology that monitors the real situation, which is welded assembly are laser proximity sensors, point or line type. Although very accurate and robust, these sensors have a significant disadvantage in terms of speed of acquisition geometry, which is based on their principle of scanning.

Alternative technology which dismisses this weakness is based on complex machine vision sensors which have at its core a triangulation of structured light. Instead of dots or lines the light source emits spatial light beam, which contains a certain logical structure. Instead of scanning, the geometry acquisition is achieved by selecting a sufficient, but remarkably small number of views on the assembly that is being welded. Parallel triangulation achieves an extremely fast and robust 3D digitization, which is very important for a robotic welding process. The application in robotic welding is a relatively new and under-researched area [3, 4, 5, 6].

This paper presents a conceptual framework for the application of a machine vision, based on a structured light triangulation. It contains a discussion of results obtained on a laboratory installation realized in Mechanical Engineering Faculty, University of Belgrade.

2. THE CONCEPT

The main requirement in the process of robot welding is to recognize deviations from the nominal geometry of the assembly that is being welded and the geometry of the workplace. Adaptive robot behaviour before, during and after the execution of the program, compensate errors that affect the quality of the welding process or prevent it altogether. These errors can be grouped into four main groups:

• Type 1: Location errors of the assembly that is being welded relative to the coordinate system of the robot workspace;
• Type 2: Macro geometry errors of the assembly that is being welded, including completeness of assembly;
• Type 3: Relative location of the joint/seam errors in relation to the local coordinate system of the assembly that is being welded;
• Type 4: Micro-geometry errors of the joint/seam;.

Fig. 1. Examples of joint micro-geometry errors on the excavator track shoe.

In all mentioned groups of imperfections visual information is the direct carrier of information. On the excavator track shoe that is produced in company Kolubara Metal, Vreoci, type 4 error is identified and shown in Fig 1.

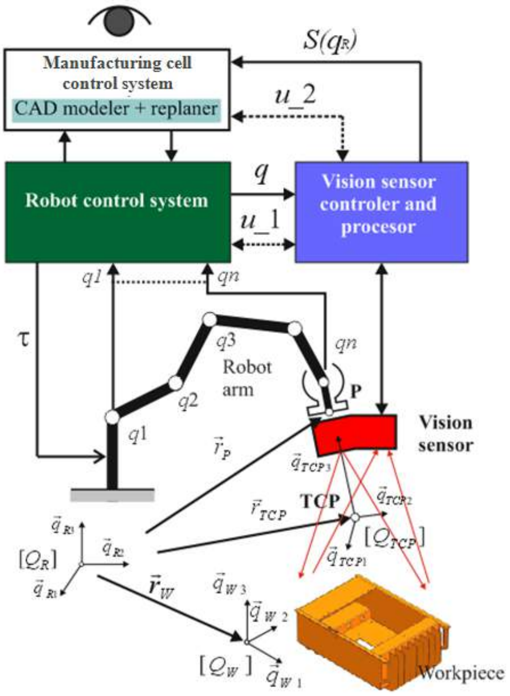

Fig. 2. General robot configuration for acquisition of workspace geometry.

As shown in Fig. 2, the robot is equipped with appropriate sensor system, which also contains a converter for pre-processing optical information (images). In order to perform welding tasks it is necessary that optical information *S(t)* is coupled with internal robot coordinates *q(t)*, and then with external coordinate system of the robot $[Q_R]$. Also we need to establish transformation matrix that links the local coordinate system of the sensor $[Q_{TCP}]$ and the local coordinate system in which the nominal geometry of welded assembly is defined $[Q_W]$. This type of transformations of digital model of the assembly that is welded is brought to the required form $S(q_R)$, which expresses its complete geometry in the coordinate system of the robots workspace. These transformations are necessary to provide that digitized model of the assembly could be taken into the appropriate CAD modeller and replaner of nominal welding task module. In Fig. 2, these modules are housed in a manufacturing cell control system which controls entire welding system. These modules achieve a very complex functionalities, including comparison of digitized assembly that is welded to the nominal CAD model. This comparison identifies errors and classifies them into one of 4 typical forms listed above. Further on, replaner module generates new, corrected trajectory or modified welding plan.

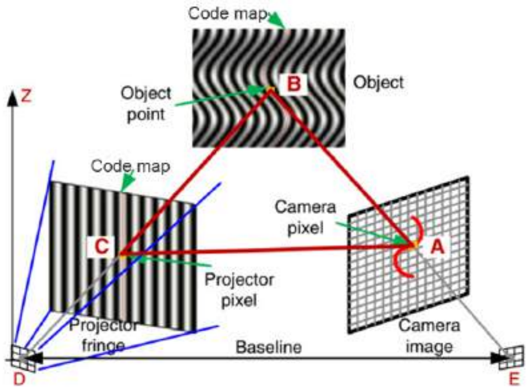

Fig. 3. Concept of spatial digitizing using structured light.

The concept of spatial digitizing using structured light is shown in Fig. 3. Programmable light source (projector) generates appropriate planar map with known coded content and projects it to the scene which contains object that is digitized. Camera's optical sensor records reflections of the projected light. Image analysis is used to identify changes, actually distortion of the projected code map. By measuring these distortions and using triangulation geometry, each pixel or group of pixels, is assigned with third spatial coordinate. This process transforms planar images into a space cloud of points. Tessellation translates obtained spatial cloud into a spatial model of the scene containing the digitized object.
In order to generate a spatial model, and assign z-coordinates of the center of each cluster in the function of its displacement measured in pixels of camera's optical sensor, it is necessary to generate the appropriate transformation matrix T which will take into account the internal and external geometry and other features of entire optical system.
Number of code maps and optical sensor resolution determine the spatial resolution of the scene. Fig. 4 shows the case of the 16 bit resolution $(m = 16)$ code map generator. It generates eight Gray code maps for the horizontal and eight maps for the vertical axis. Such a code sequence generates $2^m = 2^{16} = 65536$ coding groups, which means that the scene is discretized into 65536 spatial clusters of pixels with the same coding content.

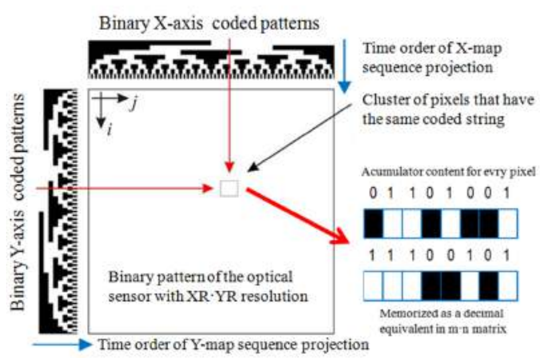

Fig. 4. Schematic representation of the m-th order binary map generator, Gray coded.

The obvious difference between discretization which is accomplished with a series of maps and coding discretization of optical drive should be distinctive. The

optical drive has to have a higher resolution, at least an order of magnitude, thus each spatial cluster should contain ten or tens of pixels. Each cluster in the further processing is reduced to a point that represents it. This point can be the center of the cluster, *c_ij*. Alternatively, methods have been developed to recognize the cluster edge pixels between two adjacent clusters, *s_ij*, [7]. Reduction to the cluster center *c_ij* requires higher level of calculations, but at the same time, this can significantly increase insensitivity to noise and other disturbances.
In the research conducted on the project TR35007 a new method of integrated calibration of the entire optical system has been developed. It is implemented directly over the field of cluster centers, generated on the scene with known spatial geometry. The complete measuring system is considered as a black box. This approach eliminates the need to build a partial model for projector and camera which is the most common approach in optical system calibration [5].

3. EXPERIMENTAL RESULTS

Practical assessment and improvement of the developed algorithms is performed on the test table, shown in Fig. 5, which was specifically developed for this purpose. The experimental system consists of the following components: 1) granite table 2) cross-table with a third rotary axis, 3) module for generating structured light with 1024×860 pixels and receiving opto electrical converters in stereo configuration with two cameras, 640×480 resolution and USB2 interfaces, 4) computer which generates the code map, i.e., programmable generator of a coded light, 5) data acquisition computer to manage cameras and transmission of sensory signals from both cameras, 6) scene with adjustable removable canopy of plane type 7) object to digitize.

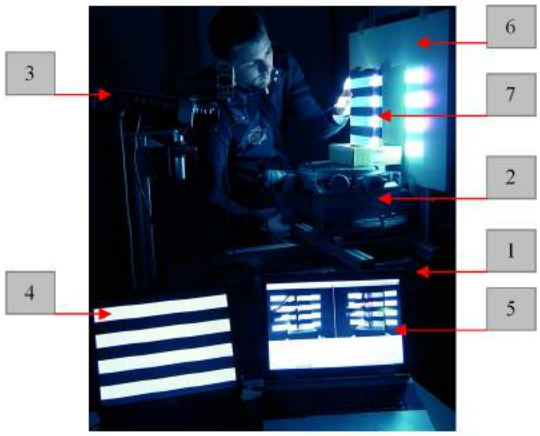

Fig. 5. Experimental system for structured light triangulation developed at CMSysLab.

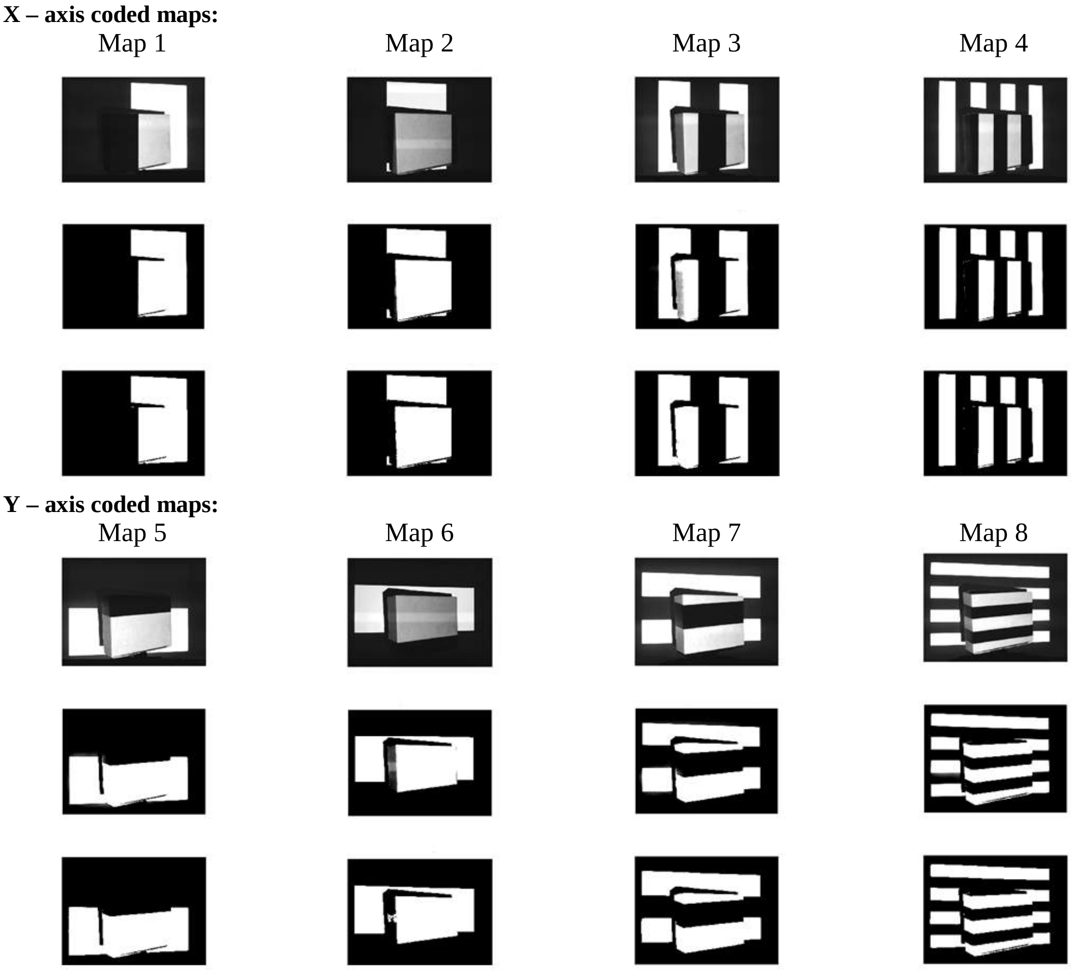

Fig. 6. Series of scene images with projected coding maps of 8 bit resolution (4 maps in X axis and 4 maps in Y axis).

Fig. 6 shows a series of images obtained by the successive projection of 8 bit code map series, where the total area affected by optical sensor is discretized into 256 coding clusters. Fig. 6 shows the results of frames processing stages as follows: monochrome original frame, the result obtained by adaptive histogram adjustment, and finally, binary transform with the given threshold for binary conversion.

The generated binary images with 640×480 resolution are superimposed with the aim to generate the corresponding 8 bit code groups for each pixel. Superposition of binary content is achieved by concatenation, following the temporal sequence of coding map projection, i.e.: $p_{ij} = b_{ij8} \cdot b_{ij7} \cdot \ldots\ldots \cdot b_{ij1}$. Further on this string is converted into its decimal equivalent and kept in the composite matrix *FS* (p_{ij}) size 640×480. This operation sets eight binary frames down to a single grayscale frame. Fig. 7 is a graphical representation of this grayscale frame with 8 bit resolution. In Fig, 7 clusters of pixels of the same code group, i.e., the same decimal value, are clearly visible.

Also, the distortion of the projected code maps is obvious. On the graphical representation of the FS matrix (Fig 7.) it is noticeable that the code group with zero decimal value is the most common. This is due to the presence of shadows and non-reflective background of the scene. By eliminating all pixels that have zero decimal value, this disturbance is eliminated.

Further processing of FS matrix involves two main activities: 1) the selection of valid clusters and 2) calculating the centers of valid clusters. The validity of clusters is determined by the measure of deviation between number of pixels contained in the cluster and the nominal number of pixel calculated for the ideal functioning of the measuring system and its compactness. Margin is adopted empirically and depends on the particular case of application, but ± 10% could be a good measure in the general case, which is used here. Cluster centers are calculated to maintain natural discretization of the scene space. Optionally it is possible to go down to subpixel resolution.

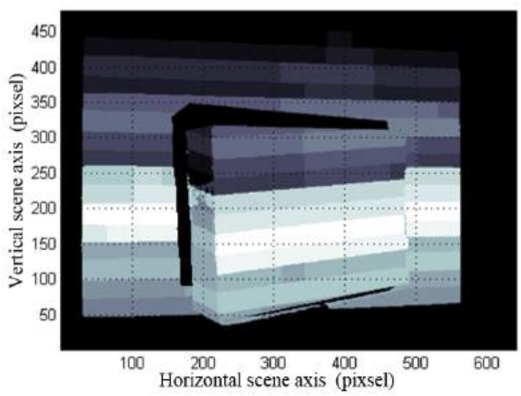

Fig. 7.
Graphic presentation of FS matrix that is obtained by the accumulation of the binary matrix derived from a set of 8 projected code maps.

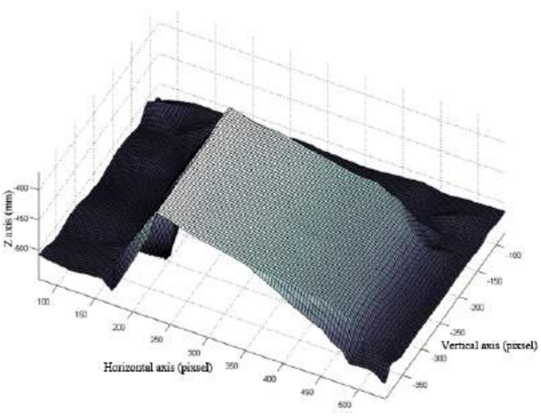

Fig. 8. Generated spatial (3D) model of the scene and the object being digitized derived from a primary point clouds and use of uniform interpolation grid with 9396 points

Based on the calculated coordinate centers of the 256 clusters, using the transformation *T*, each center of cluster c_{ij} is related to the corresponding z-coordinate. In that way a point cloud is generated, and using appropriate tessellation method is transformed into an equivalent spatial model [8]. Fig. 8 shows the spatial model of the scene and the object being digitized (prism), obtained by transformation of *FS* matrix. Fig. 9 shows the digital model coated with color map – reconstructed skinned model with original color map of acquired scene.

Fig. 9. Model from Fig.8. coated with color map taken from the initial (original) frame illuminated in uniform white.

Regardless to sufficient fidelity of generated digital model in physical scene shown in Fig 9, the process is not perfect and certain errors occur. These errors can be classified into three classes (Fig 10):

(a) Edge type errors split the cluster into two subclusters, which is the result of interference between geometry of the object that is digitized and code mask projected on it. This error is virtually impossible to eliminate because the edge is geometric primitive of discontinuity type and requires infinite resolution.
(b) Inhomogeneity type errors are caused by the cluster uniform brightness. The cluster is incompact and has an internal structure that includes several well-defined subclasters. Unlike in the previous case this error can be corrected. The first criterion is the compactness criterion, on which the error of this type

can be recognized. The second criterion is neighbourhood criterion.

(c) Scattering type errors caused by optical noise or reflections. The cluster consists of a well-defined core and a number of scattered pixels that do not form compact substructures relevant to this type of classification. An error of this kind is possible to identify and to classify the good and bad coded pixels.

Further processing can correct or eliminate identified errors. The relation of each pixel with code group can be efficiently used in that sense.

(a) Edge type errors (b) Inhomogeneity type errors (c) Scattering type errors

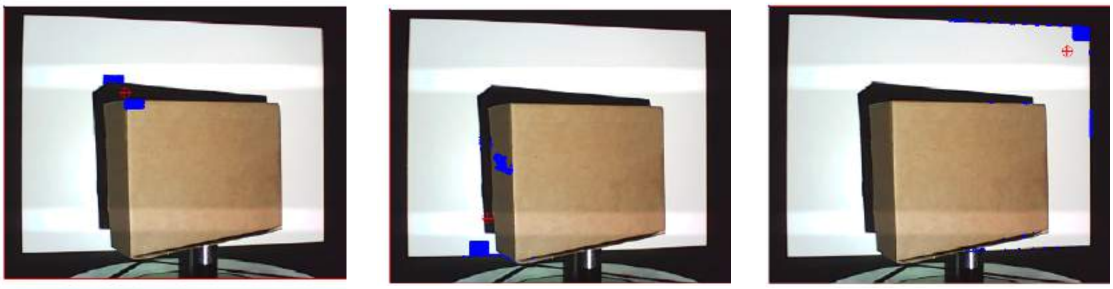

Fig. 10. Typical error types in pixel clustering that arise as a result of optical imperfections or disturbances. Blue pixels have the same coding content and the red cross is the center of the cluster of the identified code group.

4. CONCLUSION

This paper presents preliminary results of the development of sensor technology for effective interaction between the robot and the environment within the manufacturing system for welding. Triangulation of structured light is dramatically increasing the speed of scene geometry acquisition compared to the conventional solutions based on point or line laser triangulation. The low resolution system of 640×480 pixels has quite satisfactory performance for the application of this kind. Further research will be directed towards building optical modules that will have performance which will allow installation on the robot. That would make practical experiments in real industrial conditions possible.

Acknowledgement: The research presented in this paper is supported by Serbian Ministry for education, science and technology development within the project: Smart Robotics for Customized Manufacturing, under the grant No.: TR35007.

REFERENCES

[1] J.N. PIRES, A. LOUREIRO, AND G. BOLMSJO, *"Welding Robots: Technology, Systems Issues and Applications "*, Springer-Verlag London Limited 2006, ISBN-10: 1852339535

[2] T.-J. TARN, S.-B. CHEN, C. ZHOU (EDS.), *Robotic Welding, Intelligence and Automation*, Springer-Verlag Berlin Heidelberg 2007, ISBN-10 3-540-73373-6.

[3] J. B. PARK, S. H. LEE, AND I. J. LEE, Precise 3D Lug Pose Detection Sensor for Automatic Robot Welding Using a Structured-Light Vision System, Sensors 2009, 9, pp.: 7550-7565; doi: 10.3390 /s90907550

[4] PETROVIĆ, P., DANILOV, I., LUKIĆ, N., "Brza prostorna digitalizacija okruženja primenom triangulacije strukturirane svetlosti u robotskom zavarivanju" ZBORNIK RADOVA 57. KONFERENCIJE ZA ETRAN, Zlatibor, 3-6. jun 2013., RO3.1.

[5] B.G. BATCHELOR AND P.F. WHELAN: *Intelligent Vision Systems for Industry*, Springer, 2002, ISBN-10: 3-540-19969-1.

[6] P. F. STURM AND S. J. MAYBANK, On Plane-Based Camera Calibration: A General Algorithm, Singularities, Applications, IEEE Conference on Computer Vision and Pattern Recognition (CVPR'99) 1, 1999, 432'437.

[7] H. B. WU, Y. CHEN, M. Y. WU, C. R. GUAN AND X. Y. YU, 3D Measurement Technology by Structured Light Using Stripe-Edge-Based Gray Code, Journal of Physics: Conference Series 48 (2006), 537–541.

[8] W. WILKE, Segmentierung und Approximation großer Punktwolken, Dissertation, Technischen Universitat Darmstadt, Darmstadt 2002.

Metrology, quality systems and quality management

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UNCERTAINTY MODELING IN THE TECHNICAL PRODUCT RISK ASSESSMENT

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Abstract: *European Union has accomplished, through introducing New Approach to technical harmonization and standardization, a breakthrough in the field of technical products safety and in assessing their conformity, in such a manner that it integrated products safety requirements into the process of products development. This is achieved by quantifying risk levels with the aim of determining the scope of the required safety measures and systems. The theory of probability is used as a tool for modeling uncertainties in the assessment of that risk. In the last forty years are developed new mathematical theories have proven to be better at modeling uncertainty when we have not enough data about uncertainty events which is usually the case in product development. Bayesian networks based on modeling of subjective probability and Evidence networks based on Dempster-Shafer theory of belief functions proved to be an excellent tool for modeling uncertainty when we do not have enough information about all events aspect.*

Key words*: Product Development, Risk Assessment, Belief Function Theory, Evidence nets, Bayesian nets*

1. INTRODUCTION

All organizations, regardless of their field of activity and size, are faced, in realizing their objectives, with some form of risk. The objectives may vary and may be related to a strategic initiative, operative realization of a project, product, service and similar.

The importance of individual risks for an organization is determined by numerous factors, both internal ones depending on the organization itself and by external factors set forth by the environment in which the organization operates.

Technical products have to be safe for use and the best way to realize that is by creating and realizing the “inherently safe design structures” /1/ which is achieved by the process of designing, by adequate manufacturing processes involving all testing and controls, and by adequate work processes in which they are used.

In the beginning of the nineties of the previous century, the European Union accomplished, through introducing the New Approach to technical harmonization and standardization, a breakthrough in this field by integrating the product safety requirements into the process of technical products designing /1; 2/. In the directives for technical products, essential health and safety requirements have been set, which each technical product has to satisfy prior to place in the market. These requirements are defined in general form and the way of their implementation is given in the harmonized standards. In this way, designers and suppliers of technical products have got clear instructions regarding the way to accomplish conformity of these products to the directives’ requirements and the way of integrating safety requirements into the phase of developing these products. In this way, fundamental change has been achieved in preventing possible occurrence of accidents in the working space in which these technical products are used.

The decision regarding level of safety measures is based on previously conducted risk analysis and assessment.

Risk assessment is the methodology through which risk levels are quantified with the objective of determining the scope of required safety systems, all aimed at protecting operators, and all others coming in contact with the technical products, from possible injuries and damages.

Estimates of risk are becoming central to decisions about many engineering systems. In many important cases we do not have enough data on the events we try to design for. In this way, modeling and measurement uncertainty becomes central to the risk assessment of a technical system.

Probability is the most suitable method for modeling random uncertainty when there is sufficient information on the probability distribution. But very rarely we have enough information to make the reliability could use the classical theory of probability to model uncertainty. Therefore, for modeling uncertainties we use other mathematical structures and tools that were developed last thirty years such as Evidence nets (developed on the base of Dempster-Shafer theory /3; 4; 5/) and Bayesian nets based on subjective belief (probability).

This paper present concept of integration risk assessment in the technical product development process, the concept of international standardization in the risk management field and on the end base information about Evidence and Bayesian nets and is possibility use in technical product risk assessment.

2. CONCEPT OF STANDARDIZATION IN THE RISK MANAGEMENT FIELD

Experience in the business practice in the last fifteen years has shown that the risk management concept has been in the phase of significant changes. This is substantiated by the fact that business associations,

international, regional and national standardization body have created several models, standards and operation frameworks.
Presenting the standards in the world today surpasses the objectives of this paper. Therefore, we are going to focus further only on standardization in the field of risk conducted by the International Organization for Standardization (ISO) and some of the most significant national standardization bodies (Table 1).
The concept of standardization in the field of risk, implemented by the International Organization for Standardization ISO and European standards bodies (CEN and CENELEC) has got the hierarchical structure of standards, as depicted in Figure 1. The concept starts from the fact that successful implementation of risk management in any organization requires a standards structure which sets up from general standards and through the standards defining terminology to standards in which risk analysis and assessment requirements are set for individual business processes and/or functions, and further on to standards in which there are guidelines directing about how to execute these analyses and assessments, and finally, there are structures defining the tools to be used in the risk analyses and assessments.
Figure 1 depicts complete hierarchy structure of international and regional standards in the field of risk management, which are of importance for implementing the New Approach Directive (NAD).

Table 1. The most influential international and national risk management standards

Publisher	Standards	Publisher	Standards
ISO	**ISO 31000:2009, *Risk management -- Principles and guidelines***	CSA (Canada)	**CSA Q 850: 1997**, *Risk Management Guidelines for Decision Makers*
ISO/IEC	**ISO/IEC 73:2009**, *Risk management -- Vocabulary*	JSA (Japan) (withdraw)	**JIS Q 2001:2001**, *Guidelines for development and implementation of risk management system*
	ISO/IEC 51:1999, ***Safety aspects -- Guidelines for their inclusion in standards***	AS/NZS (Australia / New Zealand)	**AS/NZS 4360:2004**, *Risk Management*
	ISO/IEC 31010:2009, ***Risk management -- Risk assessment techniques***	BSI (Great Britain)	**BS 25999-2:2007**, *Business continuity management. Specification*
ISO	**ISO 14121-1:2007**, *Safety of machinery — Risk assessment — Part 1:Principles*		**BS 31100:2011**, *Risk management. Code of practice and guidance for the implementation of BS ISO 31000*
	ISO/TR 14121-2:2007, ***Safety of machinery -- Risk assessment -- Part 2: Practical guidance and examples of methods***		**BS 6079-3:2000**, *Project management. Guide to the management of business related project risk*
	ISO 14971:2007, *Medical devices -- Application of risk management to medical devices*	ON (Austria)	**ONR 49000:2010**, *Risk Management for Organizations and Systems - Terms and basics - Implementation of ISO 31000*
ISO/IEC	**ISO/IEC 27005:2011**, ***Information technology -- Security techniques -- Information security risk management***		**ONR 49001:2010**, *Risk Management for Organizations and Systems - Risk Management - Implementation of ISO 31000*
ISO	**ISO 14798:2009**, *Lifts (elevators), escalators and moving walks -- Risk assessment and reduction methodology*		**ONR 49002-1:2010**, *Risk Management for Organizations and Systems - Part 1: Guidelines for embedding the risk management in the management system - Implementation of ISO 31000*
	ISO 17776:2000, *Petroleum and natural gas industries -- Offshore production installations -- Guidelines on tools and techniques for hazard identification and risk assessment*		**ONR 49002-2:2010**, *Risk Management for Organizations and Systems - Part 2: Guideline for methodologies in risk assessment - Implementation of ISO 31000*
EN	**EN 1127-1:2011,** *Explosive atmospheres. Explosion prevention and protection. Basic concepts and methodology*		**ONR 49002-3:2010**, *Risk Management for Organizations and Systems - Part 3: Guidelines for emergency, crisis and business continuity management - Implementation of ISO 31000*
	EN 13463-1:2009, *Non-electrical equipment for use in potentially explosive atmospheres. Basic method and requirements*		**ONR 49003:2010**, *Risk Management for Organizations and Systems - Requirements for the qualification of the Risk Manager - Implementation of ISO 31000*

At the highest generic level, there is the standard ISO 31000:2009 which provides for general instructions and principles for developing and implementing risk management in any organization. In the following level, there are the standards and guidelines incorporating the vocabularies of terms. These are ISO/IEC Guide 73:2009 and ISO/IEC Guide 51:1999 standards.
This group of standards defining the terms might also be extended by standard ISO 12100-1:2010, expressing the basic overall methodology to be followed when designing machinery and when producing safety standards for machinery, together with the basic terminology related to the philosophy underlying this work. The requirements for technical products safety are given in the New Approach directives. They are defined in general form so that they cannot not become obsolete so quickly. From the risk point of view, the requirements defined in such a manner represent the risk management objectives in the process of product development related to safety of the products.
In the course of product development, designers has a dilemma of how to determine if a product is safe or not,

i.e. how to execute the risk analysis and assessment and how to improve the design solution on the basis of this. It is difficult to determine in practice the safety of a non-standardized product if there is no adequate reference with respect to which it can be done.

In response to this problem, the European Commission has initiated with CEN the development of generic harmonized standards enabling the systematic approach and providing the guidelines for: (1) identification of hazards; (2) risk assessment due to these dangers, and (3) assessment of acceptability of the selected safety measures.

Thus, a set of generic standards ensued for assessing risks in the NAD, such as: ISO 14121-1:2007 for machines products, EN ISO 14971: 2002 for medical products, ISO TR 14798:2006 for lifts, etc.

From the standpoint of product safety, these standards serve as guidelines on how to conduct the risk analysis and assessment. Thus, as it is depicted in Figure 2, they have got a dual role. On the one hand, they serve as the tool (guidelines) used by designers and engineers in analyzing and assessing the level of safety of design solution in the course of product development process, while on the other hand they are also the tool for the organization's staff and/or conformity assessment body in assessment whether a product satisfies the requirements of directives and/or harmonized standards, i.e. whether they possess satisfactory levels of safety.

At the lowest level of the standards structure hierarchy, there are the tools developed as independent standards, such as, for example, ISO/IEC 31010:2009 which provides large number of techniques that can be applied in risk assessment. In addition to the standards serving as tools, organizations very often also develop specific tools in which the risk assessment methodology given in some of the standards, such as for instance ISO 14121:2007, is adjusted to products and business practice present in that particular organization. These tools are presented in the form of various procedures, instructions or, most often, in the form of checklists (Figure 1).

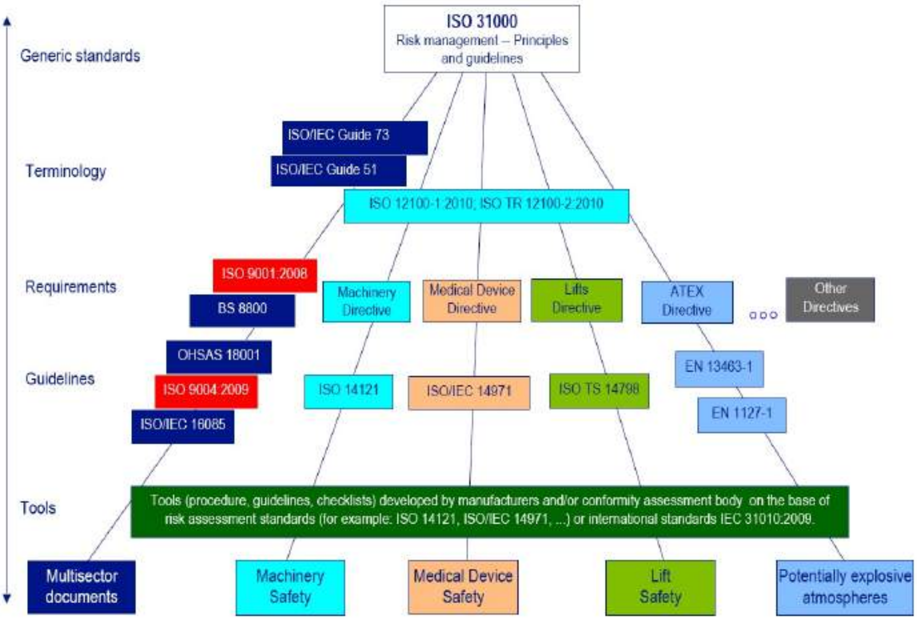


Fig. 1. Hierarchy structure of standards in the risk management field, of importance in implementing the EU technical legislation [2]

RISK ASSESSMENT INTEGRATION INTO THE PRODUCT DEVELOPMENT PROCESS

The designing process is a set of activities and its related resources, through which team of designers develops or selects means for achieving a certain goal under strictly defined conditions and restrictions.

Technical products have to be safe to use, while the best way to achieve this is through a well designed solution and through adequate work practice in which the products are used. The NAD require the technical products risks to be assessed in the phase of product designing, while adequate legislation regulations define safety of the working space in which they are used.

All designers and employees who take decisions in product development process have to be familiar with the general and/or specific processes for risks assessment as defined in the relevant ISO or EN standards.

In order to have technical products covered by the New Approach legislation and to perform their intended functions safely, it is necessary to keep the risks from all hazards at satisfactorily low levels. The risk reducing methodology is based on several key steps:

- The manufacturer or its authorized representative determines, by using harmonized standards such as, for instance, machinery standards ISO 14121-1:2007 and ISO 12100-1:2003 Parts 1 & 2, through the risk assessment procedure, the level of risk for the identified hazards, taking into consideration the limitations within which these technical products perform their functions. In case that it is determined, after risk evaluation activities, that the identified risk level exceeds the acceptable levels, new measures are requested aimed at its reduction;

- Pursuant to the risk reduction methodology, the manufacturer or its authorized representative is first going to undertake risk reduction by modifying the existing design solution, i.e. it will try to accomplish risk reduction through the so called ”inherently safe design solution”;
- If the risk reassessment shows that the risk level is still high, the manufacturer or its authorized representative will take certain measures, such as for example installation of adequate protection in the endeavor to additionally reduce the risk;
- It can be assumed that in spite all previously taken measures there still remain certain (residual) risks, so it is the task of manufacturer or its authorized representative to inform future users about all these tasks, on the product itself and by way of instructions for use.

Risk assessment in that process is the constituent part of the phase in which the designer adjusting its design to the requirements (create design solution) and on the other hand the constituent part of final product conformity assessment (final control and inspection) (Figure 2) conducted by the organization itself and/or the body for conformity assessment

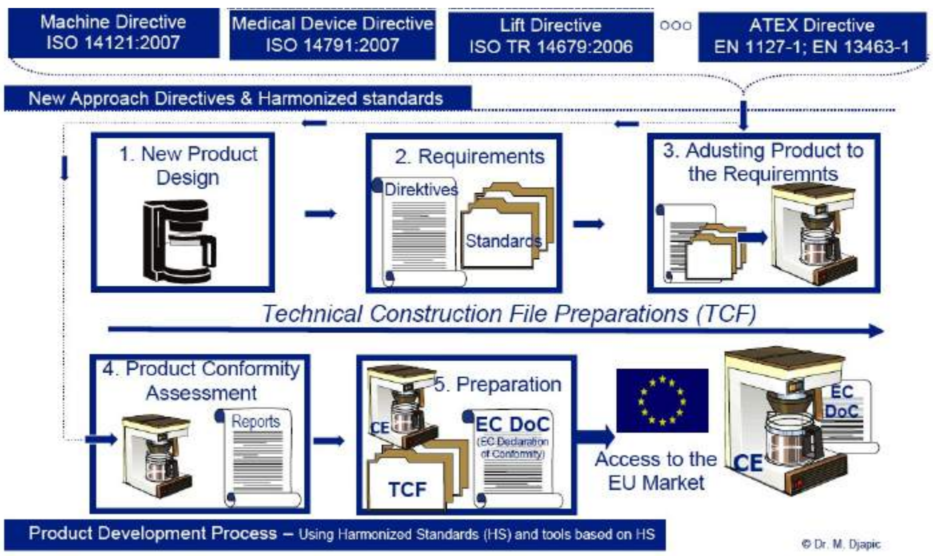


Fig. 2. Integrating risk assessment in NAD into the technical product development

UNCERTAINTY MODELING IN THE RISK ASSESSMENT

Standard ISO 31000:2009 on risk management and ISO/IEC 73:2009 guidelines for defining terms in the risk field, define risk as the **effect of uncertainty on acquiring organization’s objectives**. It is the effect of a deviation from the expected outcome of an event, situation, etc., that can be in either positive or negative direction. Risk is often expressed as a combination of consequences of an event and the probability of its occurrence. Probability is defined as a chance for something to happen, no matter whether it has been defined, measured or determined, either objectively or subjectively, or whether it has been described in quantified or qualified manner by using general mathematical terms, such as event probability (expressed in the 0-1 interval) or an event occurrence frequency in the given period of time. The uncertainty is observed as a state of lack of information and in some cases as a state of partial lack of information related to the knowledge and understanding of certain events, their consequences on the organization’s objectives or corresponding likelihood.
Out of these definitions, the conclusions that follow can be drawn:

- Risk is related to achieving objectives.
- ISO/IEC organizations use the uncertainty as the basic pillar in defining risk, and not the probability as it was formerly defined by the standard AS/NZS 4360:1995.

Today, papers can be traced in literature highlighting some shortcomings of the risk being defined in this way by the ISO/IEC organizations. Readers are directed, for example, to /Aven in 2/ etc. This is understandable, as the concept of risk is related to all fields of human activities and it is very difficult to find and define something that would be satisfactory to all. However, the authors of this paper consider this definition to be the best, most general definition that is acceptable for practitioners in most of the fields of human activities. This is additionally corroborated by the contemporary mathematical tools which enable mathematical modeling of uncertainty, such as the tools developed on the basis of fuzzy sets, Bayes’ nets or valuation nets, developed on the basis of the *Dempster–Shafer* theory of belief function /3; 4; 5/. This assertion can be additionally corroborated by the fact that the *IEC - International Electrotechnical Commission* has developed standard related to the techniques that can be used in risk management. This is the standard IEC 31010:2009 *Risk Management – Risk Assessment Techniques*, where there are some of the methods of modeling the uncertainty.

Type of Information	Models
Imprecision Information	Theory of fuzzy sets Theory of possibilities
Uncertainty Information	Theory of probabilities Theory of belief functions (**Dempster-Shafer evidence theory**)

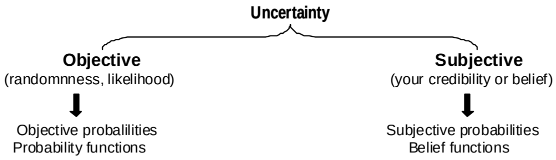


Fig. 3. Modeling uncertainty (Adapted by /5/)

If we analyze the literature Figure 3) on types of uncertainty, we can conclude the following. There are two types of uncertainty:

- **Aleatory (irreducible) uncertainty** refers to the inherent randomness or unpredictability of the system
  - Modeling by - probability theory.
- **Epistemic (reducible) uncertainty** - from lack of knowledge and such, is sometimes called imprecision or subjective uncertainty
  - Modeling by – Dempster-Shafer evidence theory or
  - Modeling by probability theory (subjective measure)

Finally comments on modeling uncertainty in risk assessment:

- There is a rich collection of theories for modeling all types of uncertainty
- These theories are not in conflict with Bayesian or classical probability but rather provide tools that complement probabilistic methods for risk assessment
- Probability is the most suitable method for modeling random uncertainty when there is sufficient information on the probability distribution
- Non-probabilistic methods (evidence theory, subjective probability) can be useful in modeling reducible uncertainty

Base of Dempster-Shafer belief function theory

Making conclusions (reasoning) about certain situation from the real world is often in difficult circumstances with insufficient knowledge, no clearly defined criteria and mutual antagonism. Information about evidence can come from different resources: based on a person's experience, from signals recorded by appropriate sensors, from the contents (the context) of published papers and so on. Such evidence are rarely clearly delimited; it's often incomplete, ambiguous in its meaning and full of flaws.
Dempster-Shafer belief function theory provides powerful tools for mathematical presentation of the subjective (opposite of what probability theory is based on) uncertainty while it relies mainly on possibility of explicit definition of ignorance [3]. It, actually, represents the generalization of Bayesian theory of conditional probability.

The model of belief function consists of variables, possible values of these variables and the evidence that support the variables. Variables are individual questions about any aspect of the problem under consideration. Answers on posed questions can be made based on data gathered from different sources, or from the context of published papers, from data acquired on measured values, from expert's opinion etc. Fully unified support for possible answer is called a evidence. Evidence can be described by belief functions that are defined as follows.
Definition.1. [4] Let Θ be a finite nonempty set called the frame of discernment, or simply the frame. Mapping *Bel*: $2^{\Theta} \to [0,1]$ is called the (unnormalized) belief function if and only if a basic belief assignment (bba) *m*: $2^{\Theta} \to [0,1]$ exists, such that:

$$\sum_{A \subset \Theta} m(A) = 1 \tag{1}$$

$$Bel(A) = \sum_{B \subset A, B \neq \varnothing} m(B) \tag{2}$$

$$Bel(\varnothing) = 0 \tag{3}$$

Value *m*(A) can be taken as a measure of one's belief that is committed exactly for subset A and it's moving freely within it.
Condition (1) shows that one's entire belief that is supported by the evidence may have a maximum value of one and the condition (3) refers to the fact that one's belief that was committed to an empty set must be zero.
Value *Bel*(*A*) represents the total belief that is committed to set A and all its subsets.
Each subset of *A* whose *m*(*A*)>0 is called focal element.
The empty belief function is a function with *m*(Θ)=1 and *m*(*A*)=0 for all subsets of $A \neq \Theta$. This function represents complete ignorance about the problem under consideration.

<u>What are the Evidential Systems (Nets)?</u>

Valuation Based Systems - VBS is an abstract framework proposed by Shenoy /3/ for representing and reasoning on the basis of uncertainty. It allows representation of uncertain knowledge in various domains, including Bayes' probability theory, Dempster-Shafer's theory of evidence which is based on belief functions and Zadeh-Dubais-Prad theory of possibility. Graphically presented VBS is called valuation network /4/.
VBS consists of set of variables and set of valuations that are defined on the subsets of these variables. Set of all variables is denoted by U and represents a space covered with problem which is under consideration. Each variable represents a relevant aspect of a problem. For each variable X_i will be used Θ_{X_i} to denote the set of possible values of variables called the frame of X_i. For a subset A (|A|>1) of U, set of valuations that are defined over Θ_A represents the relationship between variables in A. Frame Θ_A is a direct (Cortesian) product of all ΘX_i for X_i in A. The elements Θ_A are called configurations of A.
Knowledge presented in this type of valuations is called generic or general knowledge (Figure 4), which can be represented as a knowledge base in expert systems.

The VBS also defines valuations on individual variables, which represents so-called factual knowledge, and it constitutes database in expert systems (Figure 4). For a problem, general-generic knowledge defines an expert. During reasoning process that knowledge won't be modified. Factual knowledge will vary in accordance with condition of a problem currently being under consideration. The VBS treats on the same way these two kinds of knowledge.

The VBS systems suited for processing uncertain knowledge described by functions of belief function theory are called Evidential Reasoning Systems or Evidential Systems, and valuation networks are now called evidential networks (EN) (Figure 4 and 5b).

The objective of reasoning based on the evidence is an assessment of a hypothesis, in case when the actual evidence are given (the facts).

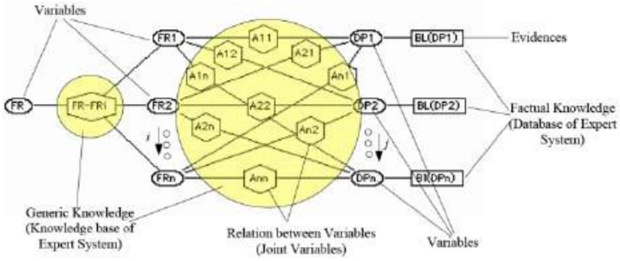
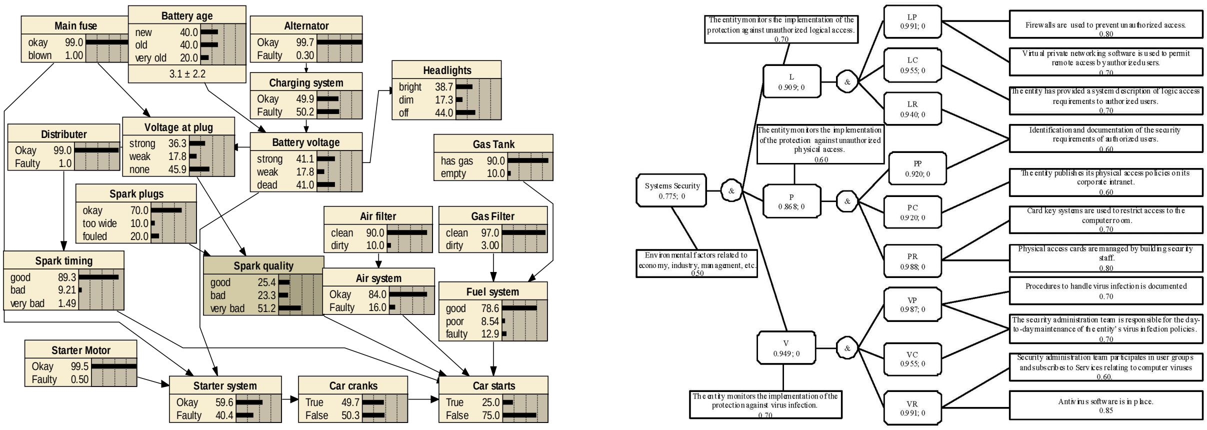


Fig. 4. The concept of evidential networks



a) Bayesian nets (Test example from Notica software)

b) Evidential nets (Srivastava, R. P., and G. Shafer. Belief-Function formulas for audit risk. The Accounting Review, Vol. 67, No. 2 (April 1992), 249-283)

Fig. 5. Two examples from literature: a)Bayesian nets and b) Evidential nets

3. CONCLUSION

European Union has accomplished, through introducing New Approach a breakthrough in the field of technical product safety. This is achieved by quantifying risk levels, in the course of the designing process. European Union has accomplished, through introducing New Approach to technical harmonization and standardization, a breakthrough in the field of technical products safety and in assessing their conformity, in such a manner that it integrated products safety requirements into the process of products design and development. This is achieved by quantifying risk levels, in the course of the designing process, with the aim of determining the scope of the required safety systems, where the safety requirements are preventively considered during the designing process. Risk assessment explicitly takes account of: (1) uncertainty, (2) the nature of that uncertainty, and (3) how it can be addressed.

There is a rich collection of theories for modeling all types of uncertainty.

Probability is the most suitable method for modeling random uncertainty when there is enough information

Non-probabilistic methods (evidence Dempster-Shafer theory, Bayesian subjective probability) can be useful in modeling reducible uncertainty when there is not enough information **which is prevalent**

REFERENCES

[1] Guide to the Implementation of Directives Based on the New Approach and Global Approach, by the European Commission (Blue Guide), (November 2011) http://ec.europa.eu/ enterprise/.

[2] Djapic, M., Lukic, Lj., Popovic, P., Technical product risk assessment integration into the enterprise risk management, Technical Gazette, (2013), vol. 20 No. 4, pp. 721-730.

[3] Djapic, M., Evidential Systems in Product and Process Development, Intelligent Manufacturing Series of Monographs No. 9, LOLA Institute, Belgrade, 2005. (In Serbian).

[4] Shenoy, P.P., Valuation-Based Systems: A framework for managing uncertainty in expert systems John Wiley & Sons, New York, 1992

[5] Xu, H., Smets, P., Some Strategies for Explanations in Evidential Reasoning, IEEE Transactions on Systems Man and Cybernetics, Vol.26, No.5, 1996, pp (599 – 607).

Acknowledgments: In the paper are presented some of the results from the project No. TR35031 which is partly funded be Serbian ministry of education and sciences.

35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
Faculty of Mechanical and Civil Engineering in Kraljevo

METHOD FOR CONTROL 3D SCANNED TURBINE BLADE IN ACCORDANCE WITH THE ALIGNMENT OF COORDINATE PLANES

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Abstract: *The paper present results of dimension control using various methods for orientation of three-dimensional scanned model of an industrial turbine blade with respect to its 3D CAD model. The analyzed methods for orientation are based on fitting of the whole models, fitting of selected features of the models and fitting auxiliary objects and alignment of coordinate planes. The usage of an auxiliary object proved to provide the good results in the case of the considered turbine blade. While from the point of control in accordance with the technical documentation, alignment of coordinate planes provide best results and gives greater breadth to control the turbine blade using different options of control. Using aligned coordinate planes of model and scan object it is possible to perform dimension control in various sections in according to defined coordinate system and gain measures which are aligned with adequate coordinate axis.*

Keywords**:** *Quality control, Dimension measurement, 3D scanning.*

1. INTRODUCTION

Results presented in this paper are obtained by analyzing various cases of dimension and deviation control of CAD model and 3D scan model of blade.

Today's challenges in the turbine industry to meet the ever growing requirement to manufacture parts faster, on schedule, and at reduced costs, it has become apparent to industry experts that traditional methods of inspection are now too slow and inadequate to achieve the required results. Turbine blades are traditionally designed and analyzed in isolation using Computational Fluid Dynamics (CFD), but multi-row CFD now considers the turbine as a whole and includes all the detailed shroud and cavity geometry.

The shape of turbine blades is complex, which represents a considerable challenge for manufacturing and quality control. Numerous methods are applied in order to define and realize efficient, reliable and accurate measurement of blade dimensions [1].

3D Scanning is a method of collecting the X, Y & Z co-ordinates of points on the surface of the object being scanned. The process can be done with a wide range of equipment of contact or non-contact type.

Blue light scanning is a 3d-scanning process using a non-contact optical scanning device which uses blue light source to project fringes on the part being scanned. The sensor of the scanner which is equipped with two cameras takes several images of the part (with fringes projected on it).

Due to complex shape of the blade, with its space angles, it is difficult to control shape of the blade, and to set base planes for dimension control in any section of blade. One of the best solutions for acquiring, big amount, of coordinate points, on surface of the blade, is optical 3D Scanning.

Optical methods of measurement represent one of the most suitable choices for measurement of complex shapes, which is used for similar purposes for more than 20 years [2]. The high accuracy of optical methods and the possibility of automation of measurement process make them also very intriguing choice for quality control in production engineering [3], although they are used in wide area of applications [4][5].

The technology is in expansion and is used for several important applications in engineering such as reverse engineering, structural analysis and quality control [6][7]. Due to the complexity of blade shape, the technology is becoming preferable choice for quality control [8][9][10][12] of blades, but also for static and dynamic structural analysis of behavior of blades and turbines [11].

2. METHOD

Control of deviation between 3D scan model and CAD model is predefined by alignment of models. Alignment of the models may be conducted in several ways, depending on the criteria for alignment of the models. In the process of alignment, points of one model are assigned to the respective points of the other model. Methods for alignment of the models may be divided to:

- methods that are based on reduction of deviation between the models Prealignment, ("best fit" method of alignment of whole geometry)
- methods that are based on definition of common features, or entities of the models (points, planes, cylinders).

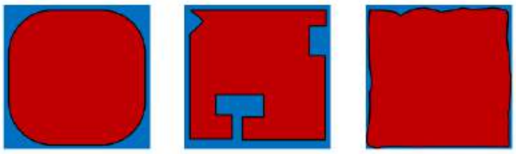

Fig. 1. Best-fit alignment of different shapes

Basic method that reduces the deviation between a CAD model and the respective 3D scan is the best-fit alignment of models, named prealignment. Prealignment is used for initial alignment of 3D scanned and CAD model. Alignment with this method minimizes overall difference between models, but does not take in consideration specific shape of models. With this method it is possible to align two similar objects similar dimension and shape, with minimal deviation of surfaces in every direction, or align different polygons (Fig. 1).

Prealignment method of alignment is used as initial alignment for further help for advance alignment setup. An extension of the Prealignments best-fit is local best-fit, which fits just selected parts of the models.

Methods that are based on definition of common features or entities of the models (points, planes, cylinders) use common features of both models that should coincide. This method of alignment is Reference Point System (RPS) and Reference Point System by Geometric Elements. Comparison of deviation between models is carried out by alignment of common features, with intention to reduce deviation between features while other parts of models are not considered in process of deviation. Several alignment methods are carried out, in dependence of features that are coincided:

- alignment with six points (RPS method), when six points of a model are brought to coincidence with the respective six points of the other model; the method has unique results, but it implies that some points on the real object do not deviate from the CAD model and other points, on distant part of model, from alignment points of models, deviates more; from the point of view of mechanical engineering, such an assumption is never satisfied, and its adoption is rarely useful;
- alignment by reference points system by geometric elements (RPS by geometric elements method), where some features of both models are constructed and then coincided; for example, parts of a models are approximated as cylinders and axis of cylinders and one point are aligned. The systems of reference points are usually more complicated, and they include construction of more complex features that are characteristic for the function of the inspected object. Concept of alignment is restriction of six degrees of freedom between models.
- alignment of the coordinate axis when the coordinate axis of the two computer models coincide; while the usefulness of the method is obvious, the problem of alignment of the models is transformed into problem of determination of orientation of the 3D scan with respect to the adopted coordinate system; to determine coordinate axis it is necessary to determine coordinate planes which are in relationship with technical documentation. This method of alignment leads to solution of problem of orientation of coordinate axis which is necessary for dimension control of specific sections which correspond to technical documentation demands.

3. MEASURMENT

The measurements are performed in the Laboratory for reverse engineering and additive manufacturing of Faculty for Mechanical and Civil Engineering in Kraljevo, 3DImpuls. The object of the case study was an industrial blade that was scanned by 3D scanner "ATOS Compact Scan 5M" manufactured by German manufacturer GOM (Fig 2). The scanner has two cameras with resolution of 5 megapixels and a projector with the blue light. The measurement volume had dimensions 150x110x110 mm with distance between points equal to 0.062 mm. The obtained 3D scans were compared to CAD model of the blade using software package "ATOS Professional".

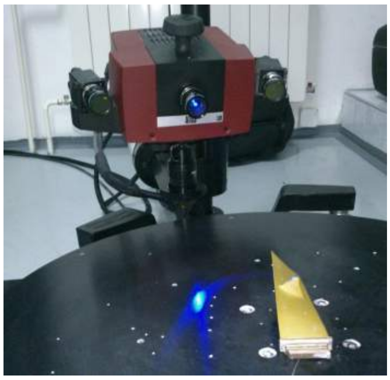

Fig 2. Three-dimensional scanner ATOS Compact Scan 5M and the controlled blade during a measurement

The industrial blade (Fig. 3-left) consists of the root and the body of the blade. The root of the blade is used for mounting of the blade and bears a limiter (Fig. 3-middle), which defines position of a blade in the turbine. The body of the blade, which is twisted, carries snubber (Fig. 3-right), which suppresses vibrations during operation. The critical part of the blade is the root of the blade and especially the limiter, because they influence positioning of a blade in the turbine assembly.

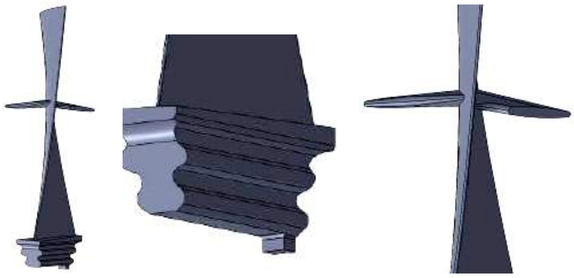

Fig. 3: The body of the blade, the root with the limiter and the snubber

In the studied case, eight different methods of alignment were used:

- Prealignment,
- three RPS with alignment of points on the root of the blade,

- two RPS by geometric elements, with alignment of constructed auxiliary elements
- RPS by geometric elements, with alignment of real auxiliary objects.
- RPS by geometric elements, with alignment of coordinate planes.

4. RESULT AND ANALYSYS

4.1. Best-fit methods

The first applied method for alignment is the prealignment. The deviation fields of the CAD model and the scanned model when they are aligned by prealignment with additional best-fit, is shown in the Fig. 4. In that and the following figures, the CAD model is presented with dark points and 3D scan is presented with the light points. The deviation fields present uniformly distributed deviations that vary between -1.23 mm and +2.00 mm. The highest deviations show the points in vicinity of the juncture between the body and the root, as well as the points in vicinity of the juncture between the body and the snubber. However, these parts of the actual blade have rounded shape due to the manufacturing process, while the CAD model is drawn as flat in that area because that area is not case of interest in this paper. Nevertheless, the fitting procedure includes reduction of deviation of these parts of the model with the same level of importance as other parts of the blade, which are manufactured with more compliance to the CAD model. This example clearly demonstrates why the best-fit in prealignment method is usually not useful for dimension control of mechanical parts.

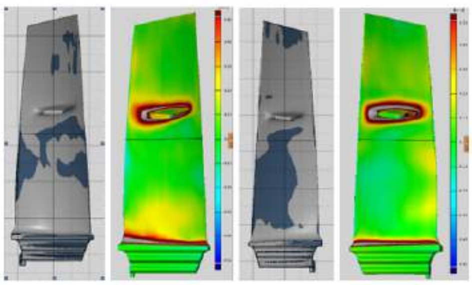

Fig. 4. Prealignment with best-fit alignment and the respective deviation fields

For the sake of comparison between the different alignments were selected maximal deviations of the points at the bottom of the root, maximal deviations of the points at edges of the snubbers and maximal deviations of the points at the top of the body of the blade.

Table 1. Maximal deviations of the scanned model with respect to the 3D CAD model Best-fit method

Part	Maximal deviations (mm)
Bootom of the root	+0.03
Left edge of the snubber	+0.35
Right edge of the snubber	+0.57
Top of the body	+0.16

4.2. RPS with features of the models

RPS with alignment of the points at the root of the blade was made with intention to check that part of the blade, which is critical for assembling the blade as a part of a turbine. For that reason, the deviations of the points at the root are more critical for the ability of a blade to be assembled, and three possible alignments of the root were checked, each using coinciding of six points for definition of RPS system:

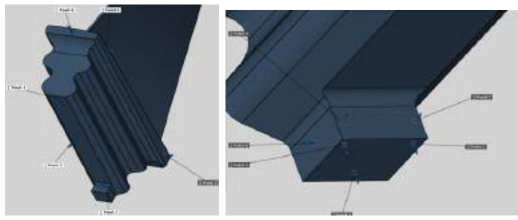

Fig. 5: RPS alignment with points on the root of the blade Left-alignment RPS 1, Right-alignment RPS 3

1) RPS 1: three points at the bottom of the root, two points at the left side of the root, and one point at the front side of the root (Fig 5. left);
2) RPS 2: similar to the previous case with the exceptions of two points which were taken at the right side instead at the left side of the root;
3) RPS 3: all six points were taken at the limiter, defining its lower, left and front side (Fig 5. right).

Table 2 shows the maximal deviations obtained by application of RPS 1, RPS 2 and RPS 3.

Table 2. Maximal deviations of the scanned model with respect to the 3D CAD model RPS by features of the models

Part	Maximal deviations (mm)		
	RPS 1	RPS 2	RPS 3
Bootom of the root	+0.05	+0.07	-0.14
Left edge of the snubber	-0.61	-0.67	-0.65
Right edge of the snubber	+0.64	+0.70	+0.93
Top of the body	+0.81	-0.88	+0.46

Any change of the selected points for definition of RPS leads to significant differences between the results of inspection.

The reasons for such behaviour are small dimensions of the root of the blade in comparison with dimensions of the blade and the fact that the root of the blade represents its ending part. Therefore, small deviations of the selected points at the root lead to large changes of positions of points at the opposite part of the blade, i.e. at the top of the body.

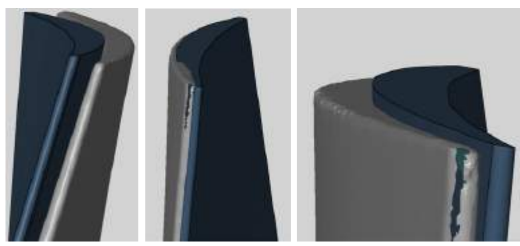

Fig. 6: The deviation of the top of the blade body using RPS alignment with points on the root of the blade

The other significant characteristic of the deviations calculated by application of the alignments RPS 1, RPS 2 and RPS 3 is that the deviations are highest at the top of the blade body. The characteristic is illustrated in the Fig. 6 for all the three cases, respectively. The deviations clearly illustrate the fact that the reduction of the deviations at the root of the blade lead to the increase of the deviations in the farthest points, i.e. in the points at the top of the blade.

Finally, the most important characteristic of the deviations calculated by application of the alignments RPS 1, RPS 2 and RPS 3 is that the deviations are considerably higher than deviations calculated by the application of the prealignment with best-fit method at all parts of the blade. The reason is that the considered methods of RPS are reducing deviations in the limited number of points of a real object, which does not have ideal geometric characteristics. Any three points at the root of the blade determine one plane, but the bottom of a real blade does not represent a plane, as it is the case with the 3D CAD model. Therefore, it is understandable that the bottom plane of the 3D CAD model aligned by the best-fit method represents at least as reasonable approximation of the bottom plane of a real blade as it is the case with any plane defined by three arbitrary points at the bottom of the root.

4.3. RPS by auxiliary elements

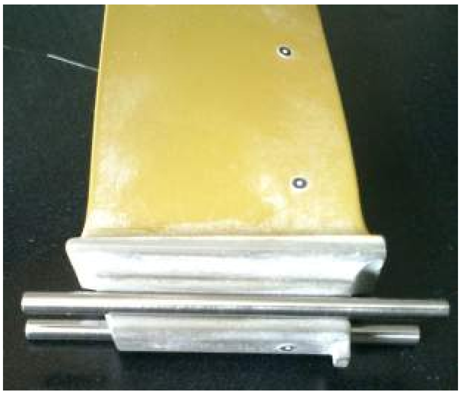

Fig.7. Root of the blade with the assembly pins

The most reliable way to perform the analogue orientation of the scanned model is to perform 3D scanning of the blade with the pins (Fig.7). In this way, it is possible to approximate the pins with cylinders and thus determine the positions of axes of the pins and, consequently, the position of the first referent plane (Fig. 8).

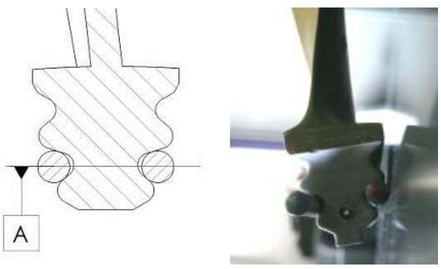

Fig.8. Referent plane of the turbine blade (left) and the respective view to the blade ready for scanning

The results of the procedure that is performed are given in the Table 3.

Table 3: Maximal deviations of the scanned model with respect to the 3D CAD model Alignment by scanned auxiliary elements

Part	Maximal deviations (mm)
Bootom of the root	+0.08
Left edge of the snubber	-0.61
Right edge of the snubber	-0.65
Top of the body	+0.18

The obtained results show reduced values of deviations at all the controlled parts of the blade, confirming that the high values of deviations determined by the application of RPS 1, RPS 2 and RPS 3 are the conseqeunce of the misalignment, and not production errors. The deviation field, which illustrates the previous conclusion is shown in the Fig. 9.

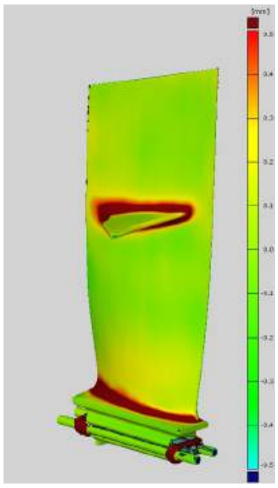

Fig. 9. RPS alignment with pins as real auxiliary element

However, it should be noted that application of the real auxiliary elements might hide some parts of the scanned object, as it is the case with gutters of the blade, which are hidden by the pins. For that reason, alternative ways for RPS alignment with auxiliary objects are worthy of examination.

4.4. RPS by approximated geometric elements

This method approximates geometry of scanned part and CAD model. Approximation of whole models is not conducted, but pars of geometry which are similar with standard primitives (cone, plane, line, cylinder, point and sfear) are constructed (fig. 10). Constructed elements are used for alignment by geometric elements, same as in previous case.

Table 4: Maximal deviations of the scanned model with respect to the 3D CAD model RPS by constructed auxiliary elements

Part	Maximal deviations (mm)	
	RPS 4	RPS 5
Bootom of the root	+0.09	+0.12
Left edge of the snubber	-0.65	-0.62
Right edge of the snubber	-0.63	-0.66
Top of the body	-0.23	+0.19

Quality control that implements similar principles may be envisioned in different ways. As the positioning of the blade is defined by position of the gutters, the simplest method that uses only the scanned model of the blade consists in definition of the RPS by elements that define the positions of the gutters. In this study, two methods of positioning of the blade using the gutters are made (Fig. 10):

1) RPS 4, defined by the axis of a cylinder that was fitted to the gutter of the blade, and a mid-point of the top of the body of the blade;

2) RPS 5, defined by the axis of the same cylinder as it is the case with RPS 4, and an end-point of the top of the body of the blade.

Maximal deviations obtained by application of RPS 4 and RPS 5 at the same parts of the blade as in the previous cases are shown in the Table 4.

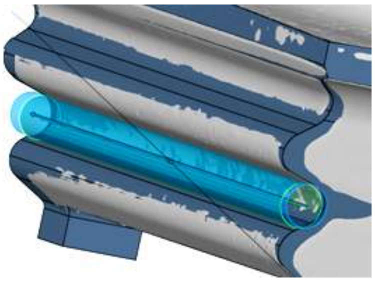

Fig. 10. RPS alignment with a fitted cylinder at the root and a point at the top of the blade

Comparison of the results of RPS 4 and RPS 5 show significant stability, not depending much on the choice of the point at the top of the blade. Actually, the highest deviations appear at the front and back side of the root, which were not defined by the very simple selection of the RPS. Deviation fields are presented in the Fig. 9. The important result is unexpected good agreement with the results obtained by considerably more elaborated, but also much longer and complicated procedure of application of pins as the real auxiliary object.

4.5. RPS of coordinate planes

Alignment of coordinate plains is next step for deviation analysis, as far most reasonable method.

As it was explained, the blade that was subject of the study operates as a part of a turbine, and assembling of the blade is performed using two steel pins that fit into gutters located at the left and right side of the root of the blade (Fig. 7 and Fig. 11), and thus is position of a blade in the assembly determined by the position of the pins.

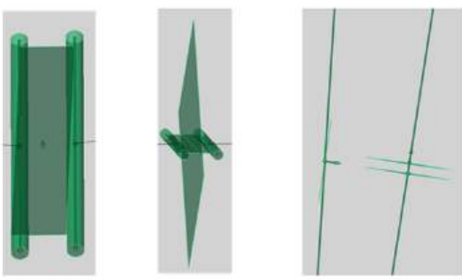

Fig. 11. RPS alignment of coordinate planes

Therefore, the position of the pins determines referent position of the blade, which should be used in a meaningful quality control procedure. For that reason, the technical documentation of the blade, which is used for quality control by classic dimension measurement methods, defines the plane determined by the axes of the pins as referent plane for definition of controlled dimensions (Fig. 8-left). The second referent plane is defined to be normal to the first plane and parallel to the front plane of the limiter, and its exact position is defined by the distance from the front plane of the limiter. The third referent plane is defined to be normal to both the first and the second referent plane, and its exact position is determined by intersection between the second referent plane and plane of symmetry of pins. This way coordinate planes are defined.

Planes are aligned with RPS by geometrical elements, and position of scanned and CAD models are defined in relation to each other. Results of deviation were more than expected, best deviation results are obtained by this method of alignment (Table 5).

Table 5: Maximal deviations of the scanned model with respect to the 3D CAD model with coordinate planes alignment RPS by geometrical elements

Alignment of coordinate planes	
Part	Deviation (mm)
Root	+0.06
Left snubber	+0.45
Right snubber	+0.59
Top of the blade	+0.15

4.6. Dimension control

Orientation of coordinate axis is defined by orientation of coordinate planes. Orientation of planes is described in previous sub-section ad it is used for further dimension control and measurement of blade in any section and any dimension of the blade in according with technical documentation which is carried out for characteristic section. Sections are constructed parallel with chosen coordinate plane.

Nine measurements of characteristic distances are carried out. Results are presented by table 6.

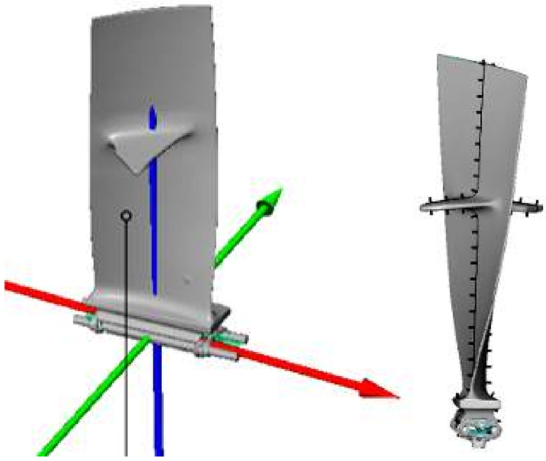

Fig. 12. Definition of coordinate system

Table 6. dimensions obtained in characteristic sections

Blade		
	LS [mm]	DS [mm]
V1	18.39	20.44
V2	18.38	20.44
V3	18.38	20.44
V4	18.38	20.44
V5	18.37	20.45
V6	18.38	20.44
V7	18.37	20.44
V8	18.37	20.44
V9	18.38	20.44
mean	18.377	20.441
stdev	0.006	0.003

5. CONCLUSION

The paper presents an analysis of various possibilities for alignment of the 3D scan of an industrial blade and its CAD model.

The analysis have shown that the prealignment of model is not reliable method for quality control of turbine blades, because, actual shape of a blade may considerably vary in comparison to the designed model at parts which are not relevant for the functionality of the blade. Therefore, a prealignment with best-fit of a 3D scan to the CAD model may include points, lines and surface that are not manufactured to fit the shape of the designed model, further leading to unreliable results.

The analysis of various RPS have shown that selection of reference points at critical parts may also lead to unreliable results, because selection of the RPS points on a critical part may lead to unstable results due to proximity of points if the critical part is small in comparison to the whole object.

The most reliable method of defining RPS is certainly usage of real auxiliary objects that enable definition of the position of a blade that most closely resembles the orientation of the blade in a real assembly. This method enables definition of coordinate planes and thus alignment of those planes.

Summarizing the previous conclusions, the authors propose application of a quality control system that closely emulates behaviour of a blade in the turbine. Use of auxiliary elements (pins) gives wider possibilities of control, and stability of results.

Acknowledgement: The authors wish to express their gratitude to Ministry for education, science and technology of Republic of Serbia for support through research grants TR37020 and TR35006.

REFERENCES

[1] H. Junhui, W. Zhao, G. Jianmin, & Y. Yu, “Overview on the profile measurement of turbine

[2] blade and its development”, 5th International Symposium on Advanced Optical Manufacturing and Testing Technologies, pp. 76560L-1-76560L-11, 2010

[3] R. Loser and T. Luhmann, "The Programmable Optical Measuring System POM - Applications and Performance", Comm. V, ISPRS Congress, 1992

[4] Heinrich Schwenke, Ulrich Neuschaefer-Rube, Tilo Pfeifer, Horst Kunzmann, “Optical Methods for Dimensional Metrology in Production Engineering”, CIRP Annals - Manufacturing Technology, Vol. 51, pp. 685–699, 2002

[5] K. Pavelka, T. Dolanský, “Using of non-expensive 3D scanning instruments for cultural heritage documentation”, International Archives Photogrammetry Remote Sensing, 34(5/C15), pp. 534-536, 2003

[6] Yu. V. Chugui, “Optical Measuring Systems and Laser Technologies for Scientific and Industrial Applications”, Measurement Science Review, Vol. 7, Section 3, pp. 1-10, 2007

[7] N. D' Apuzzo, "Overview of 3D surface digitization technologies in Europe", “Proceedings of SPIE 6056 -Three-Dimensional Image Capture and Applications “ VII, 605605, 2006

[8] Nebojsa Bogojevic, "Optical systems for 3D scanning", Mechanics, Transport, Communications, Volume 10, pp. UK-7.20-7.26, 2012

[9] J. Gao, J. Folkes, O. Yilmaz, N. Gindy, "Investigation of a 3D non-contact measurement based blade repair integration system", Aircraft Engineering and Aerospace Technology, Vol. 77, pp.34-41(2005)

[10] M. Crompton, “Optical Measurement Systems applied to Wind Turbine Blades for the Detection and Characterization of Defects”, “2010 Wind Turbine Blade Workshop”, 20th-22nd July 2010, Albuquerque (USA), (2010)

[11] N. Mannan, “3D Imaging of Turbine Blade for Comparative Deviation Analysis between Ideal Part Designs to As Built Part”, Master thesis, Rensselar Polytechnic Institute, Hartford (USA) (2009)

[12] Q. Zhang, X. Su, Y. Cao, Y. Li, L. Xiang, "Optical 3-D shape and deformation measurement of rotating blades using stroboscopic structured illumination", Opt. Eng. 44, 113601 (2005)

[13] S. Ćirić Kostić, A. Vranić, “Basic Concepts, Applications and Possibilities of Additive Manufacturing Technologies, International Symposium KEIT 2012, Keynote lecture, Mechanics, Transport, Communications, Volume 10, pp. UK-7.10-7.19 (2012)

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35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
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APPLICATION AND ACCURACY OF 3D-MODELLING IN THE FIELD OF ORTHODONTIC

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Abstract: *Development of medical/dental science, during the last couple of decades, has been marked with an ever more pronounced interdisciplinary character which, in part, can be attributed to various engineering applications. In that respect, orthodontic has always maintained close relationships with engineering disciplines, mostly relying on production engineering. Amongst the modern engineering technologies, i.e. computer-aided (CA) systems which have found broad application in this area, the most widely used are 3D-modelling, CAD, reverse engineering, CAE, CAM, laser sintering, plastic forming, rapid prototyping, CAI, CAQ, etc. Today, 3D-modelling is one of crucial segments in orthodontic CA technologies. Having this on mind, within the first part of this paper basic overview of the 3D-modelling approaches and systems applied in the field of orthodontic has been presented. In the second part of the paper results of accuracy analysis of three different systems have been presented.*

Key Words: *3D-modelling, orthodontics, accuracy, precision, quality.*

1. INTRODUCTION

Over the last few decades, the development of dental science is marked by increased interdisciplinary, which is in fact characterized by a variety of applications solutions that come from engineering. We can now say that dentistry as a branch of medicine, has the longest tradition in the application of engineering models and principles in their practice. This is especially true for orthodontic and prosthetic [1, 2, 3].

On the other hand, as well as in engineering, and dentistry, especially in orthodontics solution is based on facts and evidence and knowledge (evidence-based and/or knowledge-based orthodontics) [4,5,6].In developed countries, especially over the last decade, special efforts have been made in the area of modeling and generation in space (3D), orthodontic cases and states (diagnosis, planning and monitoring) to simulate the stresses, forces and deformations using the finite element method [7,8]. These were 3D digital models or" computer impressions" compared to conventional (plaster model), highly accurate and precise. In addition, they allowed the analysis and simulation of "n" orthodontic conditions, without taking extra impressions.Modern engineering technology, based on the research, development and applications in production engineering, which are now found application in orthodontics are [9-11]: (i) computer-aided design (CAD) - used for 3D modeling of teeth, jaws, orthodontic appliances (ii) computer-aided engineering (CAE) - in orthodontics help us to process modeling and calculations of stress and strain, using finite element method (FEM), (iii) computer- aided manufacturing (CAM) - simulation design and manufacture of brackets, (iv) rapid prototyping (RP) - simulation design and manufacture of brackets advanced technology development (still used only in research), and (v) computer-aided quality (CAQ) - modeling and quality assurance of orthodontic appliances.

2. 3D DIGITAL MODELS IN ORTHODONTICS

This is extremely important to note that the basis of the application of engineering approaches in orthodontics, 3D modeling, where we have two approaches: (i) orthodontic CAD systems, as well as specialized, problem oriented software for this purpose, and (ii) general CAD systems engineering purposes, which are used to generate digital products, and therefore "dental products", and they form the basis for implementation of other solutions mentioned [12]. In this paper we use a different approach for the following reasons: (i) is far greater opportunities for software engineering modeling, especially in the area of defining and monitoring dental arch, and (ii) easily generate, edit and search the digital database of orthodontic models.

Today, special attention is paid to the development of methods and techniques used in orthodontics to help us get a set of points, lines and surfaces of the teeth, jaw, or orthodontic appliances, based on which we can generate a 3D model of the same. This process of generating points is called digitization in orthodontics [12]. The last decade has developed several systems for 3D digitization [13-15], whose classification can perform on different bases: (i) the type of sensor for generating information (contact - mechanical, without - optical (light, laser), Rx-rays, ultrasound), (ii) measurement principle (point by point, line scanning and digitizing surface), (iii) the place where the digitization performed (intraoral - direct, extraoral - indirect), and (iv) the level of automation (manual and automatic).

CAD / CAM systems in dentistry and orthodontics therefore, are used for the process chain planning, implementation and monitoring of dental treatment, which consists of [16]: scan (point "cloud generation"), design (creation of 3D models) and processing (receiving dental compensation (part of the tooth, crowns, offset any, dentures, orthodontic appliances)). Scanning equipment translates shape of the prepared tooth in three-dimensional units of information (3D coordinates). Information contained in this computer translates the 3D map (cloud of points). Operator design a form of compensation (3D model - CAD), using computer generate the toolpath (CAM), which deals with material benefits and receives its final shape (CAI) [12].
To determine the accuracy of orthodontic diagnosis and treatment progress, orthodontists use various types of measurement and analysis. Typical measurements made on plaster models include teeth width and length of arc, and for different distances. All measurements are typically performed in the space [17], lower the plane, at least along one axis. These measurements provide insight into the available space between the teeth, which is often necessary to determine the appropriate treatment plan. Today, this procedure include: time (laboratory - taking / spills impressions), space (warehouse - storage impressions) and search for clinical use. Traditionally, these measurements are performed manually on plaster models, using a vernier calipers. Digital vernier caliper proved to be accurate, reliable, and reproducibility of the results that are satisfactory for this study [18-19].
Today's 3D sensor technology offers new opportunities to replace manual measurements, which include 3D digital models (images) scanned objects, computer-supported software for measurement. The usefulness of this technology in orthodontics is reflected in benefits including: measurement accuracy, reducing the time and storage space as well as on-line consultation and presentation capabilities therapy [20].

3. OUR RESEARCHES - CASE STUDY OF DIGITAL MODELS

Researchers in orthodontics worldwide, with their results confirm that the benefits of digital models: (i) solved the problem of keeping the plaster models, the digital format is more suitable for this purpose, (ii) digital images suitable for fast data transfer, for example colleague for consultation and establishment of orthodontic diagnosis, (iii) digital images can be enlarged and easier to localize the anatomical details, (iv) monitoring and measurement of orthodontic parameters can be done in a faster and easier way, and automatically, and (c) digital models and results measurements are available at any time, at any distance in the diagnostic, clinical and informational purposes only [12].New research shows that in the U.S., Canada, Spain and France, more than 20% of orthodontic practice using digital models [1]. However, it must be said that this approach has disadvantages: (i) if it comes to moving the scanning of dental models (impression), despite a good system focus, digital images may be blurred, (ii) image model with mixed dentition were vague and difficult to measure, and (iii) digitization model (impression), you always have to work under the same conditions.

3.1 Case study 1 – Manual measurement of jaw gypsum model - determining the dental arch

In this experiment, as measured by the 40 plaster models of jaws (40 models of the upper jaw and 40 models of the lower jaw). All models were chosen from the Clinics for orthodontics Faculty of Dentistry, University of Belgrade. In these 40 models all three classes of malocclusion wereincluded. The measurements had been made with digital caliper ORION (Germany) with the accuracy of 0,01 mm.For each selected jaw there were 12 points marked which were measured: (i) mid points of incisal edges of first and second incisors, (ii) canine`s cusp tip, (iii) buccal cusp tips of the premolars, (iv) distobuccal cusp tips of the first molars.All values were presented in tables which are specially made for this case.The measured coordinates of points in the tables have been included in the program written in MATLAB from which we got the analysis presented in this paper. Figure 1 shows the coordinates of the points written in MATLAB.

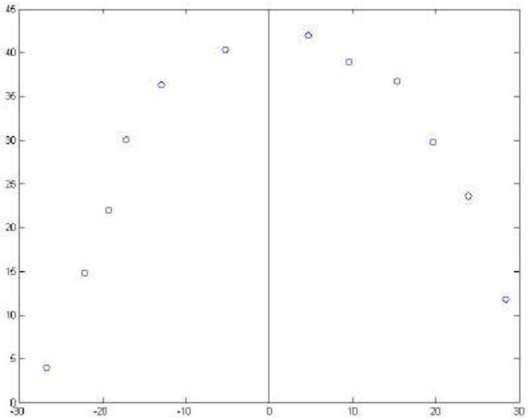

Fig.1. The coordinates measured points

In MATLAB we can approximate 10 functions and get the equations fromthese functions. Of the ten possible functions in this paper we will show comparison of six functions: quadratic function, cubic spline, function 4th, 5th, 6th and 7th polynomial degree. Figure 2 shows the approximate quadratic function and cubic spline through the given points.

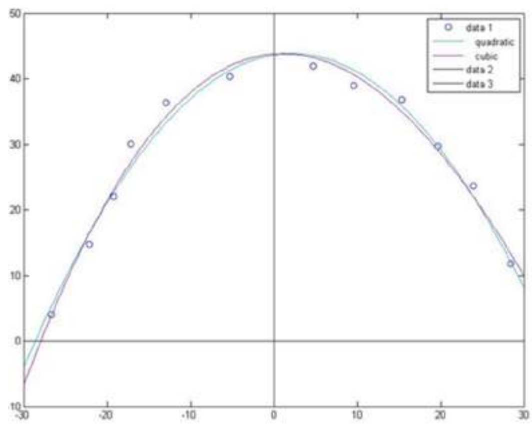

Fig.2. Approximate quadratic function and cubic spline through the given points

Equations (1) describing the quadratic function:

$$y = -0.046 \cdot x^2 + 0.2 \cdot x + 44 \quad (1)$$

Equations (2) describing the cubic spline:

$$y = 0.0002 \cdot x^3 - 0.047 \cdot x^2 + 0.099 \cdot x + 44 \quad (2)$$

Figure 3 Approximate function 4th and 5th polynomial degree.

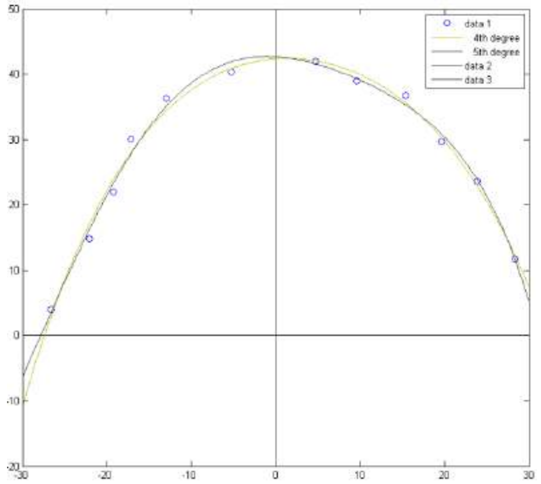

Fig.3. Approximate function 4th and 5th polynomial degree through the given points

Equations (3) describing the function 4th polynomial degree:

$$y = -1.6 \cdot 10^{-5} \cdot x^4 + 0.00023 \cdot x^3 - 0.034 \cdot x^2 + 0.094 \cdot x + 42 \quad (3)$$

Equations (4) describing the function 5th polynomial degree:

$$y = -9.1 \cdot 10^{-7} \cdot x^5 - 1.2 \cdot 10^{-5} \cdot x^4 + 0.001 \cdot x^3 - 0.037 \cdot x^2 + 0.082 \cdot x + 43 \quad (4)$$

Figure 4 Approximate function 6th and 7th polynomial degree.

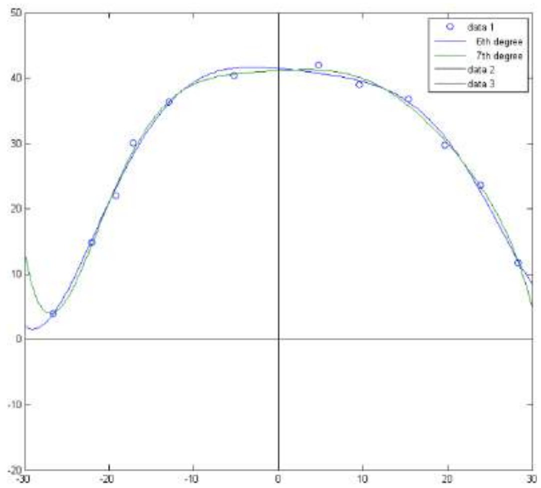

Fig.4. Approximate function 6th and 7th polynomial degree through the given points

Equations (5) describing the function 5th polynomial degree:

$$y = 7.6 \cdot 10^{-8} \cdot x^6 - 1.3 \cdot 10^{-6} \cdot x^5 - 0.0001 \cdot x^4 + 0.0014 \cdot x^3 - 0.011 \cdot x^2 - 0.12 \cdot x + 41 \quad (5)$$

Equations (6) describing the function 7th polynomial degree:

$$y = -4.2 \cdot 10^{-9} \cdot x^7 + 10^{-7} \cdot x^6 + 4.2 \cdot 10^{-6} \cdot x^5 - 0.00013 \cdot x^4 + 0.00064 \cdot x^3 - 0.0049 \cdot x^2 + 0.069 \cdot x + 41 \quad (6)$$

In this way the curve are plotted for the 40 jaws, thus we can obtain the appropriate equation from which we can see the current status of the patient and arcs approximated between the given points.

3.1 Case study 2 – Digital determining of the dental arch

By scanning the gypsum model of jaw and use of SolidWorks digitally we performed measurements of marked points on the model. Models are scaned on the scanner ATOS Compact Scan 2M. In SolidWorks we can measure with an accuracy of 10^{-8}mm which is more accurate than a digital caliper. Figure 5 shows the model jaw with marked points.

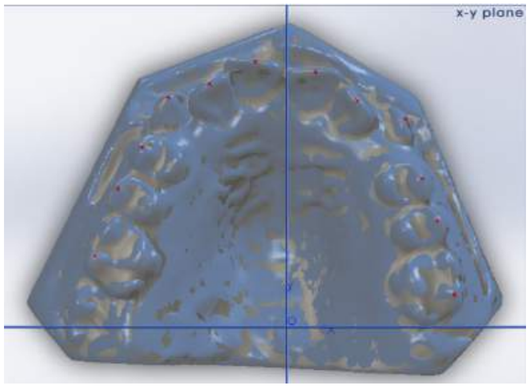

Fig.5. The model jaw with marked points

On this model is made of the same measurement points as in the previous study. Coordinates of the pointsin SolidWorks are shown in Figure 6.

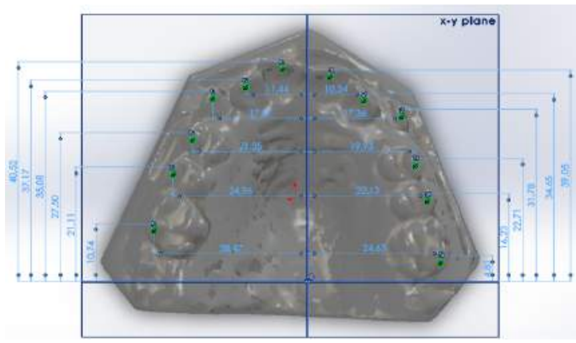

Fig.6. The coordinates of the points in SolidWorks

Coordinates of the points in MATLAB are shown in Figure 7.

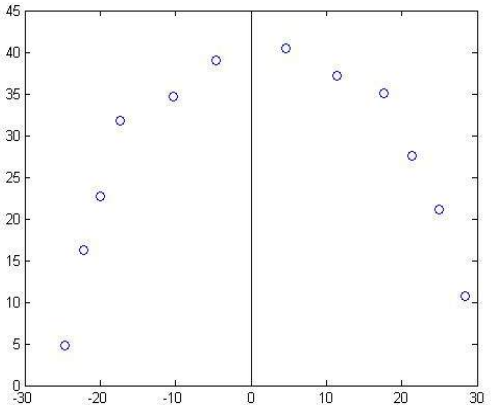

Fig.7. The coordinates measured points in MATLAB

By measuring a sufficient number of samples, in this case 40, we concluded that the arc described by cubic spline is good enough.

The general equation of a cubic spline (7).

$$y = p_1 \cdot x^3 + p_2 \cdot x^2 + p_3 \cdot x + p_4 \quad (7)$$

4. CONCLUSION AND FUTURE RESEARCHES

Our research show that the best equation for modelling the form of dental arch are cubic and 4th degree polynom. It is easier to perform and more precise measurement and analysis using 3D digital model.

In this case our future researces will be following: (i) analysis of dental orthodontics software according the best form of dental arch, and (ii) study of accuracy and repeatability 3D modeling.

REFERENCE

[1] KIHARA, T., et al, *Construction of orthodontic setup models on a computer*, Department of Oral Biology and Engineering, Division of Oral Health Sciences, Hiroshima University, Hiroshima, Japan, Am J Orthod Dentofacial Orthop 2012;141: 806-13.

[2] LOSHCHILOV, K., *The Optikdent dental CAD/CAM Suite*, Measurement Techniques, Vol. 49, No. 12, 2006.

[3] MOTOHASHI, N., KURODA, T., *A 3D Computer-Aided Dsign System Aplied to Diagnosis and Tretman Planning in Orthodontics*, European Journal of Orthodontics, 21 (1999), 263 – 274.

[4] COLLETT, T., *Evidence, judgment, and the clinical decision: An argument for evidence-based orthodontics*, Am J Orthod Dentofacial Orthop 2008;133:190-4.

[5] MADHAVJI, A., et al, *Attitudes, awareness, and barriers toward evidence-based practice in orthodontics*, Am J Orthod Dentofacial Orthop 2011;140:309-16.

[6] PAPADOPOULOS, M., *Meta-analysis in evidence-based orthodontics*, Orthod Craniofacial Res 6, 2003; 112–126.

[7] MAH, J.,Predictive Orthodontics: *A New Paradigm in Computer-Assisted Treatment Planning and Therapy*, Semin Orthod 2002;8:2-5.

[8] HARRELL, W., et al, *In search of anatomic truth: 3-dimensional digital modeling and the future of orthodontics*, American Journal of Orthodontics and Dentofacial Orthopedics, September 2002, pp. 325 – 330.

[9] FREEDMAN M, et al, *Single unit CAD/DAM restorations: a literature review.* J Irish Dent Assoc 2007; 53:38-45.

[10] N, N., *3D Scanning and Dental CAD/CAM Solution*, Frontier Advanced Technology, Patent Design, NY, 2010.

[11] BONG-KUEN CH., *Clinical Application of Three-Dimensional Reverse Engineering Technology in Orthodontic Diagnosis*, Gangneung-Wonju National University, Korea, IJPrinciples in Contemporary Orthodontics, www.intechopen.com (accessed 25.January 2013).

[12] N. MAJSTOROVIC, et al, *3D modelling in orthodontics – one approach*, 7th International Working Conference Total Quality Management – Advanced and Intelligent Approaches, Belgrade, Serbia, June 2013, pp. 77-84

[13] HAJEER, M., et al, *Current Products and Practices Applications of 3D imaging in orthodontics: Part I.*Journal of Orthodontics, Vol. 31, 2004, 62–70.

[14] HAJEER, M., et al, *Current Products and Practices Applications of 3D imaging in orthodontics: Part II.* Journal of Orthodontics, Vol. 31, 2004, 154–162.

[15] Duret F, Preston D., *CAD/CAM imaging in dentistry*. Curr Opin Dent 1991; 1: 150-154.

[16] Keatig, A., et al, *A comparasion of plaster, digital and reconstructed study model accuracy*, Journal of Orthodotics, Vol. 35, 2008, 191-201.

[17] Graber, M., Vanarsdall, L., *Orthodontics – Current Principles and Techniques*, 5th edition, Mosby, St. Louis, 2008.

[18] Santoro, et al, *Comparasion of measurements made on digital and plaster models*, Am J Orthod Dentofacial Orthop 2005; 26:101-5.

[19] Zilberman, O., et al, *Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virual orthodontics models*, Angle Orth 2005; 73:301-6.

[20] Kusnoto, B., Evans, A., *Realiability of 3D surface laser scanner for orthodontics applications*, Am J Orthod Dentofacial Orthop 2002; 22:342-9.

Production system management

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PRODUCTION MANAGEMENT SYSTEM IN THE CASE OF PLASMA CUTTING PROCESS

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Abstract: *In manufacturing processes' conversion of inputs into the desired outputs must be efficient and effective with respect to the process productivity, its cost and time needed. This paper presents the production management system, involving planning, organizing and controlling of the whole production process. The special accent was put on the optimization of the plasma cutting process itself, and gathering the data that are necessary for further activities related to the different production processes in one production facility. In order to provide simple and effective machine operation and diminish the human error, the technological calculator for prediction and/or optimization of the process parameters was created. The process monitoring and data collection derived the information necessary for managers to make proper decisions and contribute to the process optimization and automation.*

Key words: *Production management system, plasma cutting process, modeling, optimization.*

1. INTRODUCTION

Production Management represents the process that transforms input to the useful output and relates to the control of the production facilities having a number of machining stations. This process combines various resources of the production facilities in the company into the value added product.

Production Management System includes a computer for supplying information to control the segments of the production equipment/ machines, a first information network for transmitting control information from the computer to the machining stations, and a second information network for transmitting information indicating the results of operations in machining stations to downstream machining stations to allow defective portions of workpieces to be repaired in the subsequent operations.

The successful managing of the production process requires the ability to identify the customers' needs, to create quickly desired product and to produce it at low cost. In planning the production in the most effective way, the questions to be asked and which part of the supply chain (flow of materials, information, money and services from raw material suppliers through factories and warehouses to the end customers, including organizations and processes) is customer-order driven and what investments in resources, products or processes have been made independently of customer orders [1, 2]. Production Management involves the planning, organizing and controlling of the whole production process, as a set of interrelated management activities. The interrelation of those operations and activities involved in the production process is called a production system.

This paper aims to present the complexity of the information system related to the production process – plasma cutting and it's controlling, and methods needed to obtain the information needed to successfully mange the production process. The special accent was put on the optimization of the plasma cutting process itself, and gathering the data that are necessary for further activities related to the establishment of the production management system.

2. PRODUCTION SYSTEM MODEL

The most usual schematic representation of production system is represented at figure 1, containing six principal components: suppliers, inputs, transformation process, outputs, customers and management. The success is a direct result of the efficient control and synchronized acting of all participants and components involved. The seventh component is related to the surrounding and could not be controlled. However, the internal processes should be adjusted to the external environment and its changes.

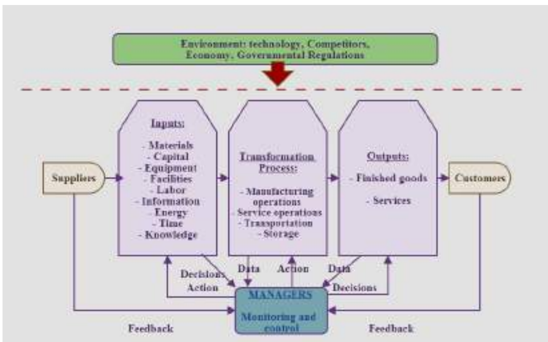

Fig.1. Production System Model

The production processes are usually very complex, implying the complex production systems, so that the production, as a functional area in the company, is very diversified comparing the other functional areas such as:

marketing, human resources, accounting, finance etc. Information systems are usually designed within each functional area, to support the area by increasing its internal effectiveness and efficiency. All those functional information systems get much of their data from the information systems that represent the process routine transactions (transactions that occur when the company produces a product), such is Transaction Processing System. This system monitors, collects, stores, processes and disseminates the information for all routine core business transactions, using them as an input to the functional information systems applications, as well as other internal or external systems. In order to enhance the flow of work and information between different departments/ functions the integrated approach is needed e.g. integrated supportive information system, as represented at figure 2. It could be observed that there is flow of information from Transaction Processing System to all functional systems, as well as the flow of information between and among functional areas, done via the integration component [3].

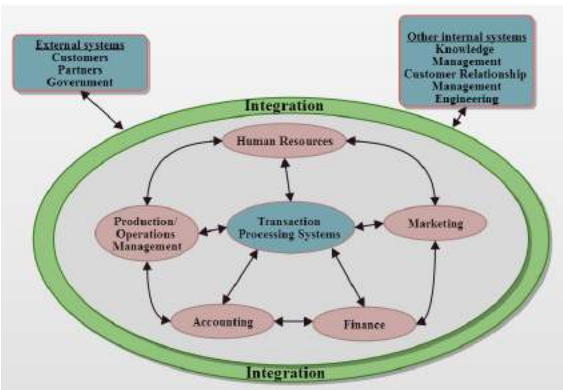

Fig.2. The functional areas, transaction processing system and integration connection

Due to its complexity, the Production Management functional area has complex and diversified supporting information systems, varying in ranges. Commonly used supportive information systems to the production system and its management are: in-house logistics and materials management, planning productions/ operations, computer integrated manufacturing (CIM), product lifecycle management etc. For example, Production Systems planning is usually supported by information technologies. Some major areas of planning and their computerized support are: Materials Requirements Planning (MRP), Materials Requirements Planning II (MRP II) and Just-in-time (JIT) systems. MRP deals with the production scheduling and inventories, while MRP II deals with the allocation of related resources in more complex cases then MRP. MRP II is system that adds functionalities to the regular MRP, determines the cost of parts and cash flow needed to pay parts, cost of labour, tools, equipment repair, energy etc. JIT is approach that attempts to minimize the waste of any kind (space, labour, materials, energy etc.) and continuously improve processes and systems [4]. However, the most widely used concept is CIM that promotes the integration of various computerized factory systems. CIM has three basic goals: simplification of all manufacturing technologies, automation of as many of the manufacturing processes as possible and integration and coordination of all aspects of design, manufacturing and related functions via computer hardware and software.

The quantity of information needed to make proper decisions in the production management area is respectively high and require different analysis and modeling methods in order to transfer data collected from the production process into the useful information. If plasma cutting process is one of the processes in the production facility, representing one segment in the production chain that needs to be controlled, there is process input information to be set in order to obtain the required output. Therefore, there are information needed to control the machine with the respect to the independent process variables, and information indicating the results of the production process, providing information needed for the subsequent operations.

3. PLASMA CUTTING PROCESS INFORMATION SYSTEM

During plasma arc cutting, high quantity of energy is focused at the small workpiece area, which implies intense heating of its surface. Energy source is ionized gas, which is ionized by direct current, passing from cathode (inside the nozzle) to anode (workpiece). When plasma jet reaches the metal surface, the material melts and is being removed from the kerf by the kinetic energy of plasma jet. Due to the high temperatures, the heat transfer from plasma jet to the material accounts for most of the phenomena encountered subsequently: shrinkage, residual stresses, structural and metallurgical changes, mechanical deformations, chemical modifications etc. Also, the changes in both workpiece material and plasma jet are frequent, interrelated and very difficult to monitor. Most of the parameters are also hard to measure in absolute values and require complex and expensive apparatuses and equipment. This makes the analysis of the process influential parameters very difficult, and the selection should be done in order to determine the most significant factors that should be measured, assessed, monitored and controlled.

Figure 3 represents the plasma cutting process parameters represented in the block diagram. The parameters are grouped into the parameters associated with the three phases of the process: generation of plasma arc, characteristics of the plasma jet and interactions between the plasma jet and material, together with phenomena which appears during the process. Finally, important parameters, also represented at the figure 3, are related to the plasma machine characteristics, proper selection of its components and plasma unit consumables and ways of production system control. Since the consideration of the second group of parameters and the analysis of their influences was very difficult, the research was focused on the impact of the input process parameters to the selected output process parameters, without dealing with the internal properties and characteristics changes.

The prediction of the process parameters was crucial for the process control and the step toward the process optimization. The model, as an abstraction of the real system was done, starting with the appropriate process consideration. Taking into account the previous consideration of the plasma cutting process complexity, the black box model was applied and presented in this paper. The objective of the process modeling was to diminish the plasma cutting machine setting time and improve the quality of the process outputs. These process outputs are considered to be the input parameters of the next process of the production facility.

Two different models were developed in order to identify the most applicable method for the plasma cutting process modeling in the particular case: statistical model, developed by regression analysis and artificial neural network, as artificial intelligence method. The next step was the selection of the most influential parameters (factors) for the modeling, in accordance with selected modeling methods.

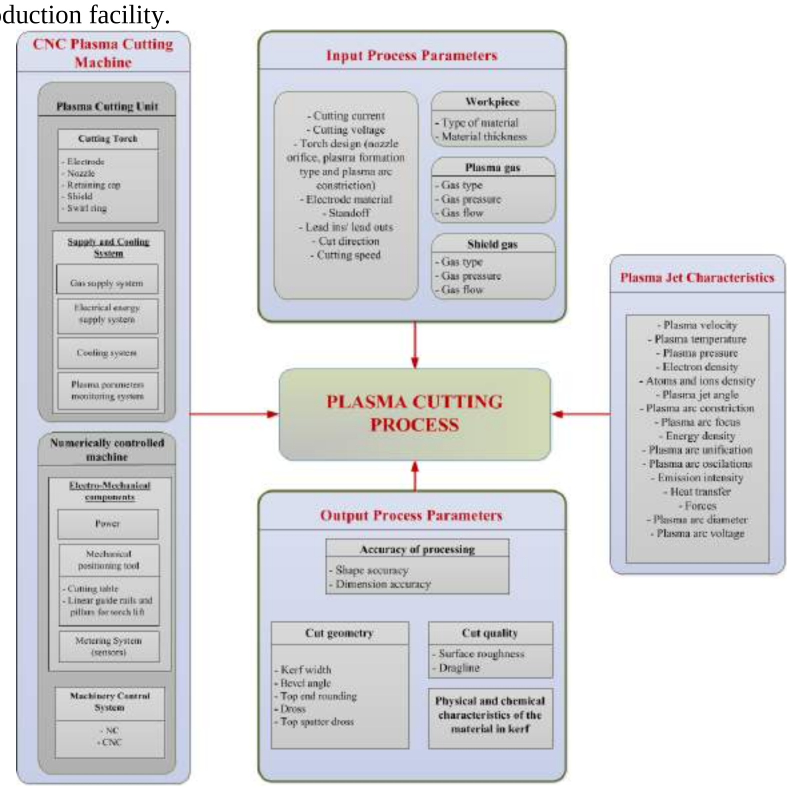

Fig. 3. Plasma Cutting Process Parameters

The selection of process parameters was supported by the analysis of available literature and manufacturers' manuals, as well as data collected by interviewing plasma cutting machine operators in the production facility, where the plasma cutting machine was located. Therefore, the number of influential parameters was reduced to three influential parameters: cutting current (I), cutting speed (v) and material thickness (s). Three dependant process variables (output process parameter) were selected for the process modeling: bevel angle, kerf and surface roughness. However, in this paper will present the modeling results only for one output parameter – kerf. The experimental research was done on the plasma cutting machine in order to obtain the data necessary for models development.

For the first statistical method, the three factorial design of experiment was created and data were collected from the process. Eight experiments were done, with three repetitions of the experiment, using the same input factors combination. The regression analysis was done using non-linear mathematical model with no interactions of influential parameters. The regression equations were generated using the Box-Wilson method, and the model adequacy was checked, as well as experiment reproductively and factors significance. The obtained regression equations provided the possibility to represent 3D diagrams showing e.g. the changes of the kerf with respect to the changes of material thickness and cutting speed, as shown at the figure 4.

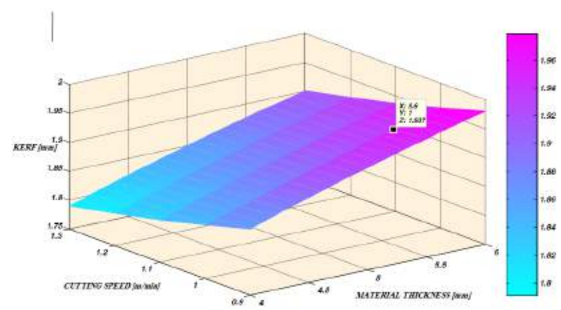

Fig. 4. Kerf dependences of the material thickness and cutting speed

For the user friendly application, the technological calculator for prediction of the plasma cutting process parameters was created.

The second method used for plasma cutting process modeling was artificial neural network. This method required higher set of experimental data (99 samples were examined). However, the experiment was done in the same range and experimental set-up so that models developed using these two methods would be comparable. Very important step in process modeling using artificial neural networks is to determine its structure and architecture, which will determine the ability of the neural network to learn and adapt to the particular problem. Artificial neural networks are composed of a large number of neurons distributed in several layers and interconnected, operating in parallel. The most suitable network structure for the kerf prediction was the network containing one hidden layer with three neurons Ns-3 (back-propagation network and with forward data processing), as represented at the figure 5.

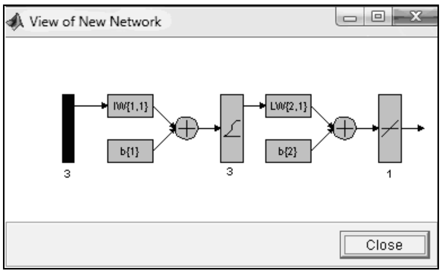

Fig. 5. Schematic representation of neural network Ns-3

After the training, the network Ns-3 was simulated with the set of data from the 32 experiments, which were not used for the network training. The selection of this data samples was carried out by random number method. After the simulation of the previously trained network, these data were compared with the experimental results for the same experiments. Figure 6 represents the comparison between experimental values and values obtained by the simulation of the previously trained network.

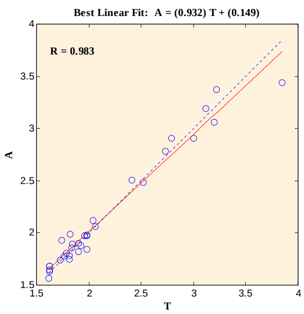

Fig. 6. Comparison experimental and morel results

Finally, in order to determine which model will be more applicable to be integrated into the production management area information system, the data obtained by the regression equations and neural network for the same combination of factors were plotted in the same diagram, together with the experimental data. The figure 7 represents the comparative representation of the experimental data, and data obtained by the regression analysis and neural network.

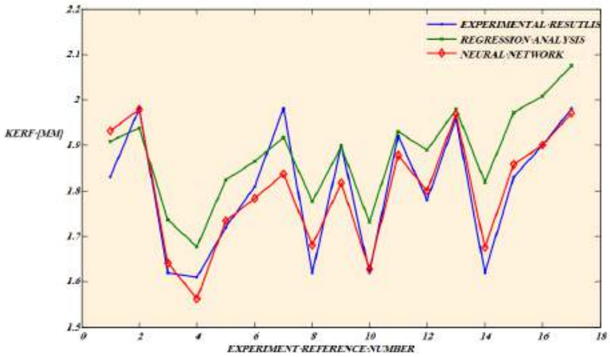

Fig. 7. Comparison between experimental and models results

4. CONCLUSION

Production Management involves the planning, organizing and controlling of the overall production process, representing the most complex and diverse functional area in the company. Its information system is therefore respectively complex. At the example of plasma cutting process it was shown which information is needed to successfully mange the production process. The special accent was put on the optimization of the plasma cutting process and gathering the data that are necessary for further activities related to the establishment of the production management system at the level of the overall production facility.
Using the data collected from the plasma cutting process, two different models were developed: regression model and artificial neural network. Their comparison showed that the artificial neural network had better agreement with the experimental results, then regression model, although both models gave satisfactory results of the plasma cutting process parameters prediction.

Acknowledgements: This paper was done in the scope of the projects: TR33027 and TR35034, funded by the Ministry of Education and Science, Republic of Serbia

REFERENCES

[1] JENS, O. R. (1992) *Integration and manufacturing strategy*, Computers in Industry, Vol.19, pp 37-50
[2] WORTMANN, J C(1992) *Production management systems for one-of-a-kind products*, Computers in Industry, Vol.19, pp 79-88
[3] LEE, A. (1999) *A Study of Production Management*, University of Salford.
[4] TURBAN, E., LEIDNER, D., MCLEAN J., WETHERBE, J. (2006) *Information Technology for Management, Transforming Organizations in the Digital Economy*, John Wiley &Sons, Inc.
[5] LAZAREVIC, A. (2010) *Modeling of the correlations between the parameters of the plasma cutting process and the analysis of the process energy balance by artificial intelligence methods*, Doctorial Thesis, Faculty of Mechanical Engineering, University of Nis, Republic of Serbia

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MODELLING AND QUANTITATIVE ANALYSIS OF RAMS INDEXES – COMPARATIVE ANALYSIS OF METHODS

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Abstract: *Optimization of infrastructure elements or components is essential for railway companies to fit the market and to compete against other means of transport. It is known that in every technical project is necessary to make different analyses – for its reliability, availability, maintainability and safety/RAMS/. These are some of the most basic indices of a system. Moreover, there is necessity for optimisation of Life Cycle Costs /LCC/ – the inevitable compromise in design phase as one of the most important decision criteria for the procurement or development of new products The RAMS analysis is based on LCC review.The balance between technical and economical aspects is considered by the life cycle costs.*

The aim of this paper is to make the comparative analysis to some of the methods for assessment and modelling of the mentioned indices /RAMS and LCC/ in the preliminary design phase, in which a high level of accuracy is accomplished.

Key words*: Modelling, analysis, RAMS methods, comparison*

1. INTRODUCTION

Optimization of infrastructure elements or components regarding technical and economic requirements is essential for railway companies to fit the market and to compete against other means of transport.

Due to the long lifetime of the infrastructure components pre-installation technical and economic assessments are necessary to optimize the system and equipment and get the return on investment (Roi) in a manageable timeframe.

LCC and RAMS technology are two acknowledged methods for assisting this optimization process. The collection and analysis of RAMS relevant key parameters is the basis for the technical optimization because it filters out under or over or bad designed components. The economical optimum is not necessarily related to the technical optimum. Only a RAMS analysis in conjunction with life cycle costing predicts the optimum repair rate taking into account the system requirements and costs.

Optimization strategies could start from the perspective of costs or technical performance. LCC analysis is a method for calculating the total cost of a system or a product over its total lifespan. LCC analysis is primary a method for decision making through economic assessment, comparison of alternative strategies and design.

On the other hand RAMS technology is a recognize management and engineering discipline for the purpose to predict the specified functionality of a product over its' complete life cycle.

RAMS technology keeps the operation, maintenance and disposal costs at a predefined accepted level, by establishing the relevant performance characteristics at the beginning of the procurement cycle and by monitoring and controlling their implementation throughout all project phases.

2. RAMS NORMATIVES

The European standard EN 50126 (Railway Applications: The Specification and Demonstration of Dependability-Reliability, Availability, Maintainability and Safety (RAMS) is issued by the CENELEC. RAMS lifecycle, according to EN 50126, is divided into 14 phases. Each phase can be analised for different options and with different methods (Fig.1).

The V-model is a graphical representation of the systems development lifecycle. It summarizes the main steps to be taken in conjunction with the corresponding deliverables within computerized system validation framework. The downward line of the V-Model implies the project definition, a constant interchange of user and functional requirements, configuration and technical specifications. This is decomposition from the global level until a detailed design is eventually generated. The upward line reverses the sequence of project test and integration (installation, validation and acceptance of the system including the acceptance by the maintenance department). Going on with monitoring of the systems performance and the modification, the model ends up with the disposal after the end of the time life of the system.

RAMS according to EN 50126 is an abbreviation describing a combination of Reliability (R), Availability (A), Maintainability (M) and Safety (S) which are describe bellow.

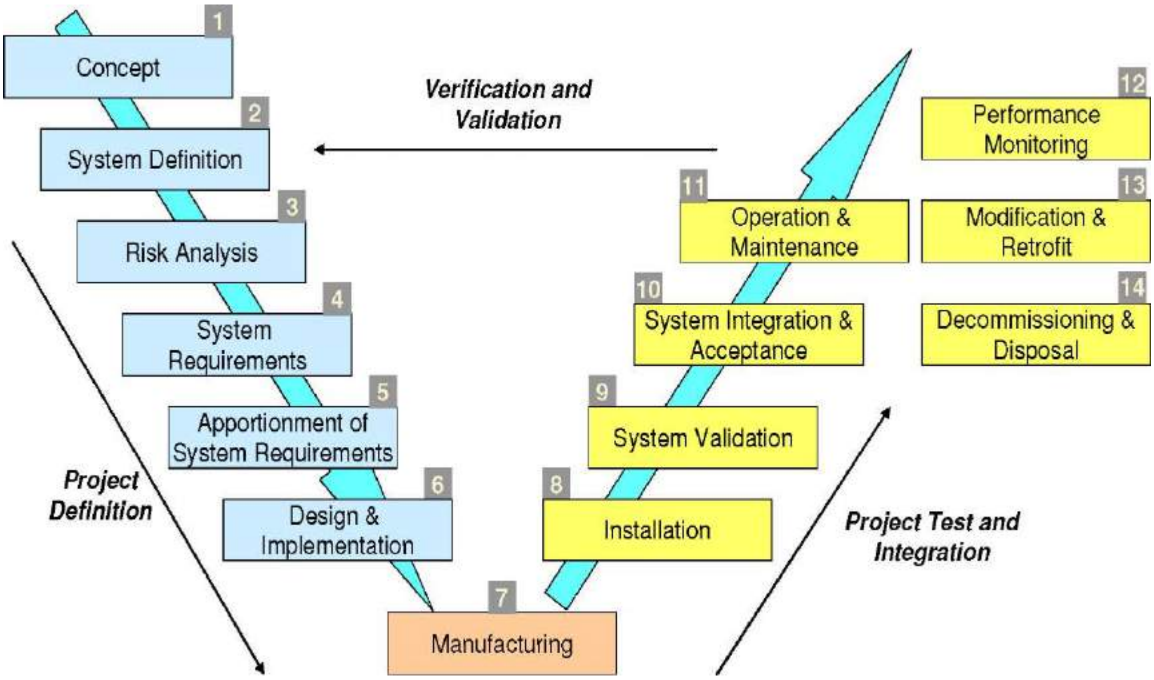

Fig.1. V- model according EN 50126

2.1. Reliability

The reliability of a system can be defined as: "the probability that the system will perform the specified functions in the defined limits, under the influence of the environment, for a certain period of time." An important part of the definition is the ability of the system to do its work within acceptable limits. They are quantified by setting constraints on the characteristics. Limitations identified by considering the effects of the failure of any variable.

Parameters for Reliability
Parameters in use are failure rate (λ), Mean Time Between Failure (MTBF), Mean Time to Failure (MTTF), Mean Time to First Failure (MTFF), Number of failures in the system per month/per year and Number of train influencing failures.
For the evaluation of the reliability can be used the following mathematical models:

Markov model – The method is suitable for assessing the reliability of systems with many states, with constant rates of the failure and restoration of independent nodes. Inclusion of sufficient additional variables in the specification of the status of the system may become a Markov process (fig.2).

Binominal model: It is used to assess the reliability of simple systems with serial or parallel nodes.
Binomial method is inherently a statistical tool for creating estimates of reliability for serial or parallel systems

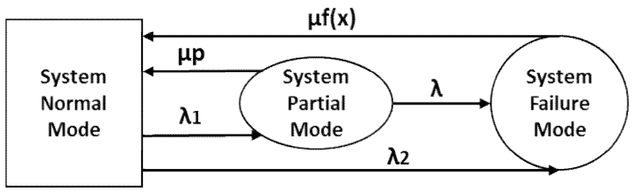

Fig.2.

Hazard and Operability Study (HAZOP)
HAZOP is a fundamental hazard identification technique, which systematically evaluates each part of the system to see how deviations from the design intent can occur and whether they can cause problems. The technique aims to stimulate the imagination of designers and operators in a systematic manner so that they can identify the cause of potential hazards in a design.

Failure Mode and Effects Analysis (FMEA) The method is a stepwise procedure for the assessment of the consequences of failures and their critically. The advantage of FMEA's that can be used in the different hierarchical levels of the system. By analyzing the different types of failures, the effect of each can be determined by the working activity of the system level in the hierarchy. The first one is functional FMEA, which recognizes that any system is designed to perform a number of functions that are classified as outputs. These results identify and measure the costs of the main entry points to the element or internal failures then calculated in terms of their impact on the system. The second is FMEA to the equipment in which successively lists the components of the equipment and analyzing the effect of each of its mode of failure to the system.

Failure Mode, Effects and Criticality Analysis (FMECA) The purpose of the assessment of critically is to prioritize the failures that are detected during the FMEA based on their effects and consequences, and the likelihood of their occurrence.
There are two approaches that can be used to analyze the causal relationships between failures of equipment and system [4]. They are inductive (from the particular to the general) and deductive (from general to particular) analysis. FMEA is an example of the first type.

Fault Tree Analysis (FTA) is the most common analysis technique used in reliability and risk analyses. FTA is a deductive method "what might cause this" and is used to identify the causal links leading to a specific mode of failure in the system - "the top of event". The main purpose of Fault Tree is in the research of safety and risk. A fault tree is a logic diagram showing the connection between system failures, subsystems, and components failures, FTA is an example of deductive analysis approach, It is a graphical approach which starts with a failure and branches out showing possible causes.
FTA method presents different ways of possible failures and this can lead to an assessment of safety and risk of systems and processes, even without taking into account the data for failure and restoration. In many cases , FTA and Failure Mode and Effect Analysis (FMEA) are used in combination - by FMEA to determine the effects and consequences of specific equipment failures and by FTA (or a number of FTA), to identify and to quantify the ways that lead to the probability of failure of the equipment and a high safety risk.

Reliability block diagram (RBD)
It is a diagrammatic method for showing how component reliability contributes to the success or failure of complex systems. RBD is also known as a dependence diagram (DD). A RBD or DD is drawn as a series of blocks connected in parallel or series configuration.

Preliminary Hazard Analysis (PHA)
It is a technique that can be used early in the design stage to identify hazards and assess their criticality. It is used as a first step to understand risk present and the need for risk control. This method was initially applied to nuclear industry and is the basis of large number of formal risk assessment today.

Human Reliability Analysis (HRA)
It is a comprehensive and structured methodology.
HRA can have benefits at every phase of the system life cycle. During the design phase, HRA is a tool that can be used to support the evaluation of concept designs by quantitatively comparing two design solutions and determining which designs best achieve the program risk objectives. HRA can assist in the identification of human actions (and corresponding system interfaces) that pose the most significant risk to the system.

2.2. Availability

The design of the availability of the system involves the use of the equipment for a certain period of time.
This is directly related to the equipment (i.e., units or components) which is able to perform a specific function within a given time period. Availability can be simply defined as "the ability of the element to be used over a period of time," and measure the availability of the element can be defined as “the period in which the item is in usable condition". Variables associated with availability, reliability and maintainability associated with temporal indicators, which are subject to failure of the equipment. These measures are the mean time between failures (MTBF), and the average stay (MDT) or mean time to restoration (MTTR).
The design of availability during the preliminary design includes intelligent computer automated method based on Petri nets (MP). They are useful for modelling of the complex systems and in the design of availability that is the subject of preventive maintenance strategies that involve complex interactions such as upgrading the components.

Markov model for Availability and Maintainability
This method is useful for modelling systems, especially large and complex systems with dependent intensities of failures and recoveries. Markov models are particularly useful in modelling of renewable systems with random manifestations of failures (i.e., constant or time-independent intensities of failures) and arbitrary recovery time (i.e., constant or time-independent intensities of recovery). The method, however, is unreliable for systems with time-dependent rates of failures and recoveries.

Modelling of achieved availability subject of the technical maintenance
In uncertain initial conditions is convenient to introduce the availability of the system only in terms of operating time and corrective maintenance.
This is the *intrinsic availability Ai,* which is defined by the formula:

$$A_i = \frac{MTBF}{MTBF + MTTR} \qquad (1)$$

where:

- MTTR – Mean Time To Restoration

After analysis of the formula becomes clear that we need to compromise between the reliability and maintenance to achieve the same availability in the engineering design.
Achieved availability (As) is commonly used during the development and initial testing of the output when a system or its equipment is not operating in its environment.
Achieved availability is more a hardware -oriented measure while working availability takes into account the relevant factors of the environment.
Achieved availability, however, depends on the willingness preventive maintenance policy , which can be strongly influenced by non-hardware considerations.
The mathematical model is achieved availability is:

$$A_s = \frac{OT}{OT + TCM + TPM} \quad (2)$$

where:
- OT – operating time
- TCM – total corrective maintenance
- TPM – total preventive maintenance

The alternative approach is used also to modelling the achieved availability taking into account the probability that a system or its equipment when used under conditions calculated in an ideal environment, it will carry out its work in accordance with specifications formulated in the preliminary development phase.
The most significant feature of the achieved availability of both approaches is that it includes the time for maintenance (corrective and preventive) and switch-off logistical delays. The mathematical model of achieved availability in this sense is given as [3]:

$$A_s = \frac{MTBM}{MTBM + TCM + TPM} \quad (3)$$

where:
- MTBM is Mean Time Between Maintenance.

The difference of intrinsic availability Ai, that in As is involved and total preventive maintenance.

Evaluation of maintainability with modelling support .
Maintainability and maintenance are closely related, but their meanings are not the same.
Maintainability refers to the measures taken during the design, development and installation of the system or its equipment, which will reduce the required maintenance efforts, logistics and costs, and in this way, and operational downtime.
Maintenance refers to measures taken to restore and maintain the system or its equipment in working order. Maintenance is a concern for the physical and operational condition of the system or its equipment. There are some mathematical models for assessment of serviceability and maintenance.
However, the support models are mainly designed to better define and predict certain aspects of maintenance as scheduled downtime, scheduled replacements and optimal warranty periods for installed systems and equipment. These models are usually based on certain probability distributions, mainly exponential distribution for the times of corrective maintenance and logarithmical normal distribution for the minimum operating time.

2.3. Maintainability

Parameters in use are: Mean Time To Repair (MTTR], Mean Time Between Maintenance (MTBM], Mean Time Between Repair (MTBR], Mean Maintenance Hours (MMH], MDT (Mean Down Time) as well as Mean Logistic Delay Time, Mean Time Between Maintenance (MTBM]

Maintainability is the aspect of maintenance that has to stay in and can be defined as “the probability that failed element can be restored to operational condition effectively within a specified period of time." This recovery of the inoperative element to effective operational condition is usually done when the effect of the repair or corrective maintenance is performed in accordance with prescribed standard procedures. Effective operational condition of the element in this context is also considered a correctable condition of the item. Corrective maintenance is the act of repairing or setting malfunction and physical conditions of the item, depending on its functions in accordance with standards. Thus serviceability is the probability that an element can be restored back to the state by corrective actions in accordance with the prescribed standard procedures within a certain time period. It should be noted that the maintainability is achieved not only through the recovery corrective action for maintenance or repair , in accordance with a prescribed standard procedures , but also within a defined period of time. This repair work is in fact determined by the mean time to recovery (MTTR), which is a measure of the performance of maintainability. So we can define the following fundamental principle: Maintainability is a measure of repair status of an item, which is determined by the average time to recovery (MTTR), established by corrective maintenance actions.

2.4. Safety

Parameters in use are Hazard rate, Number of accidents, Number of derailments, Number of accidents due to external sources, Number of accidents due to internal sources and incidents that could have led to accidents/damage.
Traditionally, risk assessments were based on allowable safety factors derived from past experience of failure or empirical knowledge of such systems operating in similar environments expected. Convenient way to assess this probability of failure is to consider the difference between the functions of demand and capacity, called safe space, which is a random variable with its own probability distribution.
Reliability index is defined as the number of standard deviations between the mean value of the probability distribution of a safe range, where its value is zero. It is the reciprocal of the coefficient of variation of the safe range.
Some common analytic methods can be used in a life cycle at different phases; research and development, investment, operation and maintenance and disposal. The methods are most often used in the initial decisions before investment. But methods like FTA and ETA can also be used in the operation and maintenance phase to analyze unexpected malfunctions.

3. CHARACTERISTICS OF THE V- MODEL

Phase 1 Concept- develops a level of understanding of the system sufficient to enable all subsequent RAMS lifecycle tasks to be satisfactory performed. Analyses during this phase are used to identify sources of hazards which could affect the RAMS performance, eg.PHA.

Applicability / Methods	Complex systems	New project	Quantitative analysis	Combinations of failures	Processing based on the sequence-dependent events	Use of independent events	**T**op to **B**ottom/ **B**ottom-**U**p	Distribution reliability	Applicability and commonality	Suitability
Forecast intensity of failures	No	Yes	Yes	No	No	No	BU	Yes	(H)	(H)
Fault Tree Analysis (FTA)	Yes	Yes	Yes	Yes	No	No	TD	Yes	(H)	(H)
Event Tree Analysis (FTA)	NR	NR	Yes	HR	Yes	Yes	BU	NR	(M)	(M)
Reliability block diagram (RBD)	NR	NR	Yes	Yes	No	No	TD	Yes	(M)	(M)
Markov analysis	Yes	Yes	Yes	Yes	Yes	Yes	TD	Yes	(M)	(M)
Petri network	Yes	Yes	Yes	Yes	Yes	Yes	TD	Yes	(L)	(L)
FMEA	NR	NR	Yes	No	No	No	BU	NR	(H)	(H)
HAZOP	Yes	Yes	No	No	No	No	BU	No	(M)	(M)
Human Reliability Analysis (HRA)	Yes	Yes	Yes	Yes	Yes	Yes	BU	No	(H)	(M)
Statistical methods for reliability	Yes	Yes	Yes	Yes	Yes	Yes	NA	NR	(M)	(H)

NR – can be used for analysis of simple systems. Not recommended as the sole method
NA – criterion is not applicable to this method
BU – Bottom-**U**p
TB – Top to **B**ottom
H –High; **M –** Middle; **L**–Low;

Table 1.Characteristics of the methods for RAMS analysis

Phase 2 System definition and application conditions - defines the mission profile if the system, the boundary of the system, establish the application condition influencing, define the scope of the of system hazard analysis, establish the RAMS policy for the system and the Safety plan. Required analyses are hazard, safety and risk analysis, e.g. PHA or HAZOP.

Phase 3 Risk analysis identifies hazards associated with the system, events leading to the hazards, determines risks associated with the hazards and establish a process for on-going risk management. Some analytic methods that could be used are HAZOP, Risk Matrix, Delphi technique or ETA.

Phase 4. System requirements, specifies the overall RAMS requirements for the system and the overall demonstration and acceptance criteria and establish the RAM Programme for controlling RAM tasks, Some analytic methods e.g., FMEA, FMECA, FTA, Markov analysis, HAZOP, PHA, ETA.

Phase 5. Apportionment of system requirements, apportion of the overall RAMS requirements to designate sub-systems, components and external facilities, Some analytic methods e.g., FMEA, FMECA, FTA, Markov analysis, HAZOP, PHA, ETA

Phase 6. Design and implementation, creates system and components conforming to RAMS requirements, demonstrates subsystem and components conform to RAMS requirements and establish a plan for future lifecycle tasks involving RAMS.

Phase 7. Manufacturing, implements a manufacturing process which produces RAMS-validated sub-systems and components, establish RAMS-centred process assurance arrangements and RAMS support arrangements.

Phase 8. Installation, assembles and installs the system and initiates support arrangements

Phase 9. System validation, Validates the total combinations of subsystem, components and external risk, commission the total combination of subsystem, components and external risks. Prepares the safety case for the system and provides data for acquisition and assessment

Phase 10. System acceptance, assesses compliance and accepts the system for entry into service

Phase 11. Operation and maintenance, operates, maintains and supports the system.

Phase 12. Performance monitoring, Maintains confidence in the RAMS performance. Analytic models e,g, RCA, FTA, ETA.

Phase 13. Modification and retrofit, controls the systems modifications and retrofit tasks to maintain the systems RAMS requirements.

Phase 14 Decommissioning and disposal Controls the decommissioning and disposal tasks.

4. CONCLUSION

The comparative analysis of the methods for assessment and modelling of the RAMS AND LCC indices in the preliminary design phase are made in the paper. During the preliminary phase of the design a high level of accuracy is accomplished and its follow by the detailed design.

The proposed analysis can be used for all investment projects in railways and also for development the measures for maintenance of the railway infrastructure.

REFERENCES

[1] STAPELBERG, R.F., (2009) Handbook of reliability, availability, maintainability and safety in engineering design, Springer,.

[2] DHILLON, B.S., (1999) Design reliability: fundamentals and applications, CRC Press, LLC 2000, NW Florida.

[3] GRANT IRESON W., COOMBS C.F., MOSS R.Y., (1996) Handbook of reliability engineering and management, McGraw-Hill, New York,

[4] CENELEC EN 50126-1: Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)

[5] CENELEC EN50128 Railway applications – Communications, signaling and processing systems – Software for railway control and protection systems”).

[6] SENELEC EN50129 „Railway applications – Safety-related electronic systems for signalling”.

[7] STOYTCHEVA N., 2005,Railway safety-critical systems modelling according CENELEC standards, Monograph, Todor Kableshkov Higher School of Transport, ISBN: 554-12-0110-5 (In Bulgarian)

35th INTERNATIONAL CONFERENCE
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25 - 28 September 2013
Kraljevo - Kopaonik
Faculty of Mechanical and Civil Engineering in Kraljevo

SAFETY REPORTS OF INVESTEMENT RAILWAY PROJECTS REQUIREMENTS AND PRACTICE

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According to the European regulations all investment railway projects have to include safety report over the preliminary design. The safety report has to demonstrate how preliminary design fulfils requirements to reach interoperability according to the Technical Specifications for Interoperability (TSIs).
The aim of the paper is to define requirements and content of the safety report according to the European legislation and Bulgarian standards of the investment railway projects.

Keywords: *Safety report, Directive 2004/49/EO, Regulation (EO) № 352/2009. Directive 2008/57/EO, TSIs*

INTRODUCTION

Motivation of the safety aims concerning structural subsystem or its respective part, including elements for achieving them. There are some normative regulations that have to be follow:

- Directive 2004/49/EO
- Regulation (EO) № 352/2009
- Directive 2008/57/EO
- Technical Specifications for Interoperability (TSIs)
- EN50126. Railway Applications: The Specification and Demonstration of Dependability - Reliability, Availability, Maintainability and Safety (RAMS)
- Ordinance №57.

The aim of the paper is to define requirements and content of the safety report according to the European legislation and Bulgarian standards including:

1. Introduction and motivation of the safety aims concerning structural subsystem or its respective part, including elements for achieving them;
2. Detailed plan for organizing the project and safety management after commissioning;
3. Technical and functional specifications of the designed subsystem;
4. Reasoned statement of expected deviations;
5. Preliminary analysis of risks;
6. Planned principles of operation and maintenance;
7. Planned actions for carrying out the safety checks in compliance with the TSI and / or national safety regulations for structural subsystem or part of it.

1. SAFETY MANAGEMENT OF THE RAIL-WAY INFRASTRUCTURE PROJECTS

The safety management of the railway infrastructure projects includes:

- Safety policy
- Qualitative and quantitative criteria of the Contractor to maintain and improve safety , and plans and procedures for achieving these goals
- Procedures to meet existing , new and altered technical and operational standards or other normative conditions
- Procedures and methods of risk assessment and implementation of measures to control the risk in the event of a change in operating conditions or the use of new materials and technologies
- Providing training programs for staff to ensure technical competence of staff
- Measures to provide sufficient information within the organization of the Contractor and , where appropriate , between organizations working on the same infrastructure
- Procedures and formats for how to document the safety and determine the procedure for the control of vital safety information ;
- Procedures to ensure that accidents, incidents and other dangerous incidents - reporting , investigation and analysis and taking the necessary preventive measures ;
- Provide action plans in case of accidents, consistent with the appropriate public authorities.
- Provisions for recurrent internal auditing of Safety Management System.

The excact scope of all above mentioned topics depend on the specific project and for each specific project there are many diferences.

2. SAFETY REPORT

2.1. Sub-systems

Before starting preparation of the safety report for the specific project the sub-systems have to be defined (fig. 1).

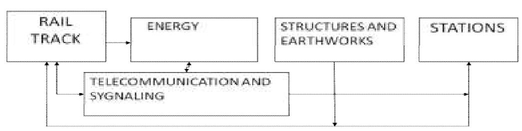

Fig. 1. Subsystems of the railway system

2.2. Motivating of safety goals

The anticipated effects on the key players in the railway transport, the related activities and the characteristics of the transport services are:

- Actual growth of freight services along the respective line, which will result in an increase of the revenues from infrastructure fees and reduction of the relative share of operational costs;
- Boosting of the economic activity in the region;
- Reduction of the travel time by an increase of the speed;
- Guaranteeing a higher level of reliability, security and safety of train movement as a result of the completed rehabilitation of the systems and interlockings at the stations, building of automatic blocking by axle counters without interlocking signals in the interstations and building of new microcomputer interlocking systems;
- Reduction of the costs on current maintenance and operation of the railway infrastructure;
- Shift from road to railway transport, which will result in reduction of environmental pollution;
- Reduction of the number and incidence of accidents and the related losses;
- Improving the quality of passenger and freight services in directions within this railway corridor;
- The attractiveness of the railway transport will grow with the introduction of certain institutional improvements (for example, introducing of a transparent tariff system, free access to time intervals, IT systems serving the customer, such as ones for freight transportation, providing real-time information about the freight, invoicing and accounting), as well as some other measures, such as servicing staff, special measures for key customers, reliability, precision, etc.;
- Creation of better conditions and safety for passenger and freights, improving of living standards by enhancing the access of persons with reduced mobility and measures for environment protection.

The implementation of the railway investment project and the full utilization of its components and systems will ensure a high level of safety guaranteed by:

- Implementation of modern and innovative technologies in the railway construction;
- Use of tested and certified materials, facilities and machines;
- Exercising of regular preventive and immediate control of the quality of construction in the course of implementation;
- Reducing the role of the human factor in the process of system management until its full exclusion from the train operations system.

The sfaety goals and the items, related to their achievement, are presented in Table 1.

2.3. Detailed design of the organization of the project implementation and management safety following putting into operation.

A detailed design is developed on the basis of a project of the Contracting Authority, as follows:

1. Name of the project;
2. Goal and designation of the project;
3. Subject and application area of the project;
4. Grounds for implementation;
5. Sources for drafting of the design terms for reference;
6. Technical requirements;
7. Content (volume) of the a working design (separately for each position);
8. Procedure for submission and coordination of the project and acceptance of devices;
9. Annexes.

The contractor carries out the construction in accordance with the terms of the application documents, the contract and the effective legislative framework of the Republic of Bulgaria in the area of construction.

The contractor drafts executive documents for the implemented construction and prepares the documents for its acceptance by a commission of acceptance under the control and with the assistance of the Consultant (assessment of compliance and independent construction supervision).

In connection with the management of safety, the following activities are envisaged following putting of the facility into operation.

2.4. Measures for maintenance of the construction and terms for conducting of repairs

1. Data and characteristics of the implemented activities in connection with the construction of the facility. These are prepared on the basis of a report by a Consultant, which conducts independent supervision in accordance with the Spatial Development Act.
2. Maintenance of the devices and systems within the warranty term. The terms for conducting preventive maintenance of the devices and systems are regulated in the respective statutory framework of the National Railway Infrastructure Company (NRIC) and the producer's operational instruction. Any defects having emerged within the warranty term are remmoved at the expense of the Contractor.
3. Terms for conducting technical tests and preventive maintenance.

The terms for conducting the technical tests of the separate devices and components of the construction are determined on the basis of Contractor-presented technical passports and instructons for operation of the separate devices and components of the railway infrastructure as well as the NRIC-approved monthly and annual schedules for maintenance of the facilities.

2.5. Safety management following putting into operation

The control of the safety requirements is exercised in the course of the construction and installation activities, start-up and commissioning and adjustment of the systems, as well as during regular operation. The safety of passenger and freight services is ensured as follows:

- The facilities and systems put into regular operation do not create any prerequisites and/or conditions for derailing or crashing of the rolling stock or consequences resulting in a change of the technical parameters of the railway infrastructure;
- Exceptions or other factors leading to violations of the construction gauge of the rail track or exposing the gauge of the rolling-stock to risk are not allowed;
- There are no disruptions of visibility or preconditions for disruption of the visibility of the signals;
- The fire safety requirements are fulfilled;
- The hygiene requirements for health protection of the living environment are fulfilled (Ordinance 7 of 1992, Amended SG 20 of 1999)

Regarding safety management, the following activities are envisaged after putting into operation:

- Maintenance of the parameters of the rail track and the railway facilities in compliance with the technical norms and observing the repair terms outside the warranty period that are regulated in the respective statutory framework of NRIC and the instruction for operation of the machines and facilities of the producer;
- Observing the deadlines for technical tests and preventive maintenance of the separate facilities on the basis of the technical passports, presented by the contractors, and the instructions for operation of the separate facilities and components of the system, as well as the monthly and annual schedules of servicing and maintenance of facilities and systems set by NRIC.

The user of the building shall observe the following while performing his activities:

- Spatial Development Act;
- Law on the Railway Transport;
- Ordinance No. 2 of 5 May 1987 on fire safety construction and technical norm issued by the Interior Minister and the Chairman of the Committee of Territorual and Urban Development;
- Ordinance No. 2 of 22 March 2004 on the minimum requirements for occupational health and safety upon conducting construction and installation activities, issued by the Minister of Labour and Social Policy and the Minister of Regional Development and Public Works;
- Ordinance No. 4 of 2 May 2001 on the scope and content of development projects, issued by the Minister of Regional Development and Public Works;
- Ordinance No. 6 of 9 June 2004 on connection of electricityproducers and users to the transmission and distribution networks;
- Ordinance No. 13 of 30 December 2005 on esnuring occupational health and safety in the railway transport, issued by the Ministry of Labour and Social Policy and the Ministry of Transport;
- Ordinance No. 55 of 29 January 2004 on the design and construction of railway lines, railway stations, level crossings and other components of the railway infrastructure, issued by the Minister of Regional Development and Public Works and the Minister of Transport and Communications;
- Ordinance No. 57 of 9 June 2004 for essential railway infrastructure and rolling-stock requirements for insurance of necessity parameters for interaction, operativeness and compatibility with Trans-European railway system, issued by the Minister of Transport and Communications;
- Ordinance No. 58 of 2 August 2006 on the rules of technical operation, train movement and signalling in the railway transport;
- Ordinance No. 4 of 27 March 1997 on level crossings;
- Technical Specification – Railway Infrastructure 002 – 2005 “Automatic level crossing devices”;
- Technical Specification – Railway Infrastructure 003 – 2005 “Level crossing traffic lights”;
- Technical Specification – Railway Infrastructure 006 – 2006 “Bareer mechanisms”;
- Technical Specification – Railway Infrastructure 007-2006 “Electricity supply subsystem of traction rolling stock 25 kV, 50 Hz. Catenary network. Pantographs. Mechanic interaction between the pantographs and the catenary network”;
- Other effective statutory instruments concerning railway transport.

Table 1. Safety goals and steps for their fulfillment

Safety goals	**Steps for fulfillment**
Infrastructure Subsystem	
Guaranteeing of security and continuity of the train movement along the railway track	Replacement of lower and upper construction Use of a new rails and sleepers grid, heavy type UIC 60E1 Rehabilitation of facilities
Safety and protective equipment to limit the access to the installed components	Elastic level crossing covering Rehabilitation and building of new platforms Access for persons with limited mobility
Energy Subsystem	
Flawless operation of the catenary network	Use of the electricity supply system, which is

	compatible with the remaining railway network Replacement of catenary conductor Fitness of the catenary network for a speed of 160/200 km/h Restoration, repair and modernization of five traction substations;
Guaranteeing of the safety of the people and the rolling stock and impact on the environment within admissible limits	Compliance with the gauge in accordance with the statutory documents. Earthing and screening – in accordance with the statutory documents Limiting the impact on the environment and natural habitats under Natura 2000
Control of Control, Command and Signaling Subsystem	
Provision of high level of safety of movement of rolling stock	Design and construction of signalling and telecommunications systems. Rehabilitation of station interlocking systems Construction of microcomputer interlocking systems Control of the use of the capacity of the rail track through axle counters Installation of ETCS level 1/2 Modernization of level crossings
Provision of operational relaibility of the systems	Limiting the access to the facilities Double electricity supply of the facilities Ventilation system and energy efficiency Heating of switches Fire alarm and use of non-flammable materials Computerization of processes
Protection from thefts, encroachment, vandalism and terrorist acts	Video surveillance Regular control of access
Information provision and warnings of passengers	Electronic information boards at the stations Loud speaker system at the stations Visualization of information Rehabilitation of the telecommunication systems

3. CONCLUSION

Safety report has to include all planned actions for carrying out the safety checks in compliance with the TSI, Detailed Territorial Law, Planned principles of operation and maintenance and / or national safety regulations for structural subsystem or part of it.

REFERENCES

[1] EU Directive 49/2004/EC

[2] LAW FOR THE RAILWAY TRANSPORT

[3] ORDINANCE No. 41 of 27 June 2001on the access to and use of railway infrastructure, (Published, SG No. 64 of July 20, 2001 and in force as of January 1, 2002; amend. SG No. 50 of 30.05.2003; amend. SG No. 87 of October 2006; amend. SG No. 70 of 08.08.2008)

[4] ORDINANCE No. 42 of 6 July 2001 for licensing of railway authorities for transportation of passengers and/or freights and for bodies issued safety certificates, amended 24 November 2006

[5] ORDINANCE No. 57 of 9 June 2004 for essential railway infrastructure and rolling-stock requirements for insurance of necessity parameters for interaction, operativeness and compatibility with Trans European railway system. Published in State gazette number 55 from 25.06.2004, revised State gazette number 60 from 09.07.2004 and number 91 from 15.11.2005, Applicable from data of Contract on accession of the Republic of Bulgaria to the European Union, State gazette number 55 from 07.07.2006, amended of 2 November 2007

[6] TCI „Control, Command and signalization", Appendix №5 to art..5, par.1 of Ordinance №57, Sofia, 2005

[7] CENELEC EN 50126-1: Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)

[8] CENELEC EN50128 Railway applications – Communications, signaling and processing systems – Software for railway control and protection systems").

[9] CENELEC EN50129 „Railway applications – Safety-related electronic systems for signalling".

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PARAMETRIC DRAWING OF A CYCLO DRIVE RELATIVE TO INPUT SHAFT ANGLE

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Abstract: *Gears with a cycloid profile have very good working characteristics in kinematic and dynamic domains. These types of gears generally have convex on concave contact surfaces, which influences the decrease in stress as well as contact wear of the sides of the gearing. The most commonly used profile of cycloid discs is an equidistant of the shortened epitrochoid.*
Given that this is a complex curve, this paper gives a program code for its automated generating. Using the input parameters of the cycloid disc, as well as those of other elements of the cyclo drive which are in contact with the cycloid disc (central static gear rollers and output rollers), the program creates a drawing of the cycloid disc as well as the afore mentioned rollers. The particular contribution of this paper is that the acquired drawing is made for any set rotation angle of the input shaft. The drawing represents a very valuable and time efficient initiate for a planar analysis of stress and deformation states using finite element analysis for cyclo drives.

Key words*: cycloid drive, cycloid gear, automated generating*

1. INTRODUCTION

Cyclo drives, part of the planetary drive group, have a wide application in the industry thanks to their excellent characteristics, particularly, their wide range of gear ratios, smooth transmission, high efficiency, compact size, and high overload capacity. Some of its other strong suits also include low noise, long and reliable service life, compact design, and suitability for frequent start-stop and reverse duty.
The basic information about cycloidal gearing is presented by Kudrijavcev [1] and by Lehmann [2]. Parametric equations for equidistant of trochoid have been developed by Litvin and Feng [3]. Meshing conditions have been covered by Chen, Fang, Li and Wang [4]. Computerized design for generation of surfaces and curves has been developed in [5]. An analytical model has been developed by Blanche and Yang [6] with machining tolerances to minimize backlash and torque ripple. Distribution of loads has been analyzed in [7], [8], and [9]. Level of efficiency has been examined by Gorla, Davoli, Rosa, etc. in [10].

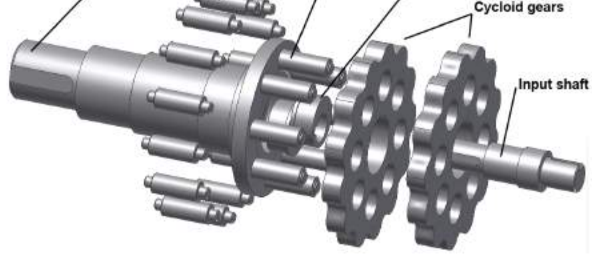

Fig. 1. Operational components of a cyclo drive assembly

The key component of the cyclo drive is the cycloid disc. The cycloid disc profile is an equidistant of the shortened epitrochoid while the annular sun (central) gear has rollers instead of teeth. The cycloid gear is made with one tooth less than the number of rollers on the central gear (only some newer cycloid drive designs have two teeth less). In practice, most commonly used systems of cyclo drives have two cycloid disks which are rotated by 180º of each. Other operational components of cycloid drives are given in Figure 1.
Stress analyses in the contact of the cycloid disc and the central rollers are most commonly performed for characteristic angles of the input shaft. This is the case due to the complex geometry of the cycloid disc which has to be rotated around the central axis by the offset cam and around its own axis, which is a time-consuming process. By automating the drawing process it is possible to avoid the likelihood of human error as well as shortening the time needed to position the gear meshing in the desired contact position.
As a basis, a two-dimensional sketch drawn in AutoCAD can be imported into any modeling and analysis program as reference geometry. AutoLISP has the capabilities of automating the drawing process, and as such is ideal for the purposes of parametric input drawing.

2. CYCLOID DISC PARAMETERS AND PROFILE

Tooth profiles are any curves which satisfy the basic laws of meshing. If the profile of one tooth, distance between axis and transmission ratio are all known, the profile of the second gear can then be defined completely. It is a curve of the same character as the profile of the first gear, except with different parameters. Roulettes are curves which satisfy the fundamental rules of meshing and they can be eater involutes or cycloids [9].

A cycloid is a curve which is traced by a point located anywhere on a (rolling) circle which rolls along a stationary (basic) circle. The rolling circle has a radius, R_a (1), while the stationary circle has a radius, R_b (2). For defining these radiuses it is necessary to know the pitch circle radius of the central gear, *r*, as well as the gear ratio, u_{rc}.

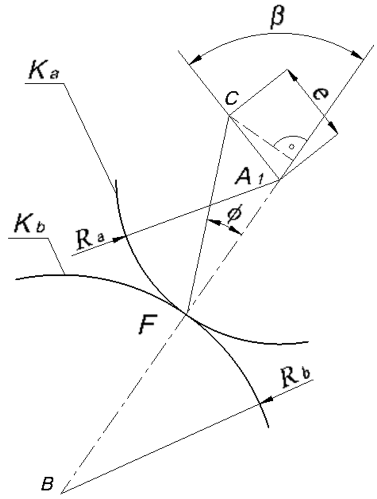

Fig. 2. Visual representation of auxiliary angles and circle radiuses

Cycloids can have different forms depending on the position of the rolling circle in relation to the basic circle, as well as the position of the point on the rolling curve which traces the cycloid. The most commonly used tooth profile for cycloid gears is an equidistant of the shortened epitrochoid.

$$R_a = \frac{r}{u_{CR} + 1} \quad (1)$$

$$R_b = r - R_a \quad (2)$$

The equations for *x* and *y* coordinates for the equidistant of the shortened epitrochoid are given by functions (3) and (4).

$$x = (R_b + R_b) \cdot \cos\alpha + e \cdot \cos(\alpha + \beta) - q \cdot \cos(\alpha + \phi) \quad (3)$$

$$y = (R_b + R_b) \cdot sin\alpha + e \cdot \sin(\alpha + \beta) - q \cdot sin(\alpha + \phi) \quad (4)$$

These equations are given as a function of the angle (α) between the starting and current position of the point of contact of the basic and rolling curve relevant to the centre of the base curve. Auxiliary angles, β (5) and ϕ (6), are used in these equations to simplify the calculation of the curve. They are functions of α, the radiuses of the basic and rolling circles and size of eccentricity, e. These angles are shown on Figure 2, where K_a is the centre of the rolling circle and K_b is the centre of the basic circle.

$$\phi = arctg\left(\frac{\sin\beta}{R_a/e + \cos\beta}\right) \quad (5)$$

$$\beta = \frac{R_b}{R_a} \cdot \alpha \quad (6)$$

3. PROGRAM REQUIREMENTS AND ROUTINE

In this section, the requirements as well as the methodology of the program will be explained. The program is written in AutoLISP which is a dialect of the LISP programming language. AutoCAD can be programmed by AutoLISP to automatically generate parametric drawings and perform other manipulations. Variables are input via the command line in the AutoCAD interface. Writing the code for AutoLISP is possible with the use of any text editor or the Visual LISP editor.

3.1. Input And Output Requirements

The necessary input values, as well as the order in which they are calculated and input, required to draw the drive are given in Table 1. These values are derived from a basic previous calculation based on the drive requirements.

Table 1. Values required by the program in order of input

No	Value	Label
1	Radius of the pitch circle of central gear	r
2	Gear ratio	u_{CR}
3	Correction coefficient	ξ
4	Radius of ring gear *	r_2
5	Radius of central gear roller *	q
6	Input shaft rotation angle	Θ
7	Diameter of output mechanism	D_{vk}
8	Adopted number of output rollers	u
9	Diameter of shaft needle bearing	D_{cz}

The values marked with an asterisk (*) are meant to be adopted from calculated values which the program should display for the user before its required input.

The output of the program needs to be a simplified drawing of a cross-section of a cyclo drive's operational elements assembly (cycloid gear, output rollers and central gear rollers) at a given input shaft angle. Also the program should give axis for all elements in the form of points. The resulting elements are shown in Figure 3.

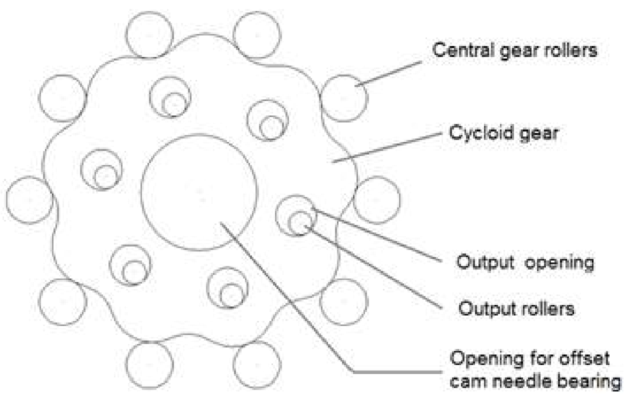

Fig. 3.Components of resulting drawing

3.2. Program Code

The entire program is written without subroutines due to its simple requirements. It does however consist of six major parts. First the input of values, drawing the gear center at input shaft angle, drawing the cycloid profile and opening for offset cam needle bearing, drawing output openings, drawing output rollers and finally drawing central gear rollers. Input of adopted, previously calculated, values is shown in Figure 4.

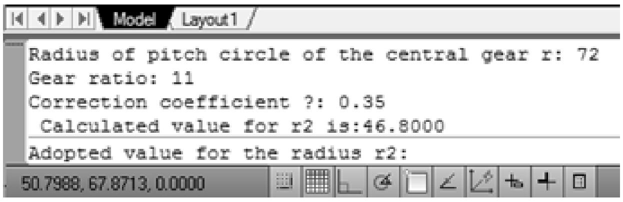

Fig. 4. Example of inputting values in command line

Given in figure 5 is the part of the program code with a predetermined density of points to be joined by the curve of n=50·z_1. A density of 50 points per tooth gives a very high precision of the curve. This segment of the code is designated for the creation of the profile curve of the cycloid gear.

The function of creating points required for curve generation is repeated m times, where m= n+1, because the spline curve which will connect them needs a tangent for its final point.

The angle α starts at the angle of the input shaft, Θ and changes by n/360 with every consecutive iteration creating a point at an equal distance from the previous one.

In the code an angle named "tetan" is used as an auxiliary which represents the rotation angle of the cycloid gear around its own axis. Rotation around its own axis and the rotation around the offset cam are divided in separate equations for the purposes of simplifying the equation. Only the final coordinates of the rotated points are used to create the spline which makes the cycloid curve.

The rest of the program consists of similar repeat functions for creating points and circles drawing the holes for the output mechanism rollers, as well as the central and output gear rollers.

4. PROGRAM RESULTS AND PRACTICAL EXAMPLES

As a result of the created program AutoCAD is able to generate a two dimensional drawing of a cycloid drive assembly from the user's values which have previously been typed into the command line.

Table 2 gives the input values for two different cycloid drives at three different input shaft angles (0º,45º and a randomly selected angle of 198º) which have been drawn using this program.

The resulting drawings for these gears are shown in Figures 6 and 7.

```
(setq alpha teta)
;;starts alpha from set rotation angle

(setq tetn (+ (/ pi z1) (/ (- 0 teta) z1)))
;;angle of rotation arround own axis relative to offset cam angle

;;______________________________ SPLINE ______________________________;;
(setq pts nil)
(repeat m
  (setq alpha (+ (/ (* pi 2) n) alpha))
  ;;gives the step of change for alpha
  (setq
    x (- (+ (* (+ Rb Ra) (cos alpha))
            (* e (cos (+ alpha (/ (* Rb alpha) Ra))))
         )
         (* q
            (cos (+ alpha
                    (atan (/ (sin (/ (* Rb alpha) Ra))
                             (+ (/ Ra e) (cos (/ (* Rb alpha) Ra)))
                          )
                    )
                 )
            )
         )
      )
  )
  ;;x coordinates
  (setq
    y (- (+ (* (+ Rb Ra) (sin alpha))
            (* e (sin (+ alpha (/ (* Rb alpha) Ra))))
         )
         (* q
            (sin (+ alpha
                    (atan (/ (sin (/ (* Rb alpha) Ra))
                             (+ (/ Ra e) (cos (/ (* Rb alpha) Ra)))
                          )
                    )
                 )
            )
         )
      )
  )
  ;;y coordinates
  (setq xs (- (* x (cos tetn)) (* y (sin tetn))))
  (setq ys (+ (* y (cos tetn)) (* x (sin tetn))))
  ;; Rotation arround own axis
  (setq xt (+ xs (* e (cos teta))))
  (setq yt (+ ys (* e (sin teta))))
  ;; rotation of offset cam - final coordinates
 (setq pts (cons (list xt yt 0.0) pts))
   ;;draws points for spline
  )
  ;;end of repeat function
  (command "spline")
  (mapcar 'command pts)
  (command "" "" "")
  ;; draws spline from final points
```

Fig.5. Segment of the program code dedicated to drawing the cycloid profile

Table 2. Values required by the program in order of input

Required input values for:	***Drive 1***	***Drive 2***
Radius of the pitch circle of the central gear, r	72	86
Gear ratio, u_{CR}	11	13
Correction coefficient, ξ	0.35	0.4
Radius of ring gear, r_2	48	56
Radius of central gear roller, q	10	7
Input shaft rotation angle, Θ	0,45,198	0,45,198
Diameter of output mechanism, D_{vk}	8	14
Adopted no. of output rollers, u	6	8
Diameter of shaft bearing, D_{cz}	40	50

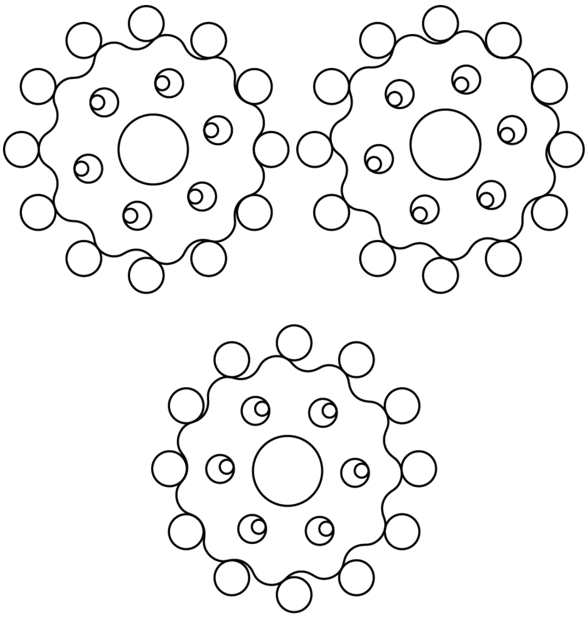

Fig. 6. Resulting assembly drawing for Drive 1 at input shaft angles 0º,45º and 198º

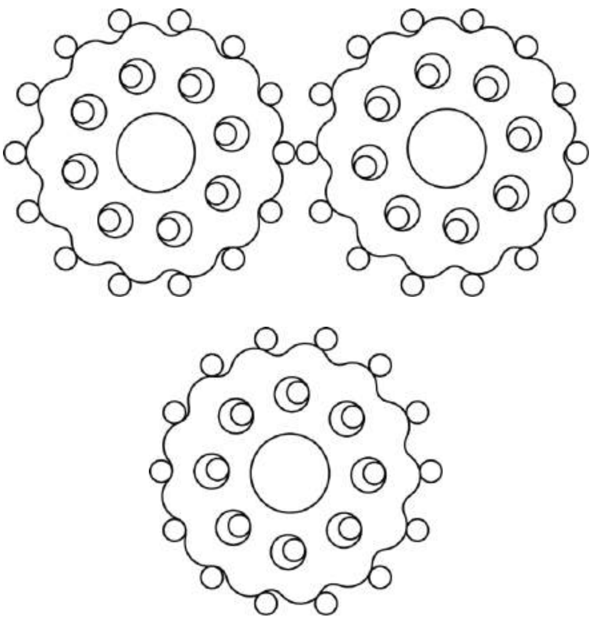

Fig. 7. Resulting assembly drawing for Drive 2 at input shaft angles 0º,45º and 198º

5. CONCLUSION

Cycloid gears have exceptionally admirable working characteristics in both kinematic and dynamic domains. The fact that the profile of the cycloid gear has a very complex geometry, a shortened equidistant epitrochoid curve, is the only limiting factor to its wider use. In comparison to involute gears the production of cycloid gears is much more intricate due to the cycloid gears sensitivity to change in axial distance [9].

Creating an automated method of drawing the gear profile has been developed in this paper. This program enables the drawing of any cycloid drive at a particular input shaft angle in minutes, where as this process would take a considerably longer time to do using conventional methods, especially for a larger number of angles. Also this program reduces the possibility of human error and the necessary time to draw each drive position individually. The general idea behind the addition of giving the cycloid drive drawing at a particular input angle is to enable easier creation of analysis models at various angles with a different contact for each.

REFERENCES

[1] KUDRIJAVCEV, V.N. (1966) *Planetary Gear Train (in Russian),* Mechanical Engineering, Leningrad

[2] LEHMANN, M. (1976) *Calculation And Measurement Of Forces Acting On Cycloid Speed Reducer (in German)*, PhD Thesis, Technical University Munich

[3] LITVIN, F., FENG F. (1996) *Computerized Design And Generation Of Cycloidal Gearings*, Mechanism and Machine Theory, Vol.31, No 7, pp 891

[4] CHEN, B.K., FANG, T.T., LI, C.Y., WANG, S.Y., (2008) *Gear Geometry of Cycloid Drives, Science in China Series E: Technological Sciences*, Vol. 51, No. 5, pp. 598-610

[5] LITVIN F., DEMENEGO A., VECCHIATO D., (2000) *Formation by Branches of Envelope to Parametric Families of Surfaces of Curves*, Computer methods in applied mechanics and engineering, Vol. 190,No. 35-36, pp. 4587-4608

[6] BLANCHE J.G., YANG D. C. H., (1989) *Cycloid Drives With Machining Tolerances*, Journal of Mechanisms, Transmissions, and Automation in Design, Vol.111, pp. 337-344

[7] CHMURAWA M., LOKIEC A.,(2001) *Distribution of Loads in Cycloidal Planetary Gear (CYCLO) Including Modification of Equidistant*, 16th European ADAMS User Conference, Berchtesgaden, Germany

[8] BLAGOJEVIC, M., MARJANOVIC N., DJORDJEVIC Z., STOJANOVIC B., DISIC, A. (2011) *A New Design of a Two-stage Cycloidal Speed Reducer*, Journal of Mechanical Design (ASME),Vol.133, No. 8.

[9] BLAGOJEVIĆ, M. (2003) *Kinematic and Dynamic Analysis of a Single Stage Cycloid Drive (in Serbian),* Master thesis, Faculty of Engineering, Kragujevac

[10] GORLA C., DAVOLI P., ROSA F., LONGONI C., CHIOZZI F., SAMARANI A. (2008). Theoretical and Experimental Analysis of a Cycloidal Speed Reducer, Journal of Mechanical Design (ASME), Vol. 130.

35th INTERNATIONAL CONFERENCE ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
Faculty of Mechanical and Civil Engineering in Kraljevo

OPTIMAL TOOL PATH MODELING IN CONTOUR MILLING PROCESS

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Abstract: *In the design of CNC metal cutting technology, the tool path in contour milling is usually adjusted to technology form of the modeled work piece and contour to be processed, which satisfies the geometric criterion, that is the simplest in the choice of tool path. In this tool path selection, other criteria in terms of cutting forces, tool wear intensity, maximum depth, maximum cutting speed and desired surface quality, which are crucial for the productivity and efficiency of machining processes, are neglected.*
This paper presents the analysis of influencing factors on tool path choice in contour milling including phenomenological appearance in the cutting zone to identify the possibility of determining the optimal tool path. Among other things, an overview of the opportunities offered by modern CAM systems in generating NC code, which solves the problem of the tool path selection in contour milling, is given here.

Key words*: cutting process, contour milling, tool path, CNC technology*

1. INTRODUCTION

One of the most common operations in machining metal parts is pocket milling: removing all the material inside some arbitrary closed boundary on a flat surface of a work piece to a fixed depth [1].
In High Speed Milling (HSM), the spindle rotation speeds as well as the feed rates are much higher than for the conventional milling with an objective to minimize the manufacturing time without decreasing the part quality. In this paper, generation and optimization of tool paths for pocket machining is analyzed for High speed milling.
One of the pocket-machining paradigms changed by high-speed machining is that machine dynamics can be ignored when a tool path is generated. Conventionally, dynamics have been pretty much ignored; the best path was the shortest, and it either reflected the part pocket boundary shape in its entirety so-called parallel-offset paths or consisted of many straight-line segments zig-zag or raster scan. [2].

2. POCKET MILLING

Most of mechanical parts consist of faces parallel or normal to a single plane and free form objects require a 2.5D rough milling operation of the raw work piece, making 2.5 D pocketing one of the most important milling operations. Almost 80% of the milling operations to produce mechanical parts are produced by NC pocket milling [3].
In usual pocket milling using flat end milling tool, the pocket is generated by sweeping a cylindrical tool inside the pocket boundary. The rotating tool sweeps the material to be removed in its feed direction along a set of lines, circles and splines, which are usually referred as tool paths [3].

2.1. NC tool paths

NC tool paths can be classified into two major types, namely linear and non-linear. Examples of simple and easy-to-generate linear tool path are the zig and the zig-zag tool paths as shown in
Fig. *1* (a) and (b). The zig path is a uni-directional cutting path, and hence a consistent up-cut or down-cut chip removal method can be maintained. However, there is a considerable amount of non-productive time involved in returning the cutter to the start-cut position at the end of each cutting path. On the other hand, the zig-zag path is a bi-directional cutting path in which material is removed both in the forward and backward paths. Although the zig-zag tool path can reduce non-productive tool positioning time, it has the disadvantage that the up-cut and down-cut methods are alternately applied. This will lead to problems such as machine chatter and shorter tool life [4].

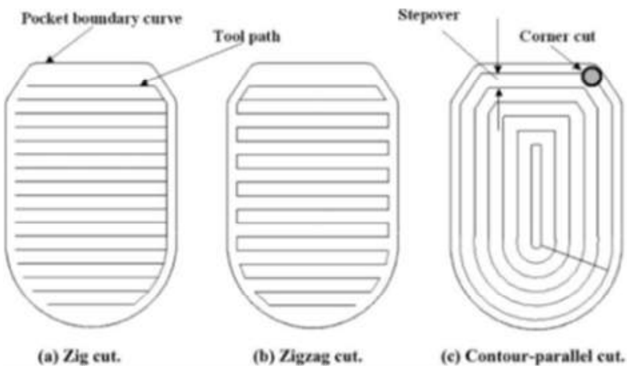


Fig. 1. Three commonly used tool path patterns. (a) Zig cut; (b) zig-zag cut; and (c) contour-parallel cut [4]

Parametric-based tool path is frequently used as a finishing tool path for machining parametric surfaces as the tool path is driven directly along the *u–v* parametric curves of the surface itself. As shown in Fig. 1(c), contour-parallel tool path pattern is derived from the boundary of the concerned machining region. It is a coherent tool path in the sense that the cutter is kept in contact with the cutting material most of the time. So it incurs less idle times such as those spent in lifting, positioning and plunging the cutter. At the same time it can also maintain the consistent use of either up-cut or down-cut method throughout the cutting process. Contour-parallel tool path is therefore widely used as a cutting tool path especially for large-scale material removal.

The contour parallel tool paths consist of contours of two types of offsetting. The very first offset of the boundary should be equal to the radius of the tool and then the usual offset based on the step over value is determined.

The contour parallel in-out strategy i.e. to cut the material from the middle of the pocket to the outside boundary is usually preferred as it involves first slotting with a minimum length of cut. Contrary to spiral-out tool paths, spiral in tool paths don't require boundary conformation as the first pass itself is the usual offset of the pocket boundary by the tool radius. These tool paths are usually practiced in automobile and aerospace industry where the thin walled boundaries have high rigidity requirements.

2.2. Tool path generation

The generation of a contour parallel tool path in a pocketing operation requires an offsetting operation of the inner boundary of the pocket and outer boundary of the island. The offsetting of a boundary has been a classical problem in computer graphics and consequently many methods from computer graphics are applied for contour parallel tool path generation.

The contour-parallel tool path generation can be divided into three different approaches: (1) 'pair-wise intersection', (2) 'Voronoi diagram', and (3) 'pixel-based'.

Offsetting of a boundary using 'pair-wise intersection' is a two stage process: (i) Determining the offset of the spline in an iterative manner until the error in the offset is reduced below a user defined limit (ii) detecting the singularities and redundant portions and correcting them.

Voronoi diagram is one the earliest approach to construct the contour parallel tool path. Held [5] utilized the method for creating the tool path, but restricted his approach for linear and circular segments, because these representations can easily be fed to CNC machines. Although this approach has been extended for non-linear segments, the method based on Voronoi diagram employs costly two dimensional boolean set operations, relatively expensive distance calculations and an overhead of extraneous geometry.

Similar to bypassing the step to detect and remove the self intersection features, a pixel simulation based approach for the offsetting is developed, where the tool path is generated by successive sweeping of the tool. This method is based on the Z-map and hence, high computational time and huge memory is required to achieve a desired level of precision due to its dependence on the resolution of the Z-map.

However, the adaptation of any method requires some preprocessing as well as post processing of the original method to make the generation of path efficient.

3. ENGAGEMENT ZONE MODELING

Cutter engagement is a measure that describes what portion of the cutter is actually involved in machining at a given instant of time. During complex milling operations, usually only a portion of cutter engages in cutting and, therefore the cutter engagement varies along the cutter path. The different engagement conditions for pocket milling are shown in
Fig. *2*. It is clear that as the tool is moving along the tool path the engagement condition can drastically change and hence the cutting loads.

Therefore, by monitoring the cutter engagement, we can monitor and control cutting forces. A sudden increase in cutter engagement may even result in tool breakage. Determination of cutter engagement is essential for adjusting feed rate. Cutter engagement value can also be used in generating efficient cutter paths [6].

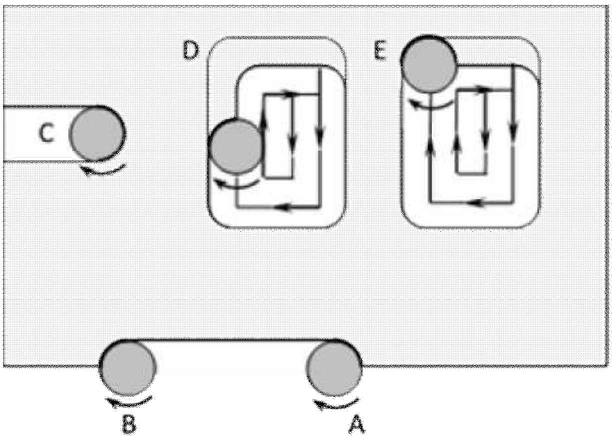


Fig. 2 Different Engagement Conditions, full engagement at scenario C and E, Half engagement for A, B and D[1]

A number of methods have been developed to calculate the engagement zone at any instant of 2.5D axis milling. These methods can be broadly divided into the following categories: (i) Analytical methods (ii) Discretized models (iii) Solid modeller based solutions. In Analytical modelling, the concept of half spaces is used to find the overall combinations of intersection of different part straight lines or circular arcs with the tool. The method yields results very fast, however, there are a number of limitations due to the analytical nature of the existing method [1]: limitation on work piece shape (only considers geometry with limited features like circles and straight lines, also there should be no cavity or hole in the initial geometry), limitations in work piece modelling (the equations of straight lines and circles must be provided), limitations in tool path (self intersecting tool path to be avoided).

Further, in discretized models, the primary focus is given on the material removal simulation of milling process by means of computer graphics. The primary goal of these simulations is to verify a given NC program for unwanted material removal and gouges in sculptured milling. The two main sub methods in this domain are: the vector method and the z-buffer technique. These methods have been used for the force calculation also in sculptured surface milling with consideration of tool deflection.

In solid modeling based methods, the standard Boolean operations are used to calculate the resultant geometry with the swept volume of the tool and the original work piece geometry. Although these Boolean operations are more computationally expensive than the other discretized methods, they represent the accurate geometry of engagement at each simulation step.

A solid modeling based extraction of CWE (Cutter Work piece Engagement) in feature based machining is carried out recently by Yip-Hoi and Huang [7].

Based on feature recognition, a database of different CWE corresponding to each feature is developed. However, there are two main assumptions that make it difficult to generalize the model for the actual 2.5D milling process. These assumptions are, first, the part should be rectangular prismatic and second the set up changes should be orthogonal to each other. Also, the approach depends upon the feature recognition capability of the system, which has its own limitations. Recently, Merdol et al. [8] has proposed a computational efficient algorithm for simulating the flute action on the arbitrary engagement zone either by CSG or Z-buffer and for reformulation of milling forces. The intersection points of flutes are computed analytically for simple engagement zones or numerically for complicated zones.

As the Constructive Solid Modeling represents the exact boundary information a general approach to extract CWE and further action of the helical flute is developed to calculate the cutting force. This approach doesn't require the feature extraction ability to be available in the system. It is an approach to simulate an arbitrary NC program with apparently no restriction on the initial work piece shape for 2.5 axes milling or higher.

Once the final part, raw work piece and the NC program are generated in any commercial software, the engagement areas can be calculated. The developed method, based on the solid modeling approach, inevitably calls for the Boolean operation between intersecting entities. Along the tool path, at any position of the tool, Boolean operations are required to update the work piece geometry and find the common entity (area) between the updated work piece and tool. In many cases it may happen that this engagement zone doesn't vary along some portion of the tool path. This portion is called force invariant feature and is already introduced in [7]. If the tool path segments are known, the number of Boolean operations can be significantly reduced.

4. MILLING MACHINING TIME EFFICIENCY MODELING

The machining time is one of the most important criteria to compare the machining efficiency of the tool path. The theoretical machining time is mostly obtained by summing up the time values from the division of each length segment with associated programmed feed rates.

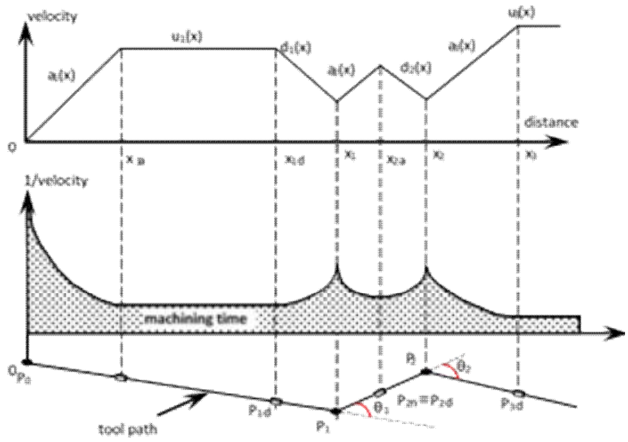


Fig. 3 Milling time modeling based on acceleration and deceleration of machine tool [9]

The theoretical machining time always underestimates the actual time because it does not take into account the effects of acceleration and deceleration of CNC machine. To compare the developed tool paths with the conventional ones, the machining time calculation based on the machining time model, which takes into account the controller's dynamic behaviour, has to be taken into account. Fig. 3 shows that the change in the direction of motion makes the feed rate profile vary due to the acceleration and deceleration of the machine tool.

Kim and Choi [9] concluded that the effect of acceleration and deceleration of a machine tool on the milling efficiency of various tool paths is large for high feed rate milling.

5. HSM TOOL PATHS

After the advent of High Speed Machining (HSM) in aerospace and automotive industries for machining complex machining parts made of aluminum and its alloys, the HSM is becoming increasingly popular as an innovative technology in all the manufacturing sectors. High Speed Milling assures two times more productivity, first in cutting speeds and second in feed rates. Modern High speed machine tools are capable of achieving very high spindle speed up to 50,000 RPM and traverse rates up to 16,000 mm/min.

In high speed milling (HSM), machining efficiency is improved by increasing cutting speed. For the purpose of lightening cutting resistance, reducing vibration and avoiding distortion, cutting depth is reduced in HSM, so that the operating load is lowered [10].

5.1. HSM considerations

The contour-parallel tool path generation is usually purely geometric in nature, which leads to a variation of radial depth of cut especially at sharp corners. The usual problems encountered due to this variation are: (i) left over material at corners (ii) sudden tool breakage, which leads to choosing worst scenario cutting conditions in manufacturing practices. Also, with the advent of high speed machining, the focus has been to develop smooth and curved tool paths for material removal to ensure machining quality.

From the machine dynamics and cutting tool point of view, the variation in the cutting load affects the tool life as well as the machine tool condition itself. Conventional contour parallel tool path based approaches such as spiral milling although they insure smooth tool paths; they result in a high variation of the radial depth of cut, which influences the tool load and machine dynamics.

Again as per the conventional paths, the problem specially arises at the corners and hence corner cutting or excess material removals at convex corners have long been studied analytically. For the general cases, there are two popular approaches mentioned in the literature to find the solution for the cutting load variation problem along the machining tool path: feed rate scheduling and tool path strategies. In feed rate scheduling, feed rates are typically programmed for the worst-case scenario to avoid tool breakage. Online optimization routines are sometimes used for maximizing material removal but that require a considerable amount of setup and maintenance efforts for the machine hardware.

The type of optimization depends upon the type of cutting tool used, its diameter, length, material, number of flutes and the work piece material. Further, these routines put an extra effort on the machine tool controller as well as the machine components to change feed rate for each block of NC code.

On the other hand, the approach to adapt or modify the tool path for achieving a constant load is independent from the cutting tool diameter, length, number of flutes and work piece material.

5.2. Corner cutting strategies

Further the generation of smooth tool paths could lead to high gains in machining time [11]. For the excess material removal at a sharp corner, circular loops are usually suggested. Zhao et al. [10] suggested the self-intersection like bi-arc transitions at each corner to avoid the restriction on the step over at a sharp corner in order to improve the tool path length **Error! Reference source not found.**. However, the tool is over engaged at the corners and needed to slow down at the corner. Also, the cutting direction is reversed as the tool travels from the apex of the loop to the end of the loop.

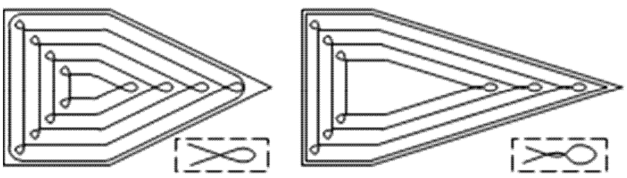


Fig. 4 The simulation of two type of biarc toolpath transitions. (a) Using the first type of biarc transition and (b) Using the second type of biarc transition [10]

A recent approach by Choy and Chan [4] describes the single loop and double loop strategy at the corner **Error! Reference source not found.**. However, their approach is limited to the nine combinations of clockwise circular, anticlockwise circular and straight line portion of the corners. Further, the number of loops required may be greater than two, which has not been addressed adequately.

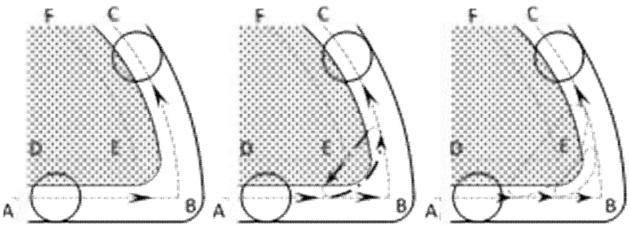


Fig. 5 Corner cutting strategies. (a) Conventional; (b) SLS; and (c) DLS.[4]

Further, Pateloup et al. [11] studied the behavior of different possible configurations of tool paths for a simple rectangular pocket geometry with right angle corners considering the dynamics of machining. The emphasis is given to maintain a minimum variation on the radial depth of cut on smooth tool paths. However, no automatic computing system is either specified or developed to generate the tool paths for complex geometries.

5.3. Generic tool paths

Dhanik [3] develop a recursive method to identify the excess material at the corners and to remove this material at each corner which is independent of segment types forming a corner and is generic in nature.

This method based on the signed distance function generate contour parallel tool paths which keep track of the in-process material boundary and confirms the material removal to the boundary of the pocket. Tool paths are smooth in nature for the high speed milling condition. This method and algorithms avoids the leftover material at the corners and minimizes the variation of radial depth of cut at each level of contour milling and consequently tries to maintain the same cutting conditions specified as the starting cutting parameters which are favorable for process reliability, part quality and tool life.

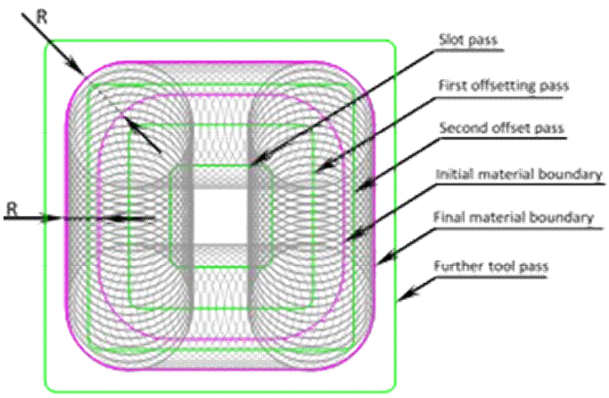


Fig. 6 The first offset pass and radial depth of cut variation [3]

In order to make a constant radial depth of cut, it is needed to modify the tool pass such that the material removal is same all along the tool path. Thus, for a given step over, the modified pass is determined by finding a boundary which is offset of the material boundary outwards by the amount of (Radius of tool- radial depth of cut). This concept is shown in Fig. 7. Note that the modified pass determined according to the above formulation coincide with the conventional tool path corresponding to the linear portion of the material line. But as soon as the material line deviates from the straight line the modified tool path also changes (the portion BC in Fig. 7 a). However, in this way the modified tool path also produces a new material line. This new material line is determined by offsetting outwards the modified tool pass by the value of tool radius. Proceeding in this manner may result in material left at the corners of the pockets. Thus an automatic program is conceptualized to detect and make additional passes to remove the material from these corner profiles.

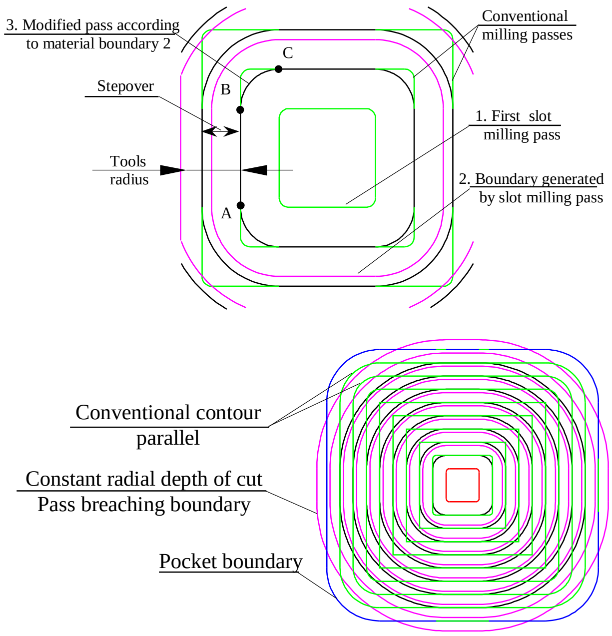


Fig. 7 Conception of Tool Path Modification [3]

The constant width of cut passes was achieved for spiral-out tool and the inevitable corner loops were constructed for the pocket to be constructed conforming to its required boundary.

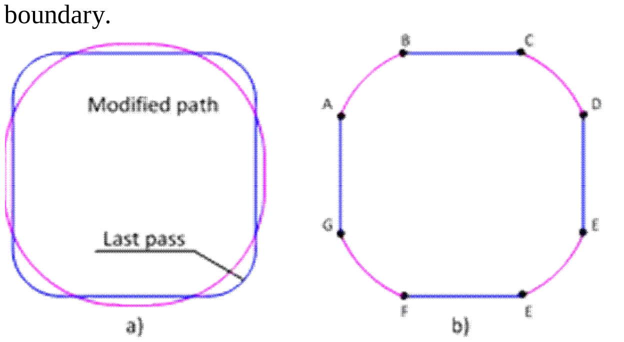


Fig. 8 Non-conformation of tool path (b) The conformed tool path [3]

5.4. Boundary conformed tool paths

Spiral in tool paths don't require boundary conformation as the first pass itself is the usual offset of the pocket boundary by the tool radius. These tool paths are practiced when the thin walled boundaries have high rigidity requirements. Thus, a slot milling pass at the boundary is utilized to minimize the change in the part rigidity. Dhanik [3] develop the method which optimize the successive contour parallel offsets for the smoothness as well as the engagement change. 'Efficient' geometrically feasible spiral in tool path which minimize the variation of the milling process engagement from its steady state while minimizing the curvature of the tool path is generated.

The geometry of the pocket for this method is assumed to be simple convex shaped which insures the inward offsetting always converges to a point or set of lines (called median axis) and there is no segregation of the offsets.

For a general non convex pocket segregation of offsetting area the problem of linking between different offsetting areas by tool retraction is observed and this has been found detrimental for the high speed machine tool efficiency.

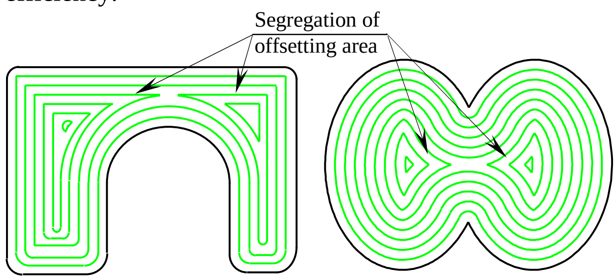


Fig. 9 Some examples of Segregation of offsetting area for non-convex geometries [3]

Hence, recent work has been focused on milling any arbitrary geometry of pocket without retraction of milling tool.

Held and Spielberger [12] developed smooth spiral tool paths for arbitrary pocket boundary composed of lines and circles where the radial depth of cut were kept strictly greater than zero and less than the maximum desired value. Different circles are fit along the median axis of the Voronoi diagram and their envelope is found and smoothened to develop the required tool pass. In general, Voronoi based HSM tool path offers an attractive solution to High speed milling requirements, yet this method is limited to pocket boundary with lines and circular arcs.

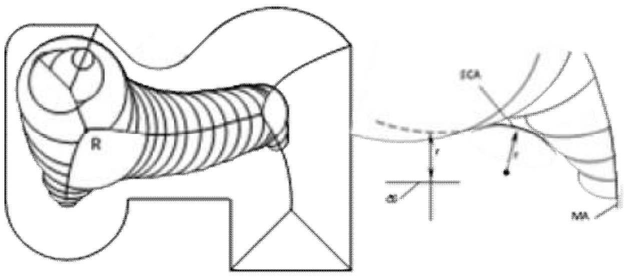


Fig. 10 Growing M-disks on the medial axis and smoothing circular arc [12]

In his work [3], Dhanik develop an alternative method to produce high speed milling compatible tool paths for arbitrary 2D pocket geometry with no tool retraction which are then optimized for the radial depth of cut or the engagement angle.

For a given closed boundary, signed distance function is used for initialization of the pocket boundary:

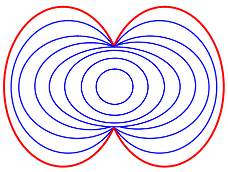
$$\emptyset(X,0)=\begin{cases}+d(X,X(0)), & X\in interior\ of\ X(0)\\ 0 & X\in X(0)\\ -d(X,X(0)), & X\in exterior\ of\ X(0)\end{cases} \quad (1)$$

Where, $d(X , X (0))$ represents the distance of point X from the pocket boundary $X(0)$. Then, curvature based motion low :

$$F_{curv}=-bk \quad (2)$$

is used for the tool path generation. According to this low the shrinkage speed of any closed boundary is proportional with its curvature at any point. Topology of the closed curve changes during the evolution and attains a circular profile of uniform curvature.

Next, the profiles in Figure 13, can be superimposed over each other and the smooth contours can be obtained for the tool path generation. It has been shown that the evolution of a curve is breaching the boundaries of the initial boundary. This can be observed for all non convex corners where the curvature is smaller than zero. This can be rectified by modifying the speed law:



$$\begin{aligned} F_{curv}&=-bk & k\geq 0\\ F_{curv}&=0 & k<0\end{aligned} \quad (3)$$

Fig. 11 The zero level curve at different time instants under the modified speed law [3]

The above formulation guarantees the boundary conforming contours converging to a circle and finally disappearing to a point. However, the radial depth of cut of the tool doesn't remain the same. While the minimum cutting width is visibly zero, the maximum cutting width depends upon the curve evolution time and instantaneous speed. Dhanik developed a method to constraint the motion of the curve in order to respect the maximum width of cut.

Method for generating boundary conformed pocketing tool paths is proposed by Chuang and Yang [13]. Based on the 2D Laplace parameterization of pocket contours and the redistribution of the original Laplace isoparametrics, continuous tool paths are generated. These generated tool paths have neither thin walls nor leftover tool marks. Detailed algorithms are formulated in following steps:

Step 1: Construct the final tool path for the pocket contouring.

Step 2: Divide the clearance border into four segments for applying Laplace parameterization.

Step 3: Generate 2D parameterization for the region enclosed by the clearance border.

Step 4: Reparametrize the 2D grids via arc-length based parametric redistribution.

Step 5: Construct final continuous tool path for pocketing.

The entire pocket machining can be achieved by a single spiral tool path. The complicated issue of path sequence selection is omitted. No intermediate tool retraction is needed. Meanwhile, the possibility of the existence of thin walls is automatically eliminated. Besides, the resultant single tool path is conformed to the profile of the pocket boundary. The method can be applied to general pockets either with or without islands.

Bieterman and Sandstrom[2] developed a method for curvilinear tool path generation for a pocket by spiraling between contours of a well-chosen scalar mathematical function on the pocket. By spiraling in this manner, the path is morphed from a very smooth shape in the pocket center to the shape of the part on the pocket boundary.

Unlike the conventional path, the spiral curvilinear tool path has low, nearly constant curvature near the pocket center and slowly changes into the part shape as it gets closer to the part boundary.

The mathematical function used to morph the curvilinear path is the approximate solution of a scalar elliptic second order partial differential equation "PDE" boundary value problem that appears in many engineering design analyses.

The PDE problem is defined on a two-dimensional pocket region whose boundary is offset inward, by one tool radius, from the part. Eigen value problem is solved approximately for the Laplacian:

$$-\nabla^2 u=\lambda u \quad (4)$$

subject to Dirichlet boundary conditions $u=0$ and the normalization:

$$max_{(x,y)}u(x,y)=1 \quad (5)$$

for the principal Eigenfunction u (corresponding to the smallest of the positive eigenvalues $\left(\{\lambda_j\}_j=1,\infty\right)$.

PDE like Eq. (4) is used because this kind of equation has properties that can be exploited to generate nearly optimal curvilinear spiral paths.

The spiraling that takes place is between appropriately spaced contours of u and continues, orbit by orbit, until all material is removed. The spacing is determined by a user-specified maximum step over, or width of cut.

The discrete tool path can be replaced with a twice continuously differentiable parametric spline curve that is fit to the discrete path. The variable feed rate was chosen tominimize machining time subject to limits on maximum componentaxis-drive velocity and acceleration and deceleration.

In the tool-wear experiments,a variable feedrate was set to keep material removal rate approximately constant.

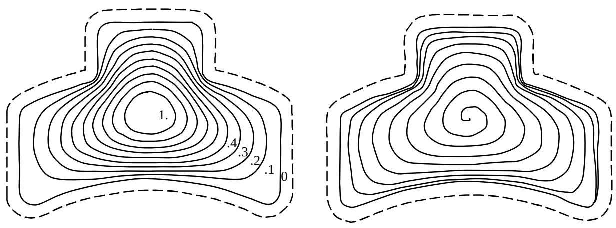


Fig. 12 a) Contours used to guide curvilinear tool path b) curvilinear tool path for pocket [2]

The morphing eliminates internal tight-radius corners in conventional paths and leads to major benefits such as machining time reduction, reduction of tool wear in cutting hard metals, reduced machine spindle wear and tear.

6. TOOL PATHS IN CAM SYSTEMS

In today's competitive environment, the milling process planner faces many challenges such as frequent changes in part design, demand on quality and high productivity. In order to meet these demands, a typical modern shop floor adopts advanced CAD/CAM (Computer Aided Design/Manufacturing) software and generic or application based High Speed CNC (Computer Numeric Control) machining centers. Today's CAD/CAM software are very successful for the construction of the tool paths to attain a desired shape on workpiece. Further, the compression of NC milling program data and dynamic feed
rate optimization are some advanced functionalities in modern CAD/CAM software[3].
Some softvers have High Feed Machining function which can optimize any 2-axis or 3-axis toolpath based on volume of material being removed and machine tool limitations to give efficient, varied feed rates tailored to each job. They can:

- Automatically vary feed rates based on volume: If there is more material to remove the cutter moves slower;If there is less material the cutter moves faster.
- Automatically ease the tool into and out of corners.

Fig. 13Advanced CAM Functionalities

Ideally, the whole area that needs to be cut to is milled with one continuous spiral tool path. Generally this is not possible. The iMachining Rough Cut algorithm developed in some softvers does the next best thing. It subdivides the area into the optimal number of sub-areas, each of which can be cut with a morphing spiral path, such that the total machining time for the whole area is minimal. It uses Modified D Type Tool Paths to cut slots to subdivide the area.
Another unique major advantage of the iMachining Rough Cut algorithm, is the fact that, on each point along the tool paths created, the values of the chip thickness, the feed and the spindle speed are always matched up according to the optimal rules laid down by the Technology Wizard.
The Morphing Spiral Tool Path is so called because unlike the spiral tool paths in most CAM systems, it gradually adapts to the shape of the area it has to clear, rather than symmetrically expanding in a circular fashion. This ability reduces machining time considerably.
Commercial CAM systems seldom consider the physical process concerns like transient thermal and mechanical loads generated during milling, which effect the part quality adversely and hence require trial experiments for new part design, and tool-workpiece combination.
Commercial CAM system are not able to compare various tool path strategies based on the various process related indicators. Tool path length is conventionally used as an indicator for process efficiency; however, in the context of High Speed Milling, it's a false indicator of milling process efficiency.
The HSM capabilities are not fully realized due to in process changes in cutting conditions with instantaneous in-process workpiece geometry varying along the tool path.

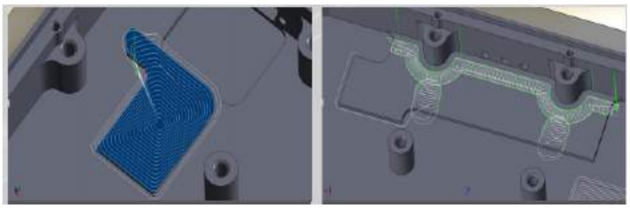


Fig. 14 Morphing Spirals and Intelligent Separation in a iMachining

7. CONCLUSION

Tool paths modifiedfor HSM application must have the following properties:
i. It should consider the effect of limiting process considerations like force, vibration and chatter for stable milling of the tool path.
ii. The physical process parameters like cutting forces, temperature etc. shouldremain constant or maintain a minimum fluctuation around a preset specifiedaverage value.
iii. The tool path must be c^1 continuous for avoiding detrimental effect of chipthinning therefore the sudden fluctuation of the feed rate should be avoided.
iv. The tool path should adhere to a c^2 continuity, however this condition may beviolated easily as the tool path processing for a typical machine tool consists oflines and arcs. The notion of spline is relatively new and not a well establishedstandard in practical milling [3].
With respect to point i, ii, and iii, one possibility to avoid sharp corner is to post-processthe conventional tool path by fitting arcs, loops or other curves for successive machining of the corner [4],[11],[10]. This leads to smaller cutting forces and less feedrate fluctuationswhile milling corner.
Another possibility is to develop a smooth spiral tool path generation using the solutionof an elliptical partial differential equation boundary value problem. Laplace basedparameterization and meshing of the domain to be machined produces smoother contourparallel tool paths [2],[13] than the conventional contour parallel tool paths, thus makesthis method suitable for the tool path generation for the roughing process.

In summary, the following are the drawbacks of existing tool path generation methods:

• Adaptation of conventional tool paths for HSM purpose requires some arc orcurve fitting for the original tool path partially or entirely, this curvefitting may require extra efforts and preprocessing of existing tool path and hencesusceptible to errors.

• Smooth tool paths constructed, for the low curvature changes along the tool path,by mapping of tool path from a parameterized space to the pocket area are proneto changes in the engagement conditions in an uncontrolled way along the toolpaths.

REFERENCES

[1] T. R. Kramer, "Pocket Milling with Tool Engagement Detection," Journal of Manufacturing Systems, vol. 11, no. 2, pp. 114–123, 1992.

[2] M. B. Bieterman and D. R. Sandstrom, "A Curvilinear Tool-Path Method for Pocket Machining," Journal of Manufacturing Science and Engineering, vol. 125, no. 4, p. 709, Nov. 2003.

[3] Sandeep DHANIK, "NC Tool Path Evaluator and Generator for High Speed Milling," vol. 4533. ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE, Lausanne, Switzerland, p. 201, 2009.

[4] H. S. Choy and K. W. Chan, "A corner-looping based tool path for pocket milling," Computer-Aided Design, vol. 35, no. 2, pp. 155–166, Feb. 2003.

[5] M. Held, "VRONI: An engineering approach to the reliable and efficient computation of Voronoi diagrams of points and line segments," Computational Geometry, vol. 18, no. 2, pp. 95–123, Mar. 2001.

[6] S. K. Gupta, S. K. Saini, B. W. Spranklin, and Z. Yao, "Geometric algorithms for computing cutter engagement functions in 2.5D milling operations," Computer-Aided Design, vol. 37, no. 14, pp. 1469–1480, Dec. 2005.

[7] D. Yip-Hoi and X. Huang, "Cutter/Workpiece Engagement Feature Extraction from Solid Models for End Milling," Journal of Manufacturing Science and Engineering, vol. 128, no. 1, p. 249, Feb. 2006.

[8] S. D. Merdol and Y. Altintas, "Virtual Simulation and Optimization of Milling Operations—Part I: Process Simulation," Journal of Manufacturing Science and Engineering, vol. 130, no. 5, p. 051004, Oct. 2008.

[9] B. H. Kim and B. K. Choi, "Machining efficiency comparison direction-parallel tool path with contour-parallel tool path," Computer-Aided Design, vol. 34, no. 2, pp. 89–95, Feb. 2002.

[10] Z. Y. Zhao, C. Y. Wang, H. M. Zhou, and Z. Qin, "Pocketing toolpath optimization for sharp corners," Journal of Materials Processing Technology, vol. 192–193, pp. 175–180, 2007.

[11] V. Pateloup, E. Duc, and P. Ray, "Corner optimization for pocket machining," International Journal of Machine Tools and Manufacture, vol. 44, no. 12–13, pp. 1343–1353, Oct. 2004.

[12] M. Held and C. Spielberger, "A smooth spiral tool path for high speed machining of 2D pockets," Computer-Aided Design, vol. 41, no. 7, pp. 539–550, Jul. 2009.

[13] J.-J. Chuang and D. C. H. Yang, "A laplace-based spiral contouring method for general pocket machining," The International Journal of Advanced Manufacturing Technology, vol. 34, no. 7–8, pp. 714–723, Jun. 2006.

35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
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DEVELOPMENT OF THE PROGRAM TO PREPARE TOOL SETS IN FLEXIBILE MANUFACTURING SYSTEM

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Abstract: *For every NC program to be implemented in the production of flexible manufacturing system (FTS), there must be a list of sets of tools to prepare for the machining process . The flexible technologies that are implemented through the execution of thousands of different operations in the processing parts of the complex geometry of the problem is relatively small series of settings of the tool is very important .*
This paper presents the concept of software systems for automated preparation of sets of tools for the production process in the FTS- in . The structure of the programming system is based on technology -based data elements set of tools and geometric parameters of technological processes contained in the NC program. Developed an original algorithm for forming sets and tools based on modern theories in terms of reduction of uncertainty , which allows for the practical application of software systems in the design of technological processes for FTS .

Keywords*: software systems , software , FTS , composing tools, theory uncertainty*

1. INTRODUCTION

Management tools in the FTS-in consists of drafting tools, determining its characteristic geometric size, selection of elements to compose a set of tools, his system of identification and monitoring, and its decomposition after completion of the technological operation. Management tools is done according to different criteria, monitoring their condition using a sensor (overheating, wear, deformation, fracture), and integrated monitoring system "Tool Management System" is included. In section preparation tool on the tool data are entered into the contactless memory element and reads a special reader connected to computer control system tools. Each set of tools must be measured and adjusted and his parameters entered into the memory element after which they are ready to be in the order of the executive program of NC machining processes involved in FTS-cell according to the instructions of the controller. Reduction of the settings tools in flexible technologies, increasing produc-tivity.

2. STRUCTURE OF TOOLSETS

Tool set is a single integrated functional unit consisting of elements: mount, extension, reducer, accessories and cutting tools (Figure 1). The elements are modularly designed, so you can compose in different ways depending on the requirements of machining processes and unit operations which the tool is running. Each set must have high rigidity and to ensure dynamic stability of the cutting part of the tool at various cutting conditions. Compatibility Toolkit elements are determined based on their dimensions.

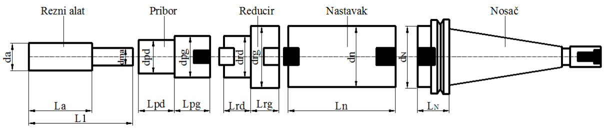


Fig. 1. The general structure of the toolbox.

Carrier establishes a connection with the main spindle can accept gripper changer in the cycle of automatic tool change and provides a number of extensions and other elements in the toolbox . Rack has a front cylindrical part of the standard diameter (dn) length (ln) that can be placed below or reducers or probor . In one set can be only one tool holder .
Continued used to it extend the total length of the set , to give the cutting tool with a grip material. Geometric size , length of process (ln) and the diameter of the tip (dn) , determine compatibility between the elements of the toolbox. As part of a set of tools can be more extensions of the same or different diameters. The diameters of the two sustedna elements must be equal. In technological practice to avoid tool kits with multiple extensions, because it reduces the dynamic stability of the machining process.
Reducer is used when you need to reduce the diameter of the set, to the cutting tool through the hole previously processed smaller diameter than the diameter of the tip (dn) or to avoid collisions of the body with a set of tools Dole workpiece under the cutting process . The reducer has a higher (drg) and lower (drd) diameter and length that fits most (Lrg) and a length that corresponds to the lower (lrd) diameter.
Accessories and accepts tightening tool. The clamping mechanism Probe must be adapted to handle, type and method of rapid contraction and release of the cutting tool. Accessories with one hand accepts cutting tool (dpd) on the other side has a connector for other elements (dpg).

Cutting tool and all its characteristics as determined by the design of the technological process , and specify the stage of the NC program . Based on NC program tool performs technical operations . Each sequence of NC programs covered by the technological cycle of an operation , execute a tool that is placed in the set . One and the same cutting tool in the set can perform multiple operations if its geometirjske and cutting performance and durability designed to allow.

Toolset is postavjla the warehouse tool machining center which has a fixed distance between the neighboring seat of tools and a maximum diameter of the cutting tool is limited. Limited by the maximum diameter and maximum length of cutting the design parameters of the machining center to automatic tool change cycle is performed without collisions .

3. FORMALIZATION RULES COMPOSING TOOLSETS

Management tools in the FTS-in consists of drafting tools, determining its characteristic geometric size, selection of elements to compose a set of tools, his system of identification and monitoring, and its decomposition after completion of the technological operation. The input data for the composition of the toolbox are: machine, tool type, diameter (d), the length of treatment (l), the values of the NC program X, Y, Z. On the basis of an intelligent machine system selects which carrier must have tool sets. Based on the type of tool for a given diameter (d) and length of treatment (l) intelligent system selects tools with diameters equal diameter hole or holes to be processed:

$$d=da \tag{1}$$

Of the selected tools so choose the one whose payload length (la) with the length of treatment (l) the smallest real positive difference:

$$\min\left[\left(l_{ai}-l\right)>0\right] \tag{2}$$

For this chosen tool holder and there are now two cases. The first case is when the Z coordinate of the NC program is less than useful tool length by:

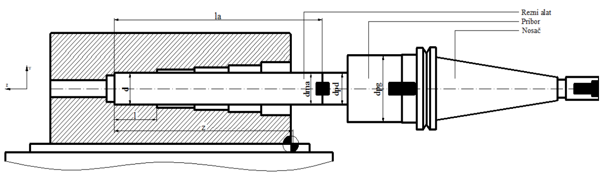


Fig. 2. Set of tools in which the Z coordinate is less than the length of useful tools.

In this case, intelligent systems have the task to choose the accessories that must be compatible with the diameter of the tool diameter to merge dm:

$$dma=dpd \tag{3}$$

and diameters dN:

$$d_N=dpg \tag{4}$$

In this case () tool sets include: tools, accessories with a reduced role and the frame. Such a set must be chosen to satisfy the condition that half of the greatest diameter of the larger set of Y coordinates of the hole or holes to be processed in order not to touch the elements of a toolbox with a desk or accessories:

$$\frac{dpg}{2}<Y \tag{5}$$

and that the total length of a set of minimum:

$$\min\left(l1+lpd+lpg\right) \tag{6}$$

In the second case, Z coordinates from the NC program is more than useful tool length by:

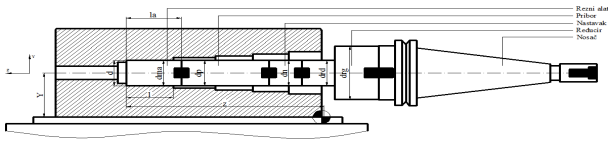


Fig. 3. Set of tools which is a useful tool length is less than Z coordinates.

In this case also an intelligent system based on machine selects carrier who must have all the tool sets. Then, based on the type of tools, processing diameter (d) and the length of time (l), the system selects the tools with diameters equal to the diameter of processing:

$$d=da \tag{7}$$

and then chooses the one whose useful tool length (la) forms a minimal positive difference to the length of treatment (l):

$$\begin{gathered} d=da \\ \min\left[\left(l_{ai}-l\right)>0\right] \end{gathered} \tag{8}$$

For this chosen tool holder on the basis of known Z coordinates system checks what is the difference between the Z coordinates of the NC program tool length in the set. The size of these differences should be filled with accessories, socket, reducer. Selected accessories must have a smaller diameter equal to the diameter of the tool for connecting a larger diameter equal to the diameter of the connection of the bracket:

$$\begin{gathered} d_N=dpg \\ dma=dpd \end{gathered} \tag{9}$$

If the total length of the set is still not greater than the Z coordinates of NC programs vacancy shall be filled in the set extensions. The goal is to find the continuation of which the total length of the toolbox with the lowest Z coordinate real positive difference:

$$\min\left\{\left[\left(Z-l1\right)-\left(lpd+lpg-l_N\right)\right]>0\right\} \tag{10}$$

Rules of composing sets of tools are presented algorithm:

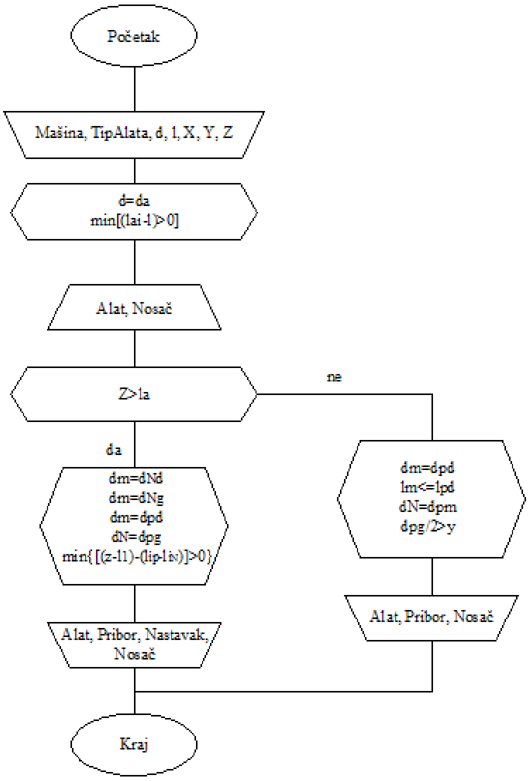


Fig. 4.The algorithm by which the set broadcasting tools.

4. TECHNOLOGICAL DATA BASE OF ELEMENTS TOOLSETS

Database technology data elements of the toolbox consists of nine buildings with attributes like this:

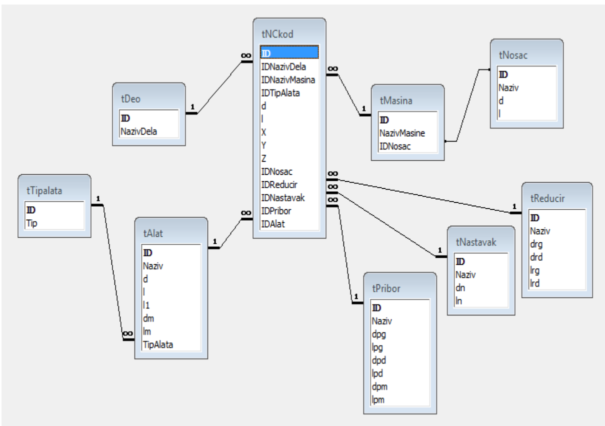


Fig. 5.Objects and attributes database

Objects or tables: TalattPribor, tNastavak, tReducir, tNosač contain information about the elements of the toolbox, tMašina object contains information about the machines that are available, and the facility tDeo contains information about workpiece.

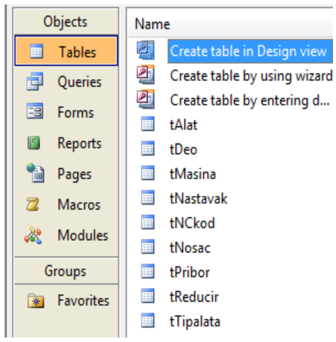
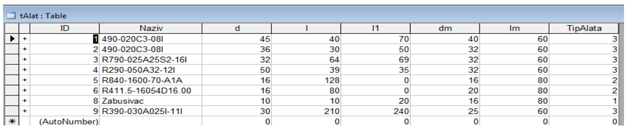


Fig.6.Objects - a table that contains an intelligent database system

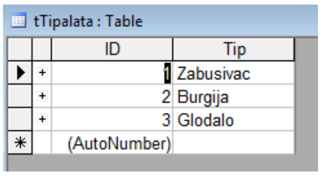
Tables: TalattDeo, tMasina, tNosac, tPribor, tReducir, tNCkod, tTipalata make a database based on an intelligent system that composes tool kits. Talat table contains information about tools for drilling, milling and zabušivanje. The last column shows the type of which the tool works. If you have more than three types should only be entered in the table tTipalata other types.



tAlat : Table

ID	Naziv	d	l	l1	dm	lm	TipAlata
1	490-020C3-08I	45	40	70	40	60	3
2	490-020C3-08I	36	30	50	32	60	3
3	R790-025A25S2-16I	32	64	69	32	60	3
4	R290-050A32-12I	50	39	35	32	60	3
5	R840-1600-70-A1A	16	128	0	16	80	2
6	R411.5-16054D16.00	16	80	0	20	80	2
8	Zabusivac	10	10	20	16	80	1
9	R390-030A025I-11I	30	210	240	25	60	3
(AutoNumber)		0	0	0	0	0	0

Fig.7.Table Talat with information on tools



tTipalata : Table

ID	Tip
1	Zabusivac
2	Burgija
3	Glodalo
(AutoNumber)	

Fig.8.Table tTipalata

Form tNCkodSarz input field value from the NC code (X, Y, Z), the input field label machine, called the workpiece, tool types for fields with a diameter and length of treatment.

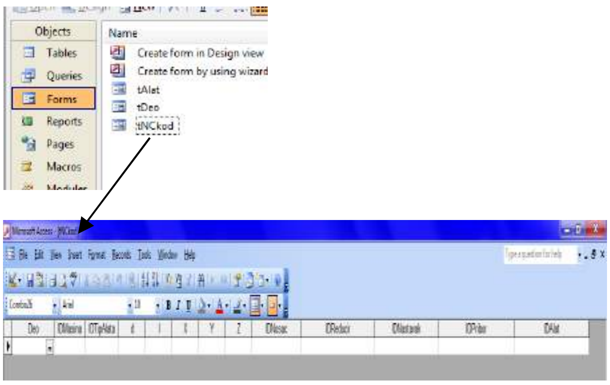


Fig. 9.The form in which the fields are created with the rules that are set broadcasting tools.

After entering the data intelligent system populates the I IDNosač, IDReducir, IDNastavak, IDPribor, IDAlat Rule for composing a set of tools.

5. INTELLIGENT AUTOMATIC SETTING TOOLS

Intelligent system for automatic setting tool includes data fields (machine name, type of tool, the diameter and length of treatment, X, Y, and Z values in the NC code), and the fields that I filled system based on rules that contain the results displayed as separate list of tool kits complete with labels of each element of the toolbox. Rules by which an intelligent system sets the tools, as given algorithm, the entries using VBA code (Visual Basic Cod). In this way, acces-this database is part of an intelligent system based on the entered rule sets the elements.

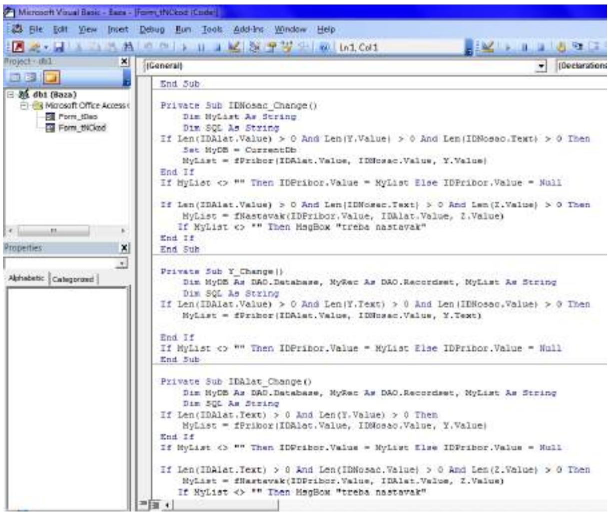


Fig. 10.VBA code by which the written rules settings tool

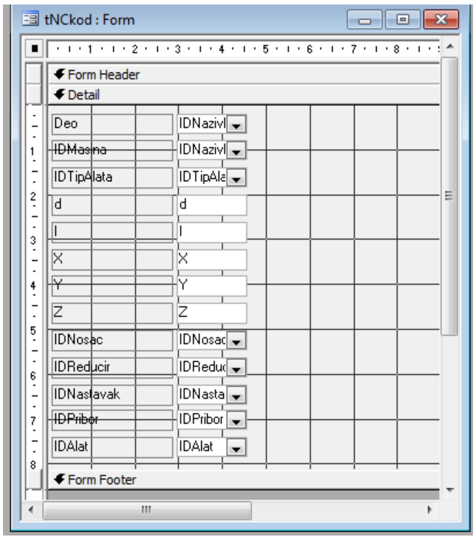


Fig. 11.The form that defines the fields and rules that the user fills and intelligent system.

6. APPLICATION SOFTWARE SYSTEM INDUSTRIAL APPLICATION

For prismatic workpiece, which is produced in large-scale volume production, using intelligent systems is made a list of sets of tools used for the implementation of the NC program.

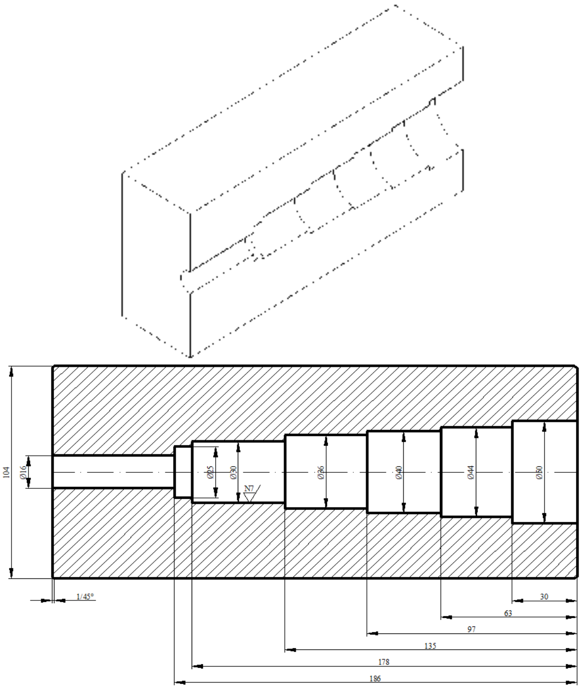


Fig.12.Prismatic workpiece which should make a list of sets of tools.

First, enter the name of the workpiece and the machine where the workpiece being processed. Based on the sequence of technological operations that are executed based on NC code on the selected machine, enter the diameter and length of treatment, type of tools and an X, Y and Z coordinates of the NC program. Based on the type of tool system knows which group of tools to choose the tool diameter and length equal to or greater than entered.

Workpiece is processed on the machine HMC 500 It is a horizontal machining center with three NC controlled axes and rotation of the desk. Treatment consists of 13 technological operations. These data into the fields shown in Figure 13 and for the past five fields I filled an intelligent system.

Fig.13.Data fields.

Based on the data entered the system selects the elements of the toolbox Rule settings.

For example, for the operation 30: rough milling holes Φ30x177 mm. First, the intelligent system enter the name of the workpiece (Part column), choose the machine on which the processing is performed (column IDMasina).

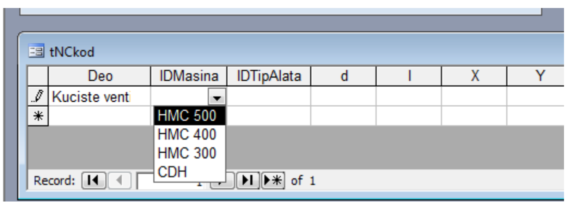


Fig.14.Filling in the fields of intelligent systems

Intelligent system based on tag machines selected carrier (ISO50, ISO40, ISO30...) which must have a set of tools.

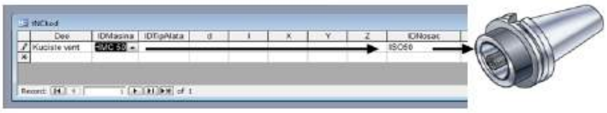


Fig.15.Intelligent choice of carrier systems.

Then enter the data on the type of tool diameter (d) and length (l), respectively, and X, Y, Z values in the NC code of the operation. 40 type of intervention tools and the cutter, turning diameter is 32 l = length of processing 178 mm useful tool length by an intelligent system chooses the la = 210 and Z coordinates of 200 mm. From data intelligent system first determines if it is the case that Z is greater than the value set by and tools to do more accessories and gear. Based on the diameter and the length of time an intelligent system selects the appropriate type of tool with a diameter equal to the diameter di whose cutting length with a minimum length of time a real positive difference. So now that the system selected tools and accessories:

Fig.16.Selection of other elements of the toolbox.

For surgery: fine milling holes Φ32x43, First enter the name of work, name of machine, tool type, diameter and length of treatment, X, Y and Z coordinates of NC code. Length of treatment was 43 mm and Z = 180 mm, so this case Z> l and intelligent system selects: rack, tools, accessories, and continued with the proviso that the total length of the set at the lowest Z coordinate a real positive difference.

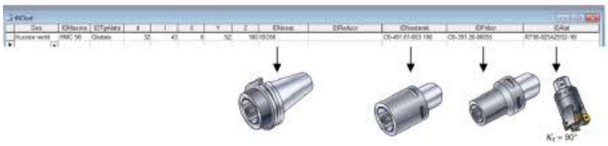


Fig.17.Selection of elementsof the toolboxin case Z>l.

The data in this way, we bring to all eight of technological operations and the system makes a list of all the elements of sets of tools with catalog name element sets that are needed in order to perform technological operations workpiece system displays in the form of a report like this:

Petrebni setovi alata

ID	Deo	IDMasina	IDTipAlata	IDNosac	IDReducir	IDNastavak	IDPribor	IDAlat
1	Kuciste ve	HMC500	Zabusivac	ISO50	-	-	C3-391.05-16030	Zabusivac
2	Kuciste ve	HMC500	Burgija	ISO50	-	-	C3-391.05-16030	R840-1600-70-A1A
3	Kuciste ve	HMC500	Glodalo	ISO50	-	-	C6-391.20-06055	R390-020A020-11L
4	Kuciste ve	HMC500	Glodalo	ISO50	-	-	C6-391.05-25030	R390-030A025l-11l
5	Kuciste ve	HMC500	Glodalo	ISO50	-	C3-391.05-16060	C3-391.05-16030	R390D-032C6-11L165
6	Kuciste ve	HMC500	Glodalo	ISO50	-	C3.391.02-32070A	C6-391.05-32030	R350-036C5-11L
7	Kuciste ve	HMC500	Glodalo	ISO50	-	-	C6-391.05-16040	R390-040A32-11L
8	Kuciste ve	HMC500	Glodalo	ISO50	-	-	C6-491.02-040040	R390-044C4-18L080
9	Kuciste ve	HMC500	Glodalo	ISO50	-	-	C6-491.02-50080	R390-050C4-18L060

Fig.18.List elemeanta set of tools for machining prismatic workpieces.

7. CONCLUSION

Intelligent model for composing sets of tools implemented in a relational data base technology and knowledge developed in Microsoft Access - in . The database contains data tables on Alatalo , fixtures , extensions , reducers and mounting tools. It also contains information about the machines on which they can process workpieces , workpiece data and fields in which employee I entered the parameters in the NC program , the type of tools needed for proper operation and choose the machine on which to perform processing . Reduction of the tool settings directly affect the productivity of production. The elements of the intelligent system is chosen to make the tool kits are certainly those elements that are in stock and which best meet the necessary requirements komonovanja geometric elements of the toolbox . This is very important if we take into account that the flexible technology implemented through thousands of different operations in the processing of parts with complex contours.

The selection criteria machines where processing is performed in this paper is discussed . This problem occurs if you have a range of several workpieces at certain shows and more machining centers available and it is necessary to choose those machining centers are the most suitable for the processing of the workpiece . Theory of belief functions and systems of record or evidentiary networks allow the expert knowledge that is needed in the choice of machining center for a given range of workpieces describe the functions of beliefs and engage in an evidence network that will, based on the entered knowledge to select the machining center that is best suited for making [3] .

REFERENCES

[1] Lukić, Lj. “Fleksibilni tehnološki sistemi”, Mašinski fakultet Kraljevo, Kraljevo, 2008.

[2] Lukić, Lj., Šolaja, V.: Ekspertni model za definisanje seta alata u fleksibilnim tehnologijama, Zbornik radova 24. Savetovanja proizvodnog mašinstva Jugoslavije, knjiga I, NoviSad (1992), str. 2.187-192.

[3] Đapić, M. „Evidencioni sistemi u razvoju proizvoda i procesa” , LOLA Institut, Beograd, 2004.

Acknowledgement: The authors wish to express their gratitude to the Ministry of Education and Science of the Republic of Serbia for support of this research through the project TR37020.

35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
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SEGMENT OF CAPP - AUTOMATED MODULAR FIXTURE DESIGN IN CAD ENVIROMENT

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Abstract: *This paper gives a contribution to the development of CAPP software systems in the scope of automation of computer aided modular fixture design. Developed software solution for automated computer aided modular fixture design is based on the use of application programming interface (API) from SolidWorks program system.*
The developed software solution is the original solution in the form of a software platform for the computer aided modular fixture design.
Verification of the implementation of the developed software solution was carried out on the computer aided modular fixture design for the body of hydraulic control valve for hydraulic shearing machine.

Keywords: *Computer Aided Modular Fixture Design, CAPP, CAFD*

1. INTRODUCTION

Automation of production processes design, starting with the application of basic CAD tools for workpieces modeling, following automated manufacturing, control and packaging at the end, is a reality and the essential need in today's competitive industrial society [1]. If the process of automation of the entire production process is seen as a continuous line, on this line there are places with breaks - in which the process of automation of certain production function is not sufficiently developed.
The biggest disruption of automation of the production cycle is in the area of computer aided process planning (CAPP). Exactly in this area there is an area of automation of modular fixture design, which is the subject of this paper.
The analysis of available literature and papers in the field of automation of modular fixture design, and analysis of real practical needs, shows that can be concluded that this area of research is of the great significance [2], [3]. The development of automation of modular fixture design increases the level of automation of process planning design.
The general objectives sets infront of the each system for automation of modular fixture design are [4] :

- Reducing time and cost required for modular fixture design;
- Results in form of quality solutions;
- Reducing designer labor effort;

These goals can be achieved by the application and integration of modern computer systems, so that the degree of automation of modular fixture design can be raised to a higher level.
The aim of this paper is to develop and implement a system for automation of modular fixture design.

Constraints in the process of development of a system for automation of modular fixture design arising from the breadth and complexity of the problem. In the development of the mentioned system it was adopted the following limitations [5]:

- The system is based on the modular fixture components based on hole-pin system;
- Modular fixture components which are used in the implementation of this system are designed in accordance with a set of modular components of manufacturer "Carr Lane" from USA [6];
- The system was developed mainly for milling and drilling operations;
- The system's structure is based on a geometric analysis of the workpiece;

Verification of the system is solely based on testing of automation of modular fixture design on examples of workpieces with prismatic shape;
In the field of automation of modular fixture design it was observed the great efforts that researchers around the world are investing in the design of new and modernization of systems for automated modular fixture design.
From access to previous research, it can generally be concluded that a higher number of realized automation systems for the modular fixture design is based on an interaction designer - system. Still, fully automated systems do not provide the desired results in the field of automation of modular fixture design [7]. The reasons lie in rigid and complex algorithmic structures, insufficient levels of knowledge representation of the design, a huge number of possible cases that can occur, a suitable choice of modular components and presenting of the output information’s.
Therefore, systems based on an interactive manner in practice give more results in compared with fully automated systems.

Each of the researchers gives their own contribution to the introduction of a specific solution in order to realize the system with a high degree of automation of modular fixture design. This specific solution is reflected in the introduction of new computer technologies in the system structure, such as databases, knowledge bases, expert systems, algorithmic structures, application of various software systems (typically graphical), different types of programming, up to the application of artificial intelligence (ANN, genetic algorithms, fuzzy logic).
Also, there are systems that are based on the using of other technologies to automate the modular fixture design:

- Systems based on the use of the Internet (web) for the modular fixture design;
- Intelligent systems based on a dynamic structure of modular fixture design;

Systems based on full virtual reality in the modular fixture design;

2. APLICATIVE PROGRAM INTERFACE - SOLIDWORKS API

Software solution for automating the modular fixture design is based on the use of application programming interface (API) from SolidWorks program system [8]. A SolidWorks and other CAD / CAM system enables automation of certain complex action (calculations, transformations) within their previously developed tools and functions. Access to advanced functions are performed via the application programming interface using higher programming languages (Visual Basic, C ++, C #, Java).
Application Programming Interfaces (APIs) are the additional software solutions that provide a link between the higher programming languages and CAD / CAM systems. These software solutions have all the features of programming languages (arithmetic and logical operations, functions for program flow control, input-output operations), but they are expanded with commands for activation of functions from the CAD / CAM program systems.
This method allows programmatically manipulation with the geometric model of the workpiece, in order to perform certain automation, depending on the needs and requirements of users of the CAD / CAM program systems.
Application Programming Interface is based on several computer technologies including COM - Component Object Model and OLE - Object Linking and Embedding technology as also ActiveX Automation.
COM is binary and genetic standard that is the basis of DCOM, ActiveX and OLE technology. COM provides standard interfaces and communication between components. With the implementation of COM technology - one application can use the properties of any other application object or operating system. COM technology allows the improvement of software components, without affecting the operation of the whole system and the design solutions. Object Linking and Embedding (OLE) is used in the provision of integration between applications, enabling a high level of application compatibility, even between different types of information. OLE technology is based on the COM, and allows the development of re-used (reusable) plug-and-play facilities that are operating with each other even within multiple applications.

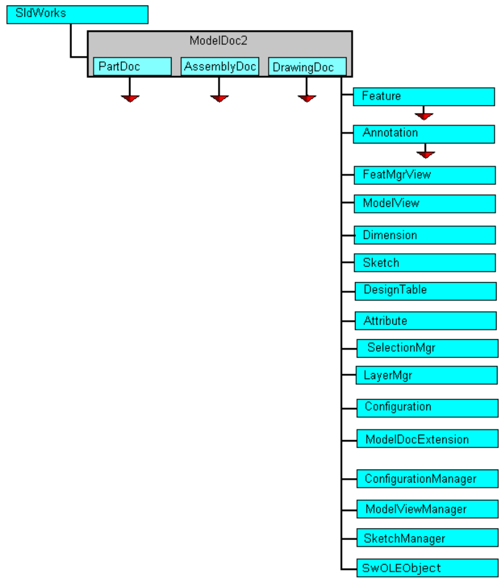


Fig.1. The hierarchical structure of the object ModelDoc2 [8]

ActiveX Automation is a well known programming interface for a computer application developed by Microsoft Corporation. This form of programming interface provides multiple connection of the Windows application, and also provides the ability to manage with specific applications. Management and connectivity of program application is done using a class library (objects) of some applications (Microsoft applications) that are made available to certain other applications. ActiveX Automation, with their own capabilities and implemented results, is ensuring a ActiveX standard, which most CAD / CAM systems implemented in their own structure.
The entire hierarchical structure of SolidWorks objects is based on “SldWorks object”. SldWorks object represents the primary (initial) object and which in his own structure contains objects which execute certain "external" function within the SolidWorks system (definition of environment-Environment, the definition of the matrix data - MathTransform). The most important object in scope of SldWorks objects is “ModelDoc2” with whom is enabled direct access to the most "internal" objects, which are used in the automation of modular fixture design, such as objects “PartDoc”, “AssemblyDoc” and” DrawingDoc”, whose hierarchical structure shown in Figure 1.

3. DEVELOPMENT OF SYSTEM FOR AUTOMATED MODULAR FIXTURE DESIGN

Structure of System for Automated Modular Fixture Design (abbreviated: APMPP system) as shown in Figure 2, is based on an interactive manner of functioning and it is intended for process planners in the process of process planning preparation. The structure of the system for automated modular fixture design (APMPP) consists of the following modules [5]:

- Module for the entry and processing of input information's (input module);
- Module for selection and configuration of modular
- fixture components (preprocessing module);
- Module for modular fixture configuration design (processing module);
- Module for generating of output information or results (post-processing module);

Module for the entry and processing of input information's (input module) provides selection of information from a dialog box in an interactive manner and loading a 3D model of the workpiece. Also, it ensuring all the required information about process planning information, information about machines and characteristics faces of the workpiece, which are necessary for the realization of the modular fixture configuration. Module for the entry and processing of input information's execute information processing at automated manner, after entering the input information, based on developed production rules which are placed in knowledge database and algorithm structure.

Module for selection and configuration of modular fixture components (preprocessing module), based on the input information, at automated manner execute selection of modular fixture components. Based on the developed logic and databases of modular fixture components, which are integral part of this module, it was execute a configuration of modular fixture components in form of modular functional units, at automated manner.

Module for modular fixture configuration design (processing module) allows to process planner as user of APMPP system, that at automated manner execute design of a modular fixture configuration. Modular fixture design in this module is based on the outputs from the Module for the entry and processing of input information's and Module for selection and configuration of modular fixture components.

Module for generating of output information or results (post-processing module) at automated manner generate the outputs from the APMPP system in the form of assembly drawing of modular fixture design, a list of modular fixture components and their coordinates in modular fixture configurations, as also additional results of the developed functions from APMPP system.

All of the above mentioned modules are developed in the CAD module of SolidWorks program system using the API function, with application of the group of general-purpose programming system (MS Excel and MS Word) and programming language Visual Basic.

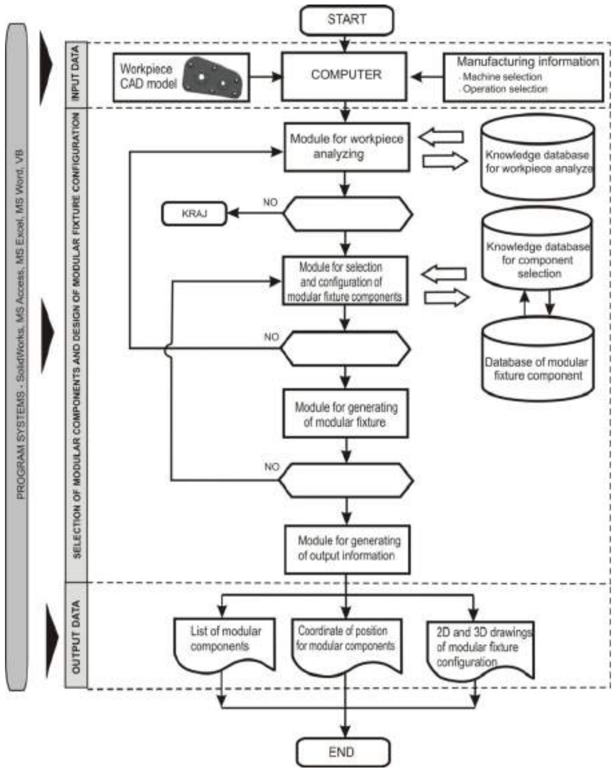


Fig. 2. Structure of system for automated modular fixture design (APMPP) [5]

4. VERIFICATION OF DEVELOPED SYSTEM FOR AUTOMATED MODULAR FIXTURE DESIGN

The developed system for automated modular fixture design was integrated into the SolidWorks software system environment. The basic structure of a developed prototype APMPP system is shown at Figure 3. APMPP system was developed for a group of prismatic workpieces with an adequate number of functional non-curvature faces.

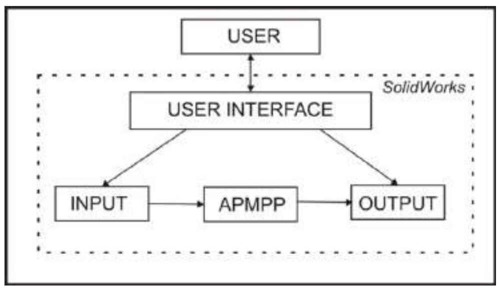


Fig. 3. The basic structure of a developed prototype APMPP system [5]

Verification of the developed APMPP system was done in the case of designing a configuration of modular fixture for the body of the hydraulic control valve for the hydraulic shearing machine, which solid model is shown at Figure 4.

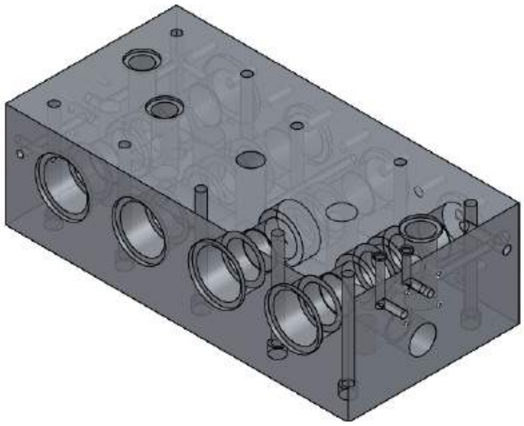


Fig. 4 Solid model of the body of the hydraulic control valve for the hydraulic shearing machine

Verification of the developed system for automated modular fixture design was performed using thirteen processes (steps) which constitute the entire course of the automated modular fixture design shown at Figure 5.

Fig. 5. Developed processes within the user interface of the developed APMPP system

These processes represent developed functions within the four modules of the APMPP system and as such, they are activated in the user interface using the appropriate keys, as follows:

Process 0 - Loading a 3D model of the workpiece in 3D environment of program system SolidWorks.

Process 1 - Selection of process planning information - designer at interactive manner execute selection of machines, basic shape of the workpiece and the face(s) which are need to be machined in the observed set-up. Dialog window of Process 1 is shown at Figure 6.

Process 2 - Initial analysis of faces of the body of the hydraulic control valve for the purpose of defining candidate faces for modular fixture design. In this process, it was executed a systematic analysis of workpiece faces with respect to the normal, overall dimensions and mutual positions.

Process 3 - Determination of functionality of the faces. Based on previously developed models and schemes for positioning and clamping as well as the results obtained from the previous processes – it was executed a defining of functionality of faces of the body of the hydraulic control valve .

Process 4 - Coloring of faces according to their functionality. This process assigns the appropriate color for the appropriate function of the face of the workpiece.

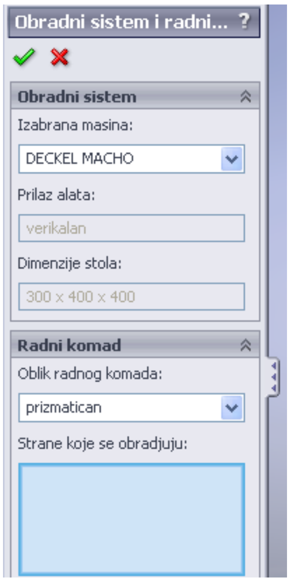


Fig. 6. The dialog window of Process 1

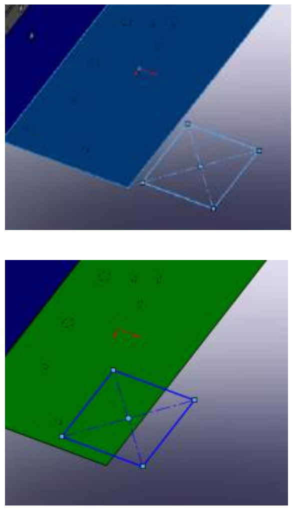


Fig.7 Segment of the face functionality analysis in Processes 6 & 8

Process 5 - Initial positioning of the workpiece. Linear and rotational transformations of the body of the hydraulic control valve with respect to the planes in 3D environment of SolidWorks software system performs the initial positioning of workpiece. Linear and rotational transformations are selected from the knowledge database in respect to previous results of analysis of the work piece.

Process 6 - Additional positioning of the workpiece was executed with analysis of face functionality of non-curvature faces for the purpose of "bottom" positioning. Analysis of face functionality is done at the fully automated manner with developed software tool which was described in detail in [4]. Segment of face funcionality analysis is show at Figure 7.

Process 7 - Definition of the holes. Process planer, at interactive manner, within the dialog system which was developed for APMPP, performed to definition of nature of holes (blind and through) which are perpendicular to the observed face of workpiece.

Process 8 - Analysis of face functionality. With this analysis it was performed an evaluation of the face functionality of the workpiece through the characteristic coefficients of accessibility and functionality. The values of the coefficients indicate face functionality in the observed point on the body of the hydraulic control valve block. If the coefficient of functionality is higher than 0.5, it means that is possible to execute contact of observed point on workpiece and component of modular fixture. Result of face funcionality for ID9 face of example part is shown at Figure 8.

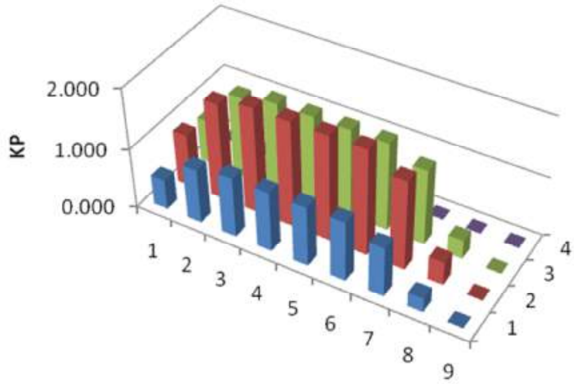
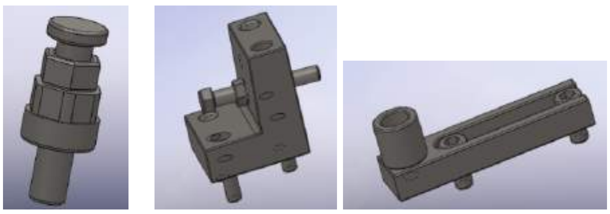


Fig. 8. Coefficients of functionality for face ID 9 of the body of the hydraulic control valve block

Process 9 - Selection of modular components. This process was executed at automated manner and it selects the components of modular fixture. Selection is made on the basis of developed production rules, previous analysis of a workpiece, previous selected model and schemes for positioning and clamping. The components of the modular fixture are placed in the database, while production rules are developed in the knowledge base. The process of selection and configuration of the components of modular fixture is described in detail in [6].



112343.100 212361.30 111331.50

Fig. 9. Modular fixture components and their clasification number

Process 10 - Configuration of modular components was executed based on the previous analysis of the functional faces and of the position of the body of the hydraulic control valve with respect to the baseplate of the modular fixture. The result of the configuration of modular components is fully set of modular functional units for the purpose of positioning and clamping, shown at Figure 9.

Process 11 - Generation of configuration of modular fixture starts with generation of the baseplate of the modular fixture and the body of the hydraulic control valve block, based on the previously developed production rules.

At automated manner it was executed a placing of all other modular fixture components on baseplate in purpose of "bottom" and "side" positioning, as well as components and functional units for clamping of the hydraulic control valve block.

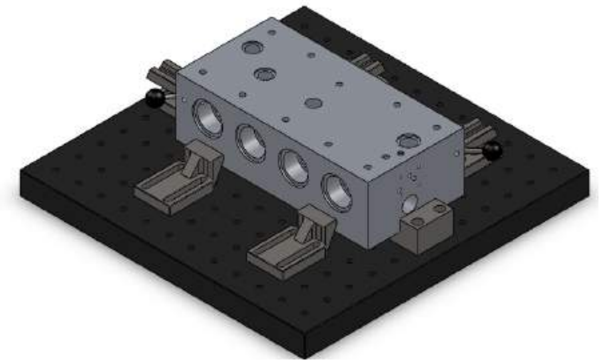


Fig. 10. Designed configuration of modular fixture for the hydraulic control valve block.

Result from Process 11 in the APMPP system is designed configuration of modular fixture for the hydraulic control valve block. Designed configuration of modular fixture for the hydraulic control valve block is shown in the form of 3D assembly at Figure 10.

Process 12 - Generation of the output information's and results in the form:

- Assembly drawings of designed configuration of modular fixture;
- A list of all the components from designed configuration of modular fixture with the additional information (Table 1);
- Results from developed functions during the implementation of designing process of modular fixture configuration in the form of reports.
- Information structure of the designed configuration of modular fixture which is shown at Fig. 11.

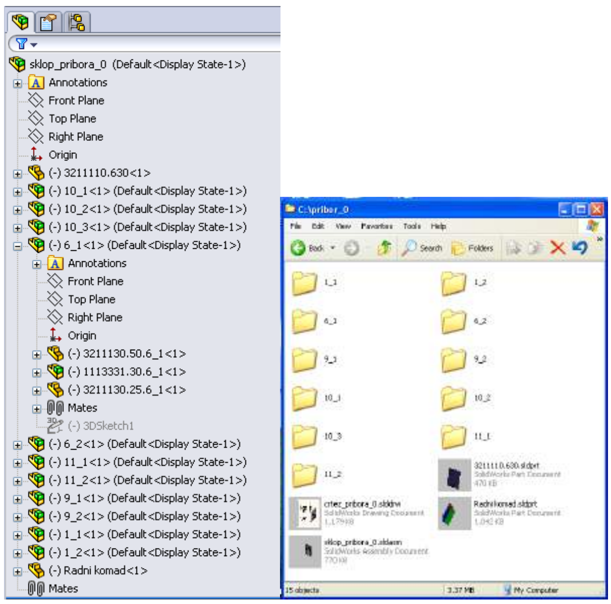


Fig. 11. Information structure of a modular fixture design in APMPP system

Table 1. A list of the components from designed configuration of modular fixture

No.	Workpiece face ID	Label of functional component	Label of modular component	Orientation of contact face	Value of adjustment size	Coordinate of modular component in assembly
1.	10	10_1	1111211.2	(0,0,1)	0	(440,240)
2.	10	10_2	1111211.2	(0,0,1)	0	(440,390)
3.	6	6_1	1113331.3	(0,0,1) (1,0,0)	0	(65,315)
4.	11	11_1	121313.25	(-1,0,0)	96	(490,315)
			3211130.5			
5.	3	3_1	2113121.50	(0,-1,0)	72	(165, 420)
6.	3	3_2	2113121.50	(0,-1,0)	72	(415, 420)
7.	7	7_1	121313.25	(0,1,0)	107	(165, 210)
			3211130.5			
8.	7	7_2	121313.25	(0,1,0)	107	(415, 210)
			3211130.5			

5. CONSLUSION

With the analysis of the design of modular fixture configuration it was set a concept of the APMPP system in the SolidWorks environment.

This concept of the APMPP system is an original solution in the form of a software platform for the design of modular fixture configurations. It contains modules and processes that may be of general interest to all users who have interest about computer aided process planning – CAPP.

The developed APMPP system contains the original software solution for automation of the design of the modular fixture configurations which are based on:

- Identification of the main activities in process of computer aided process planning;
- Analysis of existing systems for automation of the modular fixture design or CADF systems;
- Possibility of integration CAD, CAPP and CAFD systems;
- Analysis and systematization of standard modular components as parts of modular fixture system;
- Development of models, i.e. algorithmic structure of the systems;
- Development of software solutions;

Developed software solution in the form of APMPP system enables:

- Analysis of the workpiece from the viewpoint of geometric and functional characteristics of the faces of the workpiece - to define the necessary information required for the further activities of the automation of the modular fixture design;
- An automated selection and configuration of modular components;
- Automated generation of modular fixture configuration;
- Automated generation of output information in the form of: 3D assembly model of a modular fixture configuration, assembly drawings of a modular fixture configuration, reports about modular units / components as well as reports about results of the developed functions used during the design of a modular fixture configuration;

Verification and implementation of the developed APMPP system was successfully performed on the design of a modular fixture configuration for the body of hydraulic control valve for hydraulic shearing machine.

REFERENCES

[1] An Z., Huang S., Rong Y., Jayaram S."Development of automated dedicated fixture configuration design systems with predefined fixture component types: Part 1, Basic design, INT. J. OF FLEXIBLE AUTOMATION AND INTEGRATED MANUFACTURING, Vol. 7. (p.168 - 176.), 1999.

[2] Rong Y., Zhu Y. "Computer-Aided Fixture Design", MARCEL DEKKER, New York, 1999.

[3] Rong Y., Huang S. H., and Hou Z. "Advanced Computer - Aided Fixture Design", ELSEVIER SCIENCE & TECHNOLOGY, 2004.

[4] Borojević, S., Jovišević, V., Todić, V., Milošević, M., Lukić, D. "Analysis of Faces' Accessibility for the Purpose of Modular Fixtures Design", STROJARSTVO: JOURNAL FOR THEORY AND APPLICATION IN MECHANICAL ENGINEERING, Vol.54 No.2, (p.127-133), 2012.

[5] Borojević S. "Automated modular fixture design", MASTER OF SCIENCE THESIS, Faculty of Mechanical Engineering Banjaluka, University of Banjaluka, 2011.

[6] Borojević, S. , Jovišević,V. "Selection and configuration of modular components for modular fixture design", JOURNAL OF PRODUCTION ENGINEERING, Vol. 16, No.1, (p.21-26), Mart 2013.

[7] Shokri M., Arezoo B. "Computer-aided CMM modular fixture configuration design" INTERNATIONAL JOURNAL OF MANUFACTURING TECHNOLOGY AND MANAGEMENT, Volume 14, Number 1-2, (p.174 - 188), 2008.

[8] SolidWorks program system, Concord, Massachusetts, USA / Dassault Systèmes S.A. France, SW 2008

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DIFFERENT APPROACHES FOR CREATION OF HUMAN TIBIA 3D MODELS BASED ON CT DATA

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Existence of appropriate and accurate CAD models of human bones is significant in orthopedic operations planning, training of future surgeons, designing of fixators, etc. Based on this, anatomic and morphological properties of bones should be included in the modeling processes. This paper represents different approaches for creation of 3D model (surface and solid) of human tibia. Both approaches, method of rotational planes and method of characteristic regions, enable creation of 3D model (based on CT data) of satisfactory accuracy. Application of these methods, which are developed with regard to natural properties of human tibia (in this case), can be expanded onto other long bones in human body.

***Keywords: 3D* models, tibia, CAD, virtual physiological human.**

1. INTRODUCTION

Injuries and pathological processes (tumors and others) of human osteoarticular system are very common reasons for large number of surgical interventions. Anatomically correct and geometrically accurate CAD (Computer-Aided Design) models of human bones can be advantageous to orthopedic surgery. These models may be used for computer-based preoperative planning, surgery training simulations [1], creation of customized implants [2] and fixators, etc. The classification and analysis of 3D modeling methods for the creation of the human bones geometrical models are presented in [3].

In [3,4] the authors present approach which is based on reshaping (scaling) the standard sample of the human bone 3D generic model in order to match X-ray image of particular bone. Model (solid or surface) created with this approach does not have precisely defined geometric entities (points, planes, spline curves, etc.).

In [5] the authors propose the process of creating contour curves on the basis of cross-sections of bone obtained from CT (Computer Tomography) slices. Because there is no information on cross-sections other than from CT slices, this method may not give satisfactory results. For creating 3D model of femur, approach defined in [6] uses curves obtained from different cross-sections.

Methods presented in this paper enable the definition of various geometrical entities and functional relationships between them, which can be used later to create geometrical parametric model(s), as shown in [7,8].

Approaches for creating human tibia 3D models are presented in this paper. These methods are based on anatomical and morphological properties of the bone.

2. ANATOMIC PROPERTIES OF TIBIA

Situated at the medial side of the leg, tibia, excepting the femur, is the longest bone of the skeleton. It has a body and two extremities, proximal and distal. Proximal end of the tibia has a broad superior articular surface which articulates with the femur. The shaft has prismoid shape with three surfaces and three margins. The anterior margin, the most prominent of the three, commences above at the tuberosity, and ends below at the anterior margin of the medial malleolus.

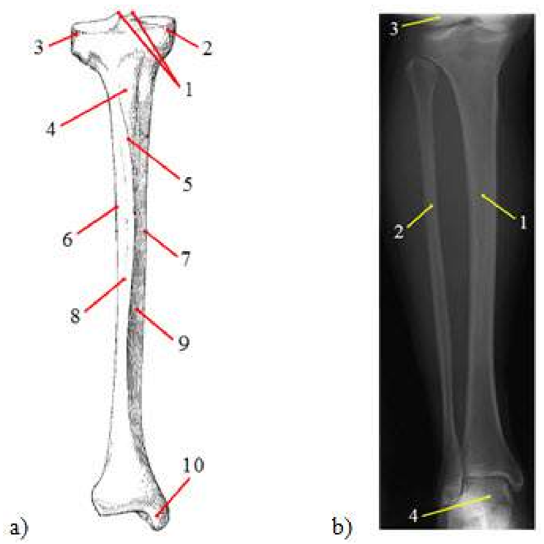


Fig. 1. Anterior view of right human tibia, a) 1. Intercondylar tubercles of intercondylar eminence, 2. Medial condyle, 3. Lateral condyle, 4. Tibial tuberosity, 5. Anterior margin of tibia, 6. Lateral margin of tibia, 7. Medial margin of tibia, 8. Lateral surface, 9. Medial surface, 10. Medial malleolus, b) X-ray image, 1. Tibia, 2. Fibula, 3. Femur, 4. Talus

Distal end of the tibia, much smaller than the upper, is prolonged downward on its medial side as a strong process, the medial malleolus. Its inferior articular surface is quadrilateral, and smooth for articulation with the talus [9,10] (Fig. 1).

3. INPUT DATA

In order to create 3D model of a particular tibia in manner presented in this study, it is necessary to obtain initial precise description of the bone. Such kind of information can be obtained by CT scan of human tibia, which was, in this case, performed in resolution of 0.5 mm. Obtained CT slices are used for creating cloud of points which represents entrance for specific CAD software for reverse modeling. Creating a large number of small triangular planar surfaces among the points in the cloud forms a mesh, which represents outer surface of tibia as well as the initial (polygonal) model used for the process of reverse modeling (Fig. 2).

4. REFERENTIAL GEOMETRICAL ENTITIES (RGEs)

After obtaining of polygonal model, recognizing and defining of RGEs [11] is the following step in reverse modeling process.
In the case of the tibia, the mechanical axis is a line from the center of the tibia plateau (interspinous intercruciate midpoint) extending distally to the center of the tibia plafond [12].
The tibia plateau (proximal/superior articular surface) was approximated with ellipse, which was best solution compared with all other tested entities: circles, spline curves, etc. The first point that defines mechanical axis is center of the ellipse, which is approximately equal with center of tibia spines notch [12]. The second point is center of the tibia plafond (distal/inferior articular surface) which was approximated with adequate lower cross-section of distal end of tibia (Fig. 2).
When the mechanical axis is determined, it is possible to position differently oriented planes which are in accordance with anatomy of tibia.

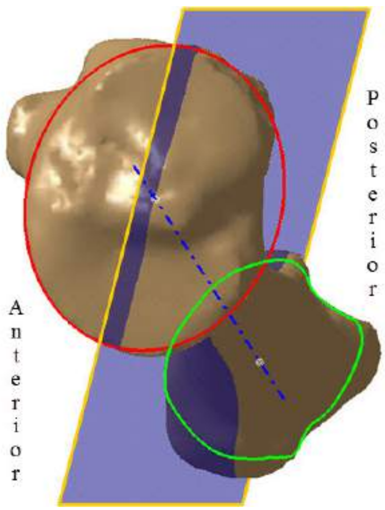


Fig. 2. RGEs on polygonal model of the right tibia: determination of points defining the mechanical axis. Mechanical axis and A-P plane

5. CREATION OF 3D MODEL OF HUMAN TIBIA

Initial contour curves are obtained in intersection of set planes and polygonal model. These curves are used for positioning the points which, when connected, create spline curves (Fig. 3, 5). Spline curves enable further creation of 3D surface model of particular tibia (Fig. 5, b)). 3D solid model can be obtained by filling the volume of surface model using known features from the CAD software. Two different types of planes selection are presented in [13]. They will be described in the following passages, with larger number of spline curves and certain improvements compared to the case [13]. Second method proved to be better (method of characteristic regions) and obtained model was then compared to polygonal model.

5.1 Rotational Planes Method

Using the first method, 3D model is created by longitudinal spline curves which include all three parts of tibia, that is, only half-planes containing mechanical axis are used (Fig. 3). Therefore, in this case, tibia is observed as a single object, not partially.

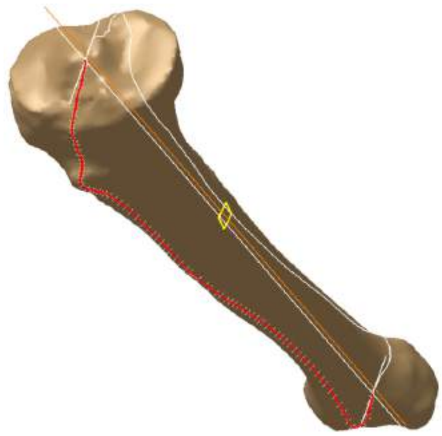


Fig. 3. Rotational planes method for creating the model of tibia. Intersection of polygonal model and half-plane defined with 70 degrees, locating the points and creation of spline curve

Anterior-Posterior (A-P) plane contains mechanical axis of tibia and divides it to anterior and posterior sides (Fig. 2). Initial curves are obtained by intersection of polygonal tibia model and half-planes oriented at: 0, 15, 30, 40, 50, 60, 70, 80, 90, 105, 120, 135, 150, 165, 180, 195, 210, 225, 240, 255, 270, 285, 300, 310, 325, 330 and 345 degrees in direction from lateral to anterior side, so that A-P plane determines the curves at 0 and 180 degrees. Using this large number of half-planes in order to obtain accurate model, problems occur in later creation of surface tibia model. Namely, undesirable deformation of the surface appears in areas where anatomy of tibia is more complex, such as medial malleolus or posterior side of proximal end, since adjacent spline curves are significantly different in these areas (Fig. 4). These irregularities can be partially corrected using transversal spline curves obtained by intersection of planes perpendicular to mechanical axis with polygonal model of tibia, and perform the function of guidelines in creating the surface. However, longitudinal spline curves are complex, since they include entire length of tibia; therefore, it is only possible to create parts of total surface, which consist of smaller number of longitudinal spline curves. Obtained partial surfaces later form entire surface of tibia, but the connecting places remain evident and irregular. Another problem with this planes selection (in this case, half-planes), arises in the posterior side of tibia shaft. Created surface is not of satisfying quality and accuracy due to large number of longitudinal spline curves which are positioned very closely together.

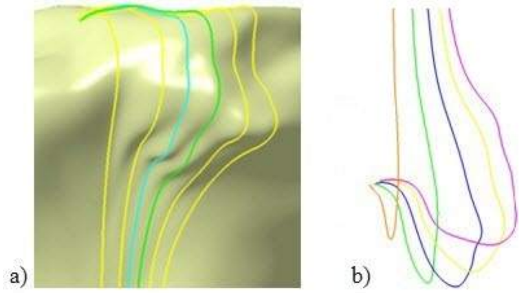


Fig. 4. a) Problem at posterior side of proximal end, b) Splines at medial malleolus the points and creation of spline curve

5.2 Characteristic Regions Method

Using the second suggested method, surface model of tibia can be created by connecting surfaces of proximal end, tibia shaft and distal end. The same half-planes are used for creating the model of proximal and distal ends, as well as for rotational planes method. These half-planes are determined in accordance with tibia anatomy; therefore, in this case, the distance between them is smaller in the area of tibial tuberosity (from 40 to 90 degrees), in order to represent this complex part of tibia in the most accurate manner possible. Similar case is with posterior side of proximal end (from 300 to 330 degrees). The same half-planes are also used for spline curves creation in distal end, but this large number of curves is not necessary for this part since it is less complex than proximal end. Spline curves in this method are shorter; therefore, it is possible to introduce spline guidelines at larger regions of tibia. In this manner the problem in posterior side of proximal end is partially solved by introducing three spline guidelines, one of which is located at the connecting point of proximal end with tibia shaft. Second guideline belongs to the plane which is at 30 mm distance from the plane of previous guideline, while the third guideline connects the peaks of spline curves which create this part of tibia surface. Each of used spline curves has end points (spline peaks) 2.5 mm from the mechanical axis, as related to corresponding intersection point of polygonal model and mechanical axis. This approximation is introduced in order to close (with circle) this surface of tibia at proximal and distal ends. There is no need for using guideline spline at anterior side of proximal end, since the surface at this region can be created without irregularities. Moreover, at this region of tibia, guidelines could disrupt the created surface. Distal end surface, as well as the proximal end, consists of anterior and posterior sections. Sections of distal end surface contain two guidelines each, one is located at the connecting point of distal end and tibia shaft, and another connects spline peaks (Fig. 5).

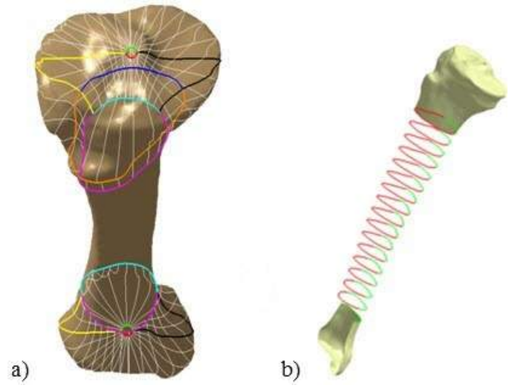


Fig. 5. Method of characteristic regions for creating model of tibia, a) Guidelines and spline curves for creating surface at tibia ends, b) Proximal end surface, posterior section surface of distal end and spline curves at tibia shaft

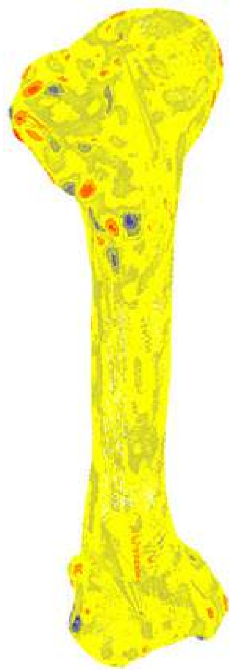
Due to shorter and less complex spline curves than in the first method, as well as due to introduction of guidelines, created surface at medial malleolus does not contain major irregularities as in application of rotational planes. Tibia shaft surface is created using spline curves located on planes which are perpendicular to mechanical axis of tibia. Number of planes is 15, each 15 mm apart from each other (Fig. 5, b)). Tibia shaft surface also consists of anterior and posterior sections. Problem with connecting surfaces of proximal end, tibia shaft and distal end into one surface is solved by using mutual spline curves at connecting points (proximal end with shaft, and shaft with distal end). In this manner, previously used surface approximations [13] are avoided, since they adversely affect the accuracy of geometrical model.

6. ACCURACY ANALYSIS OF CREATED MODEL

For the purpose of accuracy control, 3D surface model created by using the second (chosen) method (Fig. 6, a)), is compared to polygonal model. Method for accuracy control of created model is presented in (Fig. 7), using known feature from CAD software. For the purpose of comparison, it is necessary to create surface model from initial polygonal model, using feature from CAD software. This model is necessary due to peaks in polygonal model (they do not represent real geometry of polygonal model). Obtained surface model is used only for accuracy control and has no defined geometrical entities. Software sets large number of points in this surface model and in surface model created by method of characteristic regions. Comparing relevant points of these two models, software calculates the accuracy of created model (Fig. 7). The maximal difference (error) is 1.858 mm. As expected, major difference appear at proximal and distal ends. However, the largest is the number of points with error less than 1 mm. Mean value of absolute error values of all points is 0.2682 mm.

Fig. 6. a) 3D surface model of right tibia created using method of characteristic regions, b) Comparison of created and polygonal models (colored yellow)

Polygonal model and obtained model (using method of characteristic regions) are presented together in (Fig. 6, b)), which shows that the models mutually correspond.



Percentage of the total number of points		Distance between the points of compared models
0%		1.833mm
0.19%		1.371mm
0.66%		0.91mm
6.63%		0.449mm
51.24%		-0.013mm
36.16%		-0.474mm
4.29%		-0.935mm
0.78%		-1.397mm
0.04%		-1.858mm
0%		

Fig. 7. Difference in points of created 3D surface model and model obtained from the polygonal. Image of tibia (left) and statistics of points number (right)

7. CONCLUSION

This research proved the method of characteristic regions for creation of 3D models to be better, according to the criterion of accuracy of created model, compared to the method which uses spline curves enclosing entire bone. Recommendations for solution of the problem with irregularities in creation of surface model are given. They also eliminate the use of approximations at connecting points, which appear in [13]. Created 3D model is based on anatomic properties of particular tibia, and therefore, it is necessary to be familiar with the anatomy of the bone. Obtained 3D model possesses satisfying accuracy compared to polygonal model (Fig. 6, b), 7). In the case when it is necessary to create 3D model of entire tibia in a short period of time (high accuracy is not necessary), it is recommended to use the rotational planes method using smaller number of spline curves enclosing the entire bone. Method of characteristic regions enables separate creation of 3D model of specific part of tibia. In this manner, the duration of process is reduced for the cases when it is not necessary to create model of entire tibia. The problem which appears in application of presented methods is increased radiation the patient is exposed to due to usage of CT for obtaining the initial (polygonal) model.

Acknowledgement: This paper is part of project III41017 Virtual human osteoarticular system and its application in preclinical and clinical practice, funded by the Ministry of Education and Science of Republic of Serbia, for the period of 2011-2014.

REFERENCES

[1] Sourina, O., Sourin, A., Sen, H. T. “Orthopedic Surgery Training Simulation,” *Journal of Mechanics in Medicine and Biology*, vol. 7, no. 1, p. 37-53, 2007

[2] Stojkovic, M. et al. “Reverse modeling and solid free-form fabrication of sternum implant,” *Australas Phys Eng Sci Med*, vol. 33, no. 3, p. 243-250, 2010

[3] Filippi, S., Motyl, B., Bandera, C. “Analysis of existing methods for 3D modelling of femurs starting from two orthogonal images and development of a script for a commercial software package,” *Computer methods and programs in biomedicine*, vol. 89, no. 1, p. 76-82, 2008

[4] Gunay, M., Shim, M.B., Shimada, K. “Cost- and time-effective three-dimensional bone-shape reconstruction from X-ray images,” *The international journal of medical robotics and computer assisted surgery*, vol. 3, p. 323-335, 2007

[5] Jiang, T. Lin, F., Kaltman, S.I., Sun, W. “Anatomical modeling and rapid prototyping assisted surgical reconstruction,” Proceedings of the Eleventh Solid Freeform Fabrication Symposium, University of Texas Austin, p. 555-564, 2009

[6] Viceconti, M., Zannoni, C., Pierotti, L. “TRI2SOLID: an application of reverse engineering methods to the creation of CAD models of bone segments,” *Computer Methods and Programs in Biomedicine*, vol. 56, p. 211-220, 1998

[7] Majstorovic, V., Trajanovic, M., Vitkovic, N., Stojkovic, M. “Reverse engineering of human bones by using method of anatomical features,” *CIRP Annals - Manufacturing Technology*, vol. 62, p. 167-170, 2013

[8] Vitković, N., Milovanović, J., Korunović, N., Trajanović, M., Stojković, M., Mišić, D., Arsić, S. “Software System for Creation of Human Femur Customized Polygonal Models,” *Computer Science and Information Systems*, vol. 10, no. 3, p. 1473-1497, 2013

[9] Moore, K., Dalley, A., Agur, A. "Lower Limb / Tibia," Taylor, C., Heise, J., Montalbano, J. (Editors), Clinically Oriented Anatomy. Lippincott Williams & Wilkins, Philadelphia, USA, p. 520-521, 2010

[10] Brown, P. "The online skeleton," from http://www-personal.une.edu.au/~pbrown3/oskel.html, accessed on 2013-08-22

[11] Stojkovic, M., Milovanovic, J., Vitkovic, N., Trajanovic, M., Arsic, S., Mitkovic, M. "Analysis of Femoral Trochanters Morphology Based on Geometrical Model," *Journal of Scientific and Industrial Research*, vol. 71, p. 210-216, ISSN: 0975-1084 (Online), 2012

[12] Cooke, D., Sled, E., Scudamore, A. "Editorial, Frontal Plane Knee Alignment: A Call for Standardized Measurement," *The Journal of Rheumatology*, vol. 34, no. 9, p. 1796-1801, 2007

[13] Veselinovic, M. et al. "Study on creating human tibia geometrical models," Proceedings of the 3rd International Conference on E-Health and Bioengineering - EHB, Iaşi, p. 195-198, 2011

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TOLERANCE TRANSFER FROM CAD TO CAM SYSTEM

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Abstract: *Integration of CAD/CAM systems is one of the most important tasks in today's concurrent engineering. Most of CAD systems considered only the geometry of a part, rather than other product information. However, product data, such as tolerance information, is absolutely crucial pre-requirement for further downstream digital activities, such as manufacturing and automatic inspection. This paper investigate the current state of tolerance data exchange between CAD/CAM systems.*

Key words*: Tolerance transfer, CAD, CAM*

1. INTRODUCTION

The globalization of markets, shortening product life cycles, the growing complexity of products, greater variance in product range and shortening time to market, requires from manufacturers continuous improvements of business processes and reduction of costs in all areas. Computer technology has greatly impacted the life cycle of products, so CAD and CAM systems have become standard engineering tools that are used in industry. Soon after CAD and CAM systems were developed, users realized that the communication between CAD and CAM systems in distributed product and process development became the bottleneck for the improvement of productivity, so the integration of CAD and CAM systems represents for many years an active area of research.

Although a tremendous effort has been made in developing fully integrated CAD/CAM systems in the last decades, the effectiveness of these systems is not fully satisfactory. Currently, many feature-based CAD systems have been developed, but most of them cannot provide exact and complete informations about part. Namely, most CAD systems provide only the geometry of a part, rather than other product information. However, product data, such as tolerance information, surface finish, material, etc. is absolutely crucial to CAM systems.

Due the uncertainties that are present in production process, all manufactured products are characterized by inevitable variation of parameters from the ideal values. For a definition limits of these imperfections, the product designer must determine proper dimensional and geometric tolerances. Dimensioning and tolerancing of solid CAD models is important pre-requirement for further downstream digital activities, such as automatic assembly, manufacturing, automatic inspection, etc.

Modern, feature-based CAD systems have several tools for tolerance specifications in the form of annotation, for associate tolerances with geometric entities of CAD models. However, the way in which these tolerance information are represented, stored and associated with CAD geometrical entities is not fully standardized.

Furthemore, in current CAD systems tolerance annotation, instead the semantics of geometric and dimensional tolerances, mainly concerns their syntax. Consequently, tolerance annotations are not universally inclusive for downstream activities.

Apparently, tolerance information transfer is an important link between design and manufacturing and thus determination of part tolerance specifications must take into account of the manufacturing process in addition to meeting assembly design specifications. To realise this data transfer, feature-based design approach can be used, which promotes a closer connection between design and manufacturing through features, although it has not yet fulfilled its promise.

2. CAD/CAM INTEGRATION

Integration of CAD/CAM systems is one of the most important tasks in concurrent engineering. The main problem of CAD/CAM integration is related to the incompatibility of file formats that contain geometric and nongeometrical product information. Modern CAD/CAM systems, such as for example, CATIA, Pro/E, Unigraphics, etc. have specialized modules built on the same software platform architecture. These systems have a very similar way to store files and therefore communication between them is not a problem. However, because of the variety of commercially available CAD/CAM systems, in general, a problem of exchange information about products and processes is very emphasized.

Considering the importance of data exchange, CAD/CAM software manufacturers, as well as many independent organizations, are trying to establish standards in this area. Among these STEP is one of the most important standards of product data exchange. STEP standard was initially designed for replacement of IGES in neutral data exchange method, but ultimate goal of this standard is to provide a complete computer-interpretable product data format, so that users can integrate all data related to whole product life cycle. However, STEP standard does not support all types of objects that may occur in CAD/CAM systems and does not secure direct and instantly regeneration of CAD model after design modification.

Modern CAD/CAM systems can be characterized as parametric and feature-based systems. Features provide successful link between design and manufacturing and is regarded as an crucial factor in CAD/CAM integration. Term „feature“ is used to denote modeling a variety of physical characteristics of parts. Shah and Mantyla [1] define five types of feature: form features, tolerance features, assembly features, functional features and material features. Form features, tolerance features and assembly features are all closely related to the geometry of parts, and are hence called collectively geometric features.

The same part may also be viewed differently, depending on which features are relevant for application. Feature technology promotes a closer connection between design and manufacturing through features. A great deal of work has focused on feature recognition in a CAD model, because it is a crucial task for a CAM system. Current feature recognition methods mainly address geometric features, in particular, form features, rather than other product information. However, it is very important to perform recognition other types of features, i.e. tolerance feature recognition.

Geometric dimensioning and tolerancing in CAD/CAM systems is used to define the true functional limits of acceptable part geometry. This type of information, is also crucial in determining the most efficient and economic method of machining the part. For example, tighter tolerances ensure better product quality, but they increase the manufacturing cost to a considerable extent. On the other hand, wider tolerance zone can lead to an unacceptable reduction in quality and poor performance of the products. Therefore, a tradeoff is needed between the product quality and its manufacturing cost. These contradictory requirements between design and production have a huge impact on the final price of the product and are therefore many CAD systems have tolerance analysis tools, which allow the designer to ensure the widest possible tolerance, while they retain the functionality of the product.

3. CASE STUDY

Currently, many CAD systems have been developed, but they have only limited and undeveloped support to assign tolerances to individual dimensions/parameters that is use to describe part. The majority of CAD systems permit tolerances for a feature to be associated with geometric entities, but the way in which these critical data are represented, stored and associated with geometrical entities are not standardized. Moreover, tolerance annotation in current CAD systems mainly concerns the syntax of tolerances, not their semantics. Only a few very powerful CAD systems offer some form of control to avoid an inadequate combination of tolerance. Computer Aided Tolerancing Systems are systems for modeling, representation and analysis of dimensional and geometric tolerances. A commercial system CATIA supports tolerance representation in its feature-based, parametric solid modeler. 3D Functional Tolerancing & Annotation module stores all functional, topological, geometrical and other feature relationships in its database and allows the user to establish tolerances for each dimension at any time. Furthermore this system also helps in analysing tolerance stackups.

One of the fundamental function of the CAM systems is importing CAD data files. Beside pure geometric data (shape, size and form of the part) CAM systems requires additional data of the part, e.g. tolerances allowed for proper function, surface finish condition, material, heat treatments, etc.

In order to explore the extent to which CAM systems import data on conventional tolerances we use CAD model of shafts illustrated on Figure 1. CAD/CAM software CATIA V5R20 was chosen for demonstrating the solutions. Using Functional Tolerancing & Annotion module of CATIA two shaft diamaters are tolerated Ø75k6 (+0.021, +0.007) and Ø82n6 (+0.045, +0.023), as width 20P9 (-0.022, -0.074) and depth 7.4m7 (+0.021, +0.006) of slot. Thus tolerated CAD model is transferred to Lathe Machining CATIA NC Manufacturing module, where simulation and validation of manufacturing process has been performed. Furthermore, for manufacturng simulation of slot has been used Prismatic Machining Milling CATIA NC Manufacturing module.

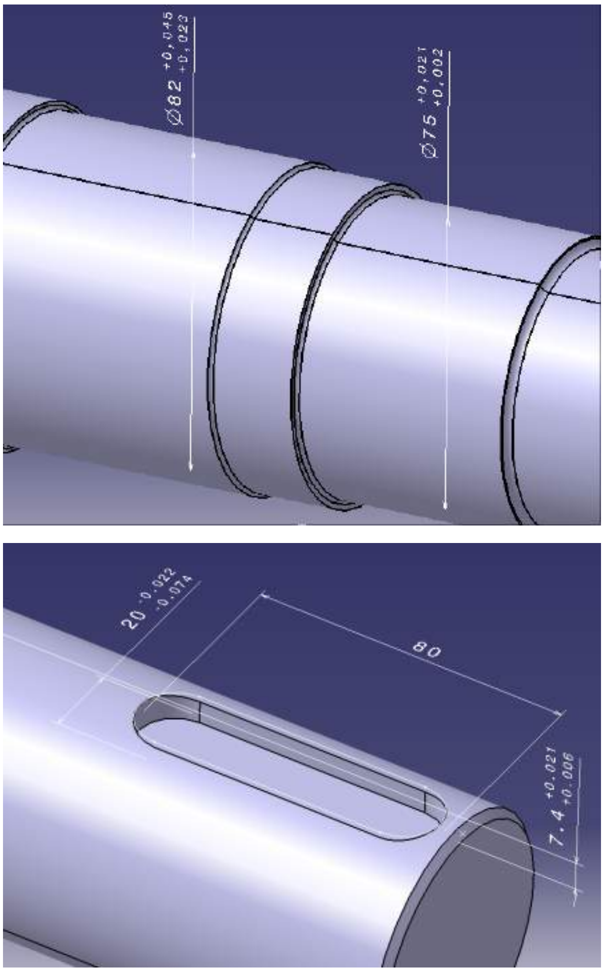

Fig. 1. Tolerated 3D model of shaft

NC code analysis block by block, which refers to the tolerated shafts diamaters Ø75k6 and Ø82n6 shows that information on tolerances are not considered (Figure 2a). Furthermore, same conclusion can be drawn for machining slot with depth 7.4m7 and width 20P9 (Figure 2b). For milling the origin of the coordinate system is located the middle of slot and machining was performed with tool radius 4 mm, so X coordinate have value of 6 mm.

a)

```
...
N210 G1 X75 Z-252.5
...
N370 G1 X82 Z-348.5
...
```

b)

```
...
N300 G1 Z-7.4 F300
...
N400 G3 X-6 Y70 I0 J-6
...
N430 G3 X6 Y10 I0 J6
...
```

Fig. 2. Fragment of case study NC code: a) turning, b) milling

As in this example, no tolerance data exchange between CAD and CAM systems may cause production of scrap. Namely, the upper and lower tolerance bound of shaft diameters both have positive values. On the other hand, the finishing tool paths have vaues of the X coordinate of 75 and 82 mm. Similar considerations are valid for manufacturing of slot, with the difference that the upper and lower bound depth of slot are positive, so it is necessary additional manufacturing.

3.1. Solution

From the above example it is clear that the tolerance associated with CAD solid model are not transfered to the appropriate CAM system. Since the information on tolerances directly influence the quality of products it is necessary to solve this problem. One possible solution is NC programs inspection and correction commands, i.e. the corresponding X, Y or Z coordinates of tool path. However, this method requires much manual work and it is very error prone.

Another possible solution is to identify information on tolerances indirectly through finish allowances, where the tool path was obtained by equidistant offsetting CL data for value of a medium sized tolerant fields. One of the most important step towards automated NC program generation is automatic interpretation of design data. In this context, the tolerance information is through the implementation of appropriate rules automaticcaly linked to the geometrical model through the definition of the individual finish allowances which result in the involment of information on tolerances in NC program (Figure 3).

It is quite clear that the proposed method of tolerance control through finish allowance is not the most effective solution that would fully satisfied the requirements of today's CAD/CAM systems, but it is a simple way of overcoming problems of tolerance data exchange between CAD and CAM systems.

a)

```
...
N210 G1 X75.012 Z-252.5
...
N370 G1 X82.034 Z-348.5
...
```

b)

```
...
N300 G1 Z-7.414 F300
...
N400 G3 X-5.974 Y70 I0 J-5.974
...
N430 G3 X5.974 Y10 I0 J5.974
...
```

Fig. 3. Fragment of case study NC code obtained with new method: a) turning, b) milling

4. CONCLUSION

Currently, many commercial CAD/CAM systems have been developed for many years and have proven to be excellent tools for design and manufacturing engineers. However, most of CAD/CAM systems cannot provide complete information about an object, such as dimensions or tolerances. Tolerance transfer is an important link between design and manufacturing and thus determination of part tolerance specifications must take into account of the manufacturing process in addition to meeting assembly design specifications.

The work described in this paper was to explore current state of tolerance transfer between CAD/CAM systems as a very import segment of CAD/CAM integration. A suitable method for tolerance transfer has been developed to integrate the technological product specification with the manufacturing process in a concurrent environment. The presented approach provides an easy tool to extract the information related to the dimensional tolerances and the geometry of the part in a common sense. In this way, satisfactory tolerance data exchange between CAD/CAM systems have been provided.

REFERENCES

[1] Shah, J. and M. Mantyla, “Parametric and Feature-Based CAD/CAM”, John Wiley, 1996.

[2] Zhou, F., T.-C. Kuo, S. H. Huang and H.-C. Zhang, “Form Feature and Tolerance Transfer from a 3D Model to a Setup Planning System”, *International Journal of Advanced Manufacturing Technology vol. 19*, 88-96, 2002.

[3] Shah, J., Y. Yan and B.-C. Zhang, “Dimension and tolerance modeling and transformations in feature based design and manufacturing”, *Journal of Intelligent Manufacturing*, vol. 9, 475-488, 1998.

[4] Gao, J., D. T. Zheng, N. Gindy and D. Clark, “Extraction/conversion of geometric dimensions and tolerances for machining features”, *International Journal of Advanced Manufacturing Technology*, vol. 26, 405-414, 2005.

[5] N. Wang and T. M. Ozsoy, “Scheme to represent features, dimension and tolerances in geometric modeling”, *Journal of Manufacturing Systems,* vol. 10, 233–240, 1991.

[6] Moujibi, N., B. Rzine, A. Saka, A. Bouayad, M. Radouani, and B. Elfahim, “Simulation of Geometric

Tolerance Values Based on Manufacturing Process Constraints", *Journal of Studies on Manufacturing*, Vol.1, 91 –99, 2010.

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INFLUENCE OF THE MATERIAL TYPE, FLEXION DEGREE AND AXIAL COMPRESSIVE LOADS ON CONTACT STRESS GENERATION ON THE TIBIAL INSERT OF THE TOTAL KNEE ENDOPROSTHESIS

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Total knee joint endoprosthesis implantation is one of the most common surgery today performed in humans. Replacement of the damaged articular surface, restoration of basic knee joint functions, and pain elimination are the basic objectives of these surgery. The aim of this study is to analyze stress distribution on the tibial insert made of polyethilen UHMWPE depending on metal components' material types, knee joint flexion, and axial compressive loads. In this study we have used reconstructed models of the femur and tibia. Knee joint prostheses model, as well as the analysis of stress distribution is created using Catia V5. The results show approximately uniform stress distribution for a given knee prosthesis design, corresponding pressure, flexion degree, and material of the tibial and femoral components. Maximal stress values are located on the lateral and medial part of the tibial insert, and thus are not of the crucial importance for the tibial insert wearing.

Keywords: *Biomaterials, stress distribution, knee joint prosthesis*

1. INTRODUCTION

Biocompatible materials usage in medicine are aimed at returning form and function of replaced biological structures. In orthopedics, materials used in implantology ensure adequate ductility, corrosion resistance, wear resistance, biocompatibility, and integration with bones [1,2].

Stainless steel, cobalt superalloys, titanium and its alloys, ceramics, and, very rarely, composite materials are generally used in orthopedic surgery today. Polymer UHMWPE has found wide application. This material has remarkable properties of the abrasion resistance, friction resistance, excellent ductility, low density, biocompatibility, and biostability. Listed properties make UHMWPE very attractive material for bearing surfaces in the total knee replacement [3, 4].

With polyethylene tibial inserts advent, great attention is focused on reducing this material wear, because it primarly affects endoprosthesis loosening in total knee replacement. Contact bearing surface stresses are the main reason for material fatigue and tibial insert wear, which further affects the implant lifetime [3, 4].

2. RELATED WORK

Static and kinematic analysis of the contact stress distribution using finite element method (FEM) presented in current studies define tibial insert thickness and sliding ratio influence on the wear occurrence

Cho et al. show elastoplastic contact between metal femoral component and polyethilene tibial insert. Stress maximal values are noticed in anterior part of the tibial insert, and greater wear is noticed in the implant medial part [5].

S. O'Brien et al. have examined and analyzed surface contact pressure between femoral component and tibial insert and sliding length using FEM [4]. The results suggest that maximal values of the contact stress are approximatily at 26,2MPa, and as such are not crucial on the wear appearance.

D.J. Van den Heever et al. exercised FEM analysis on the custom made partial knee prosthesis and prosthesis selected from a catalog. It is concluded that custom made prostheses create smaller contact stresses compared to those prostheses selected from catalog [6].

Oonishi et al. compare knee joint endoprosthesis made of cobalt alloy with aluminum and ceramic coating. Wear between femoral component with ceramic coating and UHMWPE tibial insert is considerably less than wear between femoral component without coating and tibial insert. Wear between tibial insert made of UHMWPE and femoral component with aluminum coating have shown stable low wear level [7].

3. MATERIALS AND METHODS

For the load influence on the tibial insert analysis 3D finite element model was used. We analyzed material, body weight and flexion degree influence on the tibial insert stress distribution. Same endoprosthesis knee model was used in each applied analysis. We only changed values of the body weight and flexion degree angles.

We investigated fixed bearing of the tibial component. Polyethylene UHMWPE is common tibial insert material, and tibial and femoral components materials are listed in Table 1 [1, 8].

Stress/strain analysis is conducted in Catia V5. Finite element grid includes material characteristics (defined in Table 1), and structural properties that define the structural reaction under load. Parabolic tetrahedrons demonstrated an optimal solution for the elements of the model (side 2.5mm).

3D models of femur and tibia are reconstructed from MRI images, and knee joint endoprosthesis 3D model created in Catia V5 (Fig.1).

Three different positions of the knee joint were simulated with these models, i.e. flexion of 15°,45°, and 60° [8]. In every position, tibia and its components were fixed, and femur and femoral component were loaded with axial load. Loads depend from human weight, i.e. 50kg, 75kg, 100kg, 125kg.

FE analysis simulation consider following assumptions:

- Tibial insert is deformable body with Poisson coefficient of 0.4;
- Tibial insert from underside is fixed to stationary tibial component surface;
- Femur and femoral component are rigid bodies; and
- Tibia and tibial component are rigid bodies.

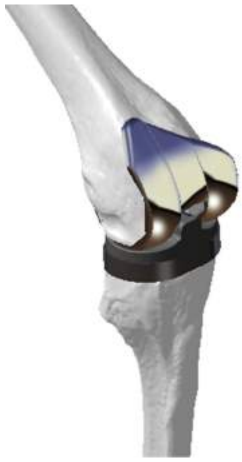


Fig. 1. Total knee Endoprosthesis Model

Table 1. Metalic materials properties applied in FE analysis [1]

Matrial type	**Rm**	**Reh**	**Rds**	**E**	**OH**	**R**
Stainless steel						
Austenitic steel AISI 316	550	205	270	198	8	7,87
Austenitic steel AISI 317	570	250	290	193	8,5	7,97
Austenitic steel AISI 321	600	230	265	197	8	7,95
Precipitation-hardening steel AISI630 (17-4PH)	1300	1500	450	202	9	7,82
Co Alloy						
Co-Cr-Mo	700	900	350	225	10	8,6
Ti Alloy						
Ti-6Al-4V	1020	1050	625	114	7,5	4,42
Fe Superalloy						
SAE A-286	110	600	370	201	9	7,92

Legend: **Rm**, **MPa** - Tensile Strength; **Reh**, **MPa** - Yield Strength; **Rds**,**MPa** - Dynamic Durability; **E**,**GPa** - Young's Module; **OH**, / - Wear Resistance; **R**, **g/cm³** - Density

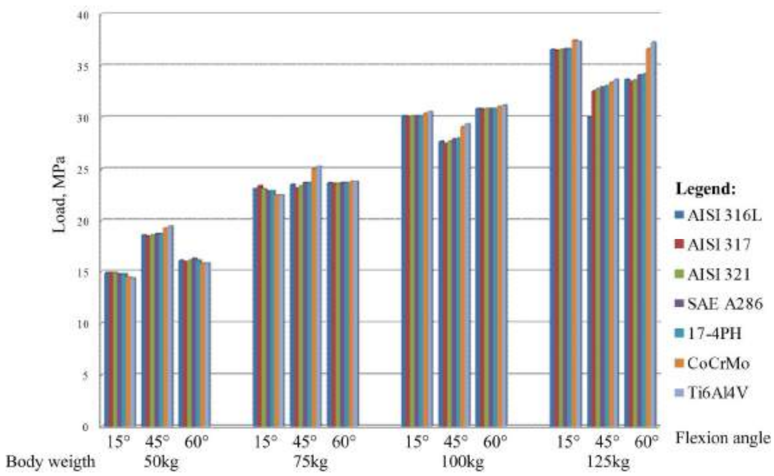


Fig. 2. Histogram of the tibial insert contact stress depending on flexion angle degree, body weight, and femoral component material type

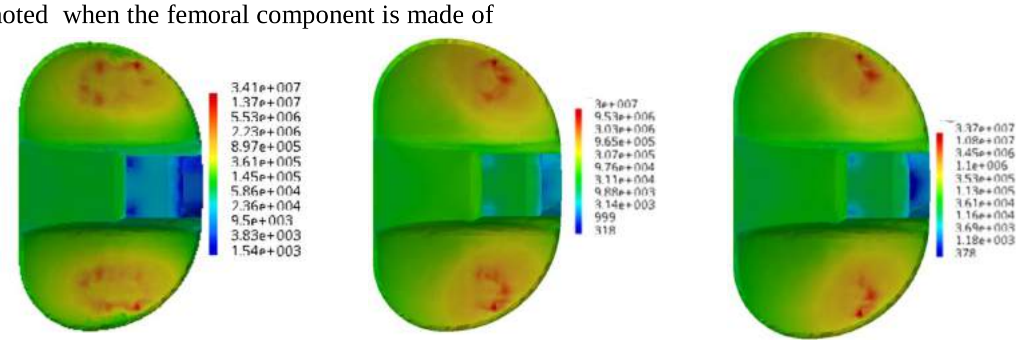
Contact between femoral component and tibial insert was simulated in such way that rigid body (femoral component) deforms soft body (tibial insert).
Tested models correspond to purely numerical modeles, having key factors, such as muscles and ligaments are not taken in consideration and are not included during modeling process. Simulation refers to compressive axial loads since the effects of torsion and bending forces are not observed [9].

4. RESULTS AND DISCUSSION

Distribution of tibial insert stresses for different body weights, obtained by FEM analysis, is shown by histogram in Figure 2.
In the first extreme case, when the body weight is 50kg, the smallest stress values occur for the flexion of 15° and 60°. These values are around 15MPa for all metal material types. Slightly higher values are for flexion of 45° and do not exceed 20MPa (Fig.2).
For men, optimal body weight is from 75kg to 100kg. In the first optimal case, it could be noticed that values of the contact stresses are approximately the same regardless material type or flexion degree. These values do not exceed 25 MPa which correspond to S. O'Brien results [4]. The only exception is a slight stress decrease flexion of 45° when the femoral component is made of cobalt and titanium alloys (Fig.2).
In the second optimal case, stress values are approximately the same. Stress decrease is observed for the flexion of 45°. For the same angle slight stress increase is noted when the femoral component is made of cobalt and titanium alloys, like in the first optimal case (Fig.2) [4, 6,8].
In the second extreme case, the greatest stress values occur. These values are slightly higher than 35MPa. Tibial insert is the most loaded for the flexion of 15°. When the femoral component is made of cobalt and titanium alloys, for the flexion of 60°, there is a stress values increase of 10MPa compared to the other metal materials (Fig. 2).
Results of this study shown in Figure 3, coincides with results presented in [5]. Maximal values of contact stresses are observed on the lateral and medial part of the tibial insert. In the case of the flexion of 15°, maximal values of contact stresses are located in the dent of the tibial insert. In the case of flexion of 45° and 60°, maximal values of contact stresses are displaced anterior (Fig.3) [8]. Anterior displacement can be related to tibia AP sliding occurrence.

5. CONCLUSION

Tibial insert of the total knee endoprosthesis is the most imposed and loaded elements of the artificial knee joint. Its overall mechanical characteristics affect wearing effects and durability. It also has the strong infuence on the range and the intensity of a patient's everyday activities. Deeper understanding of the knee joint, as well as the total knee prosthesis kinematics, requires precise geometrical, mechanical and kinematic models.



a) b) c)

Fig. 3. Von Misses Stress for flexion of:: a) 15°, b) 45°, and c) 60°

In our study we used reconstructed 3D models of human femur and tibia, 3D model of endoprosthesis, and corresponding kinematic (digital mock-up) models. Varying different prostheses parameters and gait parameters related to the knee joint we analysed the range and distribution of static loads on tibial insert of the total knee endoprosthesis. The results show approximately uniform stress distribution for a given knee prosthesis design. Maximal stress values are located on the lateral and medial part of the tibial insert, and therefore without significant importance for the tibial insert wearing. Our study is aimed at development of the integral gait analysis system for the clinical purposes that will noninvasively assist orthopedic surgeons to select the optimal prosthesis design for each individual patient.

Acknowledgment: This work presents a part of the research work under the projects "Application of Biomedical Engineering in Preclinical and Clinical Practice", supported by Ministry of Education and Science of Serbia (Grant No. III-41007), "Gait Analysis Lab" supported by Faculty of Medical Sciences, University of Kragujevac, Serbia (Grant No. JP 20/10), and BioEMIS, "Studies in Bioengineering and Medical Informatics" (530423 - TEMPUS - 1 - 2012 - 1 - UK - TEMPUS – JPCR), funded by EC-EACEA.

REFERENCES

[1] B. Ristić, Z. Popović, D. Adamović, and G. Devedžić, "Izbor materijala u ortopedskoj hirurgiji,", Vojnosanitetski pregled, Vol. 67, pp: 847-855, 2010.

[2] M. Bahraminasab and A. Jahan, “Material selection for femoral component of total knee replacement using comprehasive VIKOR” Materials and Design, Vol. 32, pp: 4471-4477, 2011.
[3] S. Utzschneider, N. Harrasser, C. Schreder, F. Mazoochian, V. Jansson, “Wear of contemporary total knee replacements – A knee simulator study of six current designs” Clinical Biomechanics, Vol. 24, pp: 583-588, 2009.
[4] S. O’Brien, Y. Luo, C. Wu, M. Petrak, E. Bohm, J.-M. Brandt, “Computational development of polyethylene wear model for the articular and backside surfaces in modular total knee replacement“, Tribology International, Article in press, pp: -, 2012
[5] C.H.Cho, T.Murakami, Y. Sakai, T. Kawano, Y. Iwamoto, “Elasto-plastic contact analzsis of an ultra-high molecural wigth polyethylene tibial component based on geometrical measurement from a retrieved knee prosthesis“, Journal of Engineering in Medicine, Vol. 213, pp: 251 - 259, 2004.
[6] D.J. van den Heever, C. Scheffer, P. Erasmus, E. Dillon, “Contact stresses in patient-specific unicompartmental knee replacement“, Clinical Biomechanics, Vol. 26, pp: 159 - 166, 2011.
[7] H. Oonishi, M. Ueno, S.C Kim, H. oonishi, M. Iwamoto, M. Kyomoto, “Ceramic Versus Cobalt – Chrome Femoral Components; Wear of Polyethylene Insert in Total Knee Prosthesis“, The Journal of Arthoplasty, Vol. 24, pp: 374 - 391, 2009.
[8] J. Shi, “Finite element analysis of total knee replacement considering gait cycle load and malaligment“, PhD Thesis, University of Wolverhampton,2007.
[9] Ž. Stepanović, M. Živković, S. Vulović, Lj. Aćimović, B. Ristić, Z. Grujović, “Visoka, otvorena, klinasta osteotomija tibije: analiza pet modaliteta unutrašnje fiksacije metodom konačnih elemenata“, Vojnosanitetski pregled, Vol. 68, pp: 867-871, 2011.

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MULTI-CRITERIA EVALUATION AND SELECTION OPTIMAL MANUFACTURING PROCESSES OF THE BODY ENDOPROSTHESIS HIP JOINT

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Abstract: *Modern production of implants is based on the use of flexible manufacturing technologies and direct manufacturing technologies such as Rapid Tooling-RT, Rapid Prototyping-RP, Rapid Manufacturing -RM, Reverse Engineering-RE, supported by appropriate CAD/CAM/CAE and other CAx systems. In both groups these technologies are possible different technological solutions, in terms of selections a combinations manufacturing process of blanks and their processing. For selections the most suitable manufacturing processes of the implant can be used the methods of multi-criteria decision making. This paper presents the results of multi-criteria evaluation and selection of the best manufacturing process of the body endoprosthesis hip joint, by using the developed conceptual CAPP system.*

Key words*: Multi-criteria evaluation, Manufacturing processes, Endoprosthesis hip joint, CAPP*

1. INTRODUCTION

Level development of the manufacturing technologies, on the one hand, and characteristics demand of modern markets, on the other hand, determine the basic tasks of modern manufacturing, where the question is no longer "Is it possible to manufacture something?" than "What is the optimal manufacturing process?".

Implants used in medical prosthetics according time of application may be temporary or permanent, while according design and manufacturing aspects can be modularity "ready-made", which is usually made serially, namely, individual "custom," according to the characteristics of the patient, which are usually made individually.

Modern manufacturing implants based on the implementation of flexible manufacturing technologies such as casting, forging, machining, and direct manufacturing technologies, such as RP, RT, RM, RE, supported by appropriate CAx systems. In both groups these technologies, possible the different technological solutions in terms of a combination selection manufacturing processes.

For selection the best manufacturing process solutions of product, successfully used method of multi-criteria optimization, namely multi-criteria decision-making (MCDM). In this paper, shown process of multi-criteria evaluation and selection of the best technological solution using the developed conceptual CAPP system, with verification on the example of the body endoprosthesis hip joint..

2. BASIC OF SELECTION MANUFACTURING PROCESSES

Selection of manufacturing process is one of the most difficult decisions in product development and is caused, mainly, economic, organizational, and technological criteria. Therefore selection of the optimal process is reduced to the problem of MCDM [1,2].

Problem of selecting the basic manufacturing processes dealt many author, such as [1] to [4] and other. Figure 1 provides an algorithm selection of basic manufacturing processes, which essentially contain the most important selection stage, common, to most of the developed methodology.

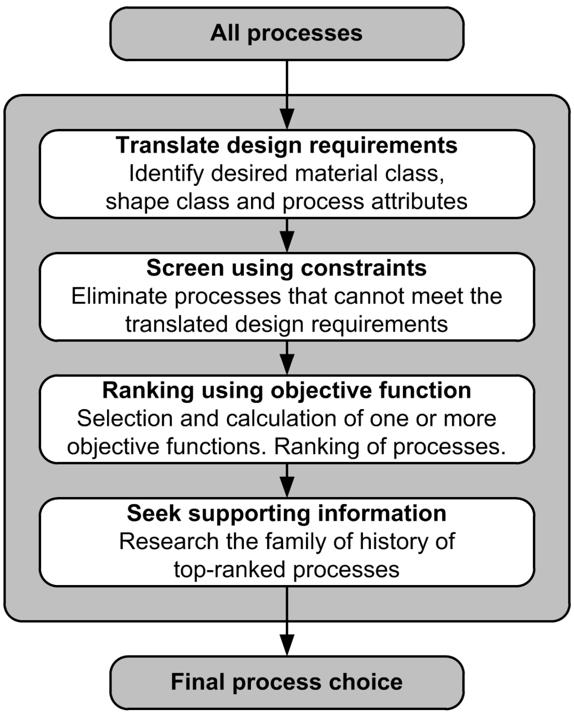

Fig. 1. A flow chart of the procedure for manufacturing process selection [2]

However, development a general model for the selection of the manufacturing process is very complex, due:

- Inability of quantifying all interactions, namely, insufficiently impact of all technologies on the structure and material properties, and inverse,
- Growing number of technologies and processes that are not fully tested and which is not fully known behavior of materials,
- Lack of complete and systematized basic for the selection of technologies and processes,
- Needs of continuous and accurate monitoring,
- "Develop rules", namely, using artificial intelligence and knowledge base in decision making.

3. DEVELOPMENT MODULE FOR SELECTION AND EVALUATION OF BASIC MANUFACTURING PROCESS

According to developed general and functional model of manufacturing preparation of production [5] in the conceptual design stage of manufacturing process planning realized four basic activities: *manufacturability of product design, selection of basic manufacturing processes, selection of basic manufacturing resources, and estimates of time and cost of manufacturing*. Based on this model is developed and an appropriate conceptual CAPP system, namely, DfM software solution, in which one of the modules related to the selection and evaluation of basic manufacturing processes.

Within the developed software solution observed modules, solve tasks related to the definition and selection of possible basic manufacturing process of parts, as well as evaluation, namely, evaluation and ranking of alternative variants of the manufacturing processes. The basic algorithmic structure this module shown in [5,6].

Basic substrate for development of this module is related to the implementation two key stages, second and third, as shown in Figure 1. In the *feasible stage* (stage 2), established the rules for the selection process based on the certain criteria, such as type of part material, economical application processes for the planned production volume, and based on manufacturing quality, accuracy, productivity, cost, etc.

After the elimination process that do not meet the criteria, implement the *optimization stage* (stage 3), which is performed evaluation and ranking manufacturing processes. In observed case is adopted an system for evaluate manufacturing processes by ASM (American Society for Metals) [3], which includes the following evaluation criteria W_i: (A) cycle time, (B) process flexibility, (C) material utilization, (D) quality/reliability and (E) operating costs.

Evaluation of processes (WRV) is performed according to formula (1), from which will determine the order of importance of the processes and their ranking.

According to the literature data [1] to [3] and other, defined weighted evaluation of the processes (P_i) for observed criteria A÷D.

$$WRV = \sum_{i=1}^{n} (P_i) \times (W_i) \qquad (1)$$

- *WRV* – weighted rank values of the processes,
- *n* – total number of criteria,
- P_i – weighted evaluation processes for certain criteria,
- W_i – weight coefficient of criteria.

Defining weight coefficients mentioned criteria (W_i), in the observed software solution can be implemented in two ways:

a) Normalization freely estimated weighted values of weights, and
b) Mutual comparison criteria and calculation of normalized weights using the methodology which is applied to the AHP method [7].

4. MULTI-CRITERIA EVALUATION AND SELECTION MANUFACTURING PROCESSES OF BODY ENDOPROSTHESIS

Account of evaluation and selection the best variant of the manufacturing process of body endoprosthesis for set requirements was performed from multi-criteria evaluation and ranking process in the module for the selection and evaluation of basic manufacturing process, as well as from estimates of manufacturing costs under the same name of a module in conceptual CAPP system, while in this paper shown only the first one.

Basic input data for a software solution conceptual CAPP system refer to data from the drawings of body endoprosthesis hip joint, BB2, Figure 2. On this figure was performed and selection of an appropriate modules of software solution.

Fig. 2. Input mask in conceptual CAPP system

In order selection the possible variants of the manufacturing process of the body endoprosthesis hip joint, entered the appropriate input data, Figure 3:

- Type of material: Stainless steel,
- Volume of production: Variant 1 (1-100 pcs/yr.) individual to small-scale production and Variant 2 (100-1000 pcs/yr). medium to large mass production,
- Required productivity: low to 10 (pcs/hr.),
- Dimensional accuracy - level of tolerance dimensions: high (<0,13mm),
- Quality of surface finish: high (<Ra=1,6), and
- Basic form of the part: 3D

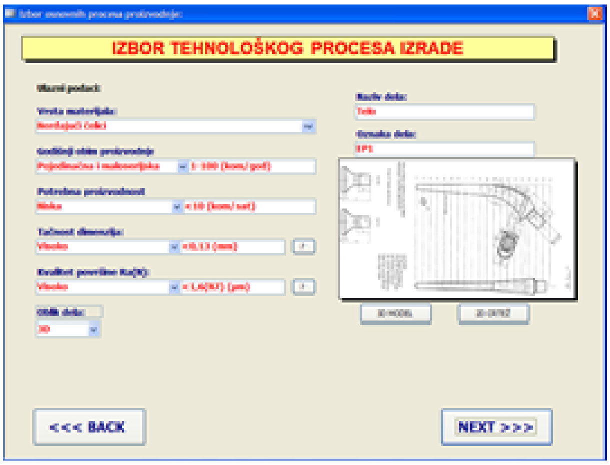

Fig. 3. Input data in module for the selection of basic manufacturing process solution

Figure 4 shows result of selection basic technological solutions for set criteria to variant 1, which are taken into account possible technological solutions for higher levels of production, corresponding to variant 2.

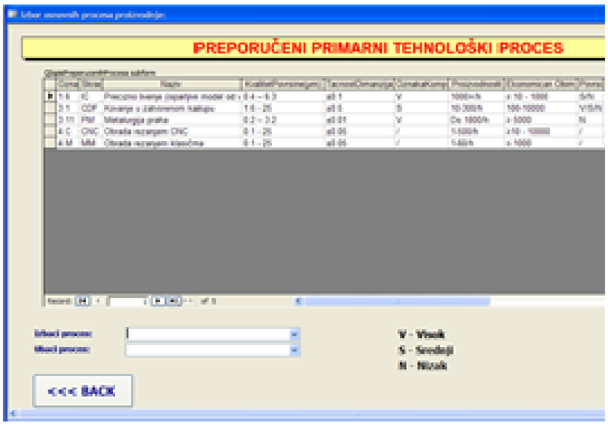

Fig. 4. Alternative basic manufacturing technologies of body endoprosthesis

Figure 5 presents entered weighted values and calculated normalized values weights for evaluating alternative manufacturing process of body endoprosthesis, according to the method (a). Figure 6 presents relative evaluation criteria and calculated values of weight for evaluating alternative manufacturing process of body endoprosthesis, according to the method (b). In both, with defining the weights, evaluation was performed for the amount who correspond to the variant 1.

After defining the weights for the evaluation processes, perform the calculation of the weighted process rank, WRV, according to formula (1). Figure 7 shows outputs of evaluating alternative manufacturing process of body endoprosthesis, in case when the applied method (a), defining the weights values, according to Figure 5.

Fig. 5. Calculation of weights for the evaluation alternative solutions – method (a)

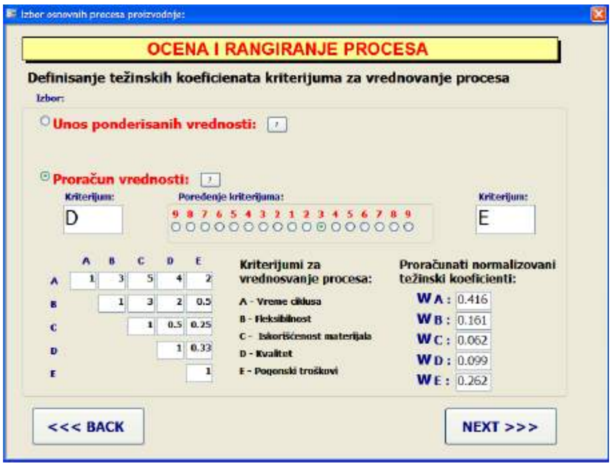

Fig. 6. Calculation of weights for the evaluation of alternative process solutions - the method (b)

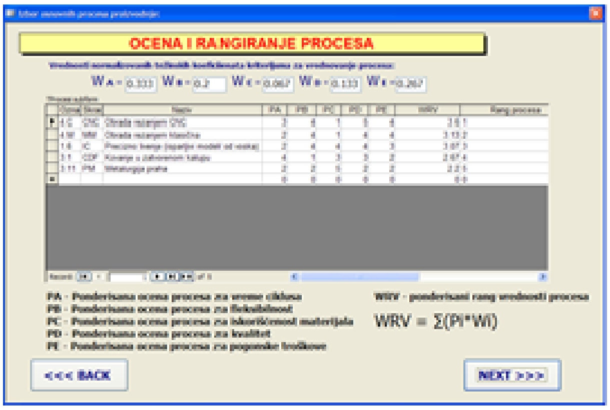

Fig. 7. Results evaluation and ranking alternative manufacturing process of body endoprosthesis

Similarly, in Figure 8 shown outputs ranking alternative manufacturing process planning of body endoprosthesis, for case when applied another way of defining the weights, according to Figure 6.

Fig. 8. Results evaluation and ranking alternative manufacturing process of body edoprosthesis

4. CONCLUSION

Process planning is one of most important activities in the development of quality products, reduce the time and cost of production. This paper briefly presents the basic foundation for the development software solution module for multi-criteria selection process, as piece of the conceptual CAPP systems, and its application for the selection of the optimal manufacturing process planning of the body endoprosthesis.

Based on the obtained results it can be concluded that is for the given manufacturing conditions best option manufacturing on CNC systems, which is also confirmed and applying in modules for cost estimation.

Acknowledgments:: This paper is part of a research on project "Modern approaches to the development of special bearings in mechanical engineering and medical prosthetics," TR 35025, supported by the Ministry of Education, Science and Technological Development, Republic of Serbia.

REFERENCES

[1] CREESE, R.C., “Introduction to Manufacturing Processes and Materials”, Marcel Dekker, Inc., New York, 1999, ISBN 0-8247-9914-3.

[2] ASHBY, M.F., “Materials Selection in Mechanical Design”, Butterworth-Heinemann, 2005. ISBN 0-7506-6168-2.

[3] ASM Handbook,“Material Selection and Design, Vol. 20”, ASM, Ohio, 1997, ISBN 0-87170-386-6.

[4] BOOTHROYD, G., DEWHURST, P., KNIGHT, W., “Product Design for Manufacture and Assembly”, 2nd edition, Marcel Dekker, New York, 2002, ISBN 978-0824705848.

[5] LUKIĆ, D., “Development of a General Technological Preparation of Production Model”, Doctoral thesis, University of Novi Sad, Faculty of Technical Science, 2012.

[6] LUKIĆ, D., TODIĆ, V., MILOŠEVIĆ, M., JOVIČIĆ, G., VUKMAN, J.,“Software Development for Conceptual Process Planning”, 11th DEMI, Faculty of Mechanical Engineering, Banja Luka, 2013, pp. 375-381, ISBN 978-99938-39-46-0.

[7] SAATY, T.L.,“Multi-criteria Decision Making: The Analytic Hierarchy Process”, Pittsburgh, PA: RWS Publication, 1990, ISBN 978-0962031724.

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ANALYSIS OF DEVELOPED SOFTWARE SYSTEMS FOR STEP COMPLIANT MANUFACTURING

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Abstract: *Rapid advancement of information technologies related to NC technology, production environment has significantly changed in the last decade of the 20th century. Standard ISO 6893, which is still used as a link between CAM and CNC systems are now represent an obstacle to global, collaborative, and intelligent manufacturing. The development of various CAD/CAPP/CAM/CNC systems within the CAx environment have created a prerequisite for the exchange of standard data models, to allow for the integration of data between the machine tool and control systems from different manufacturers. In order to remove the obstacles effluent from the ISO 6893 standard, as well as various defects so far developed standards for data exchange, was approaches in internationally developing better quality standards for the exchange of information. The result of this efforts represent the development of a STEP (ISO 10303) standards, as well as its extension to the numerical control STEP-NC. In this paper present an overview of the research developed CAx systems based on the STEP standard, namely STEP compliant CAD/CAPP/CAM/CNC systems.*

Key words*: STEP, STEP-NC, CAD/CAPP/CAM/CNC systems.*

1. INTRODUCTION

Development of different CAD/CAPP/ CAM/CNC systems within the CAx environment, created conditions for the exchange of standard data models, in order to enable the integration of data between the machine tools and control systems from different manufacturers. Since the appearance of CAD and CAM systems there was a need for an effective method for data exchange between different CAx systems. The first effort for data exchange has been made to framework AECMA (Aircraft European Contractors Manufacturers Association), during which was attempted to solve the problem of different mathematical interpretations of the same geometrical surface by introduction first common commercial format for data exchange. Among the first standards for exchange of CAD information was IGES standard. After IGES was developed and VDA-FS standard by the German automobile manufacturers association and then a number of other standards for data exchange, such as SET, DXF, EDIF, PDES, etc. Various disadvantages of IGES and VDA-FS standards, as well as other standards that have been developed for data exchange, was resulted approaches that development better standards for exchange of information in the international frameworks. Standard PDES (Product Data Exchange Specification) was proposed by the ISO TC 184/SC4 (Technical Committee 184/ Subcommittee 4), and was considered as the basic for what is now known as ISO 10303 [2], namely STEP standard.

STEP standard is designed so that represent the whole life cycle of a product. However, the current development of STEP oriented primarily on data concerning at product design information, with minor turn on manufacturing, and in particular on CNC machining [1].

In the last fifteen years, significant efforts have been invested in the development of new standards based on STEP, in order to bridge the gap between the information of CAD/CAPP/ CAM and CNC systems. This new standard is defined as ISO 14649, namely STEP-NC [3].

This paper presents a short review of individual developed prototype systems based on STEP-NC.

2. FORMAT BASIC OF STEP-NC STANDARD

STEP-NC has been developed with the aim of providing a data model for a new type of intelligent CNC controllers. The purpose of STEP-NC data model is to provide standardized data requirements for machining processes that are related with CNC machining system. STEP-NC standard represents an extension of the STEP standard and allows connection between STEP-compliant CAx and CNC systems *[4]*. Within the ISO organization, two different subcommittees, SC1 and SC4 of TC 184, have contributed to the development of this standard. SC1 is related on control of machines, while SC4 is related on industrial data. Between SC1 and SC4 there is natural overlap, since numerical control programs for machining are data for the control of industrial machines. ISO 14649 was developed by subcommittee SC1 and his models are written using the EXPRESS language and they are represented as Application Reference Model (ARM), in which use domain terminology to describe machining *[5]*. Subcommittee SC4, which is also known as STEP-manufacturing group, has adapted ISO 14649 as an ARM model for the application protocol ISO 10303 AP-238. Both, ISO 10303 AP 238 and ISO 14649, are commonly represent “STEP-NC” *[6]*. Unlike ISO 14649, which is divided into separate parts, AP 238 incorporates the equivalent all parts of ISO 14649 (except Part 1) with a few modifications in a single model. The model is then mapped to the STEP integrated resources to obtain an implementation model — the Application Interpreted Model (AIM). STEP-NC standard allows bi-directional data flow between CAD/CAPP/CAM and CNC systems, without any loss information, Fig. 1 [7]. STEP-NC does not describe tool movements for specific CNC machine tool, as it is the case with the G-code, but provides a feature based data model [8].

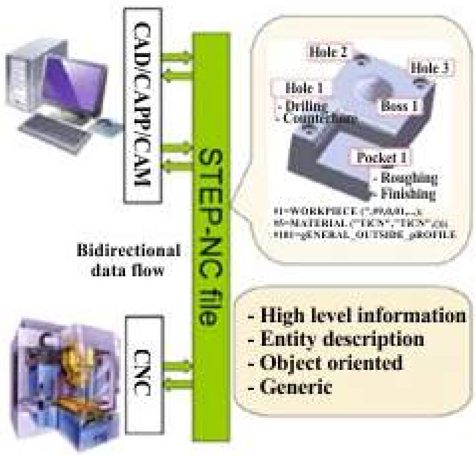

Fig. 1. Integration of CAD/CAPP/CAM and CNC systems by STEP-NC standard

3. OVERVIEW OF DEVELOPED SYSTEM FOR STEP COMPLIANT MANUFACTURING

STEP-NC is created as a result of several research projects that have been conducted by various companies and research institutions. One on the earliest international research projects for the development of STEP compliant system was a project OPTIMAL, which was based on feature information and machining strategies.

After OPTIMAL project, ensued various research that are conducted by major research groups around the world, and which are dealt with the application STEP-NC to integrate CAD, CAPP, CAM and CNC systems [9]. In the framework of this research, were realized projects: IMS STEP-NC; ESPRIT STEP-NC; Super Model project; STEP Manufacturing Suite (SMS); Rapid Acquisition of Manufactured Parts (RAMP); Intelligent manufacture for STEP-NC compliant machining and inspection with more technical insight [10].

Also, conducted researches of research groups from different countries, such as: Germany, USA, Korea, New Zealand, etc. Table 1 [11] shows some of the most important research in this area.

In the next chapter shown a short analysis of developed system for STEP compliant manufacturing, with particular turn on systems oriented for turning.

Table 1. Review of developed systems for STEP compliant manufacturing

No.	System	Year	Country
1	AB CAM (CAPP)	2002	UNITED KINGDOM
2	PROSFP (Milling) Shop Floor	2003	KOREA
3	STEPTurn (CAPP) (Turning)	2006	GERMAN
4	WOPTurn Shop Floor	2006	GERMAN
5	TurnSTEP (Turning)	2006	KOREA
6	STEPcNC	2006	NEW ZEALAND
7	G2STEP	2007	KOREA
8	Step Reader	2008	INDIA
9	SCSTO	2009	UNITED KINGDM

4. ANALYSIS OF DEVELOPED SYSTEMS BASED ON STEP

One of the first systems based on STEP, which refers to machining rotating parts, namely for turning process was STEPTurn, Fig. 2 STEPTurn has been developed at the Institute for Control Engineering of Machine Tools and Manufacturing Units at the University of Stuttgart (ISW), Germany [12]. Generally speaking, STEPTurn represent CAPP system, which bridging the gap between CAD and CAM systems. The system can accept and read geometry data from STEP AP-203 Part 21 and then performing process planning tasks, in terms of feature recognition and define Workingstep sequencing, with the aim of defining the STEP-NC physical file.

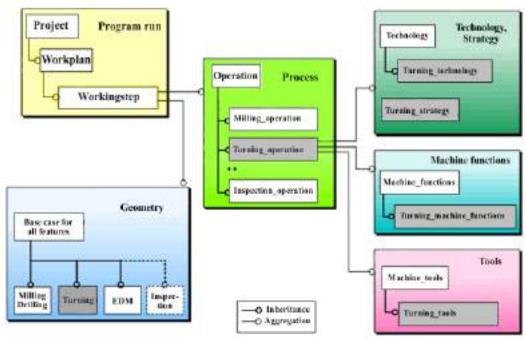

Fig. 2. Basic elements of STEPTurn model for turning

One of the earliest STEP compliant system for turning process based on STEP-NC data model was developed by POSTECH (Korea) and ISW, and called TurnSTEP [13], Fig. 3. TurnSTEP is intended to support intelligent and autonomous control of NC machines for e-manufacturing. The main purpose of TurnSTEP was to test the validity and effectiveness of the STEP-NC data model for turning and to support intelligent and autonomous execution of NC machines by fully utilizing rich STEP-NC information. Additionally, it has a role to optimize the machining sequence of a target manufacturing process, as well as provide to support automated and interactive generation of process plan utilizing feature recognition, alternative generation of process sequences, cutting conditions, etc., and finally to provide a variety of data interfaces for e-manufacturing including physical file and XML translation capability. TurnSTEP consists of three functional systems [13]: code for generation system; code for edit system and autonomous control. The main disadvantages of this system is the impossibility of automatic recognition threading and what the content of the process planning must edit manually by user.

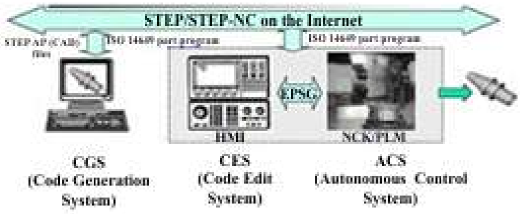

Fig. 3. Three functional system of TurnSTEP

The following system which was developed, it was from Siemens and called ShopTurn [13]. It represents programming on Shop-floor Programming System (SFPS) which is integrated into the Siemens CNC systems. Initially, it was developed for single spindle CNC lathe with 2 axis control, X and Z axes. The main purpose of ShopTurn system is CAM oriented programming for turning machines that makes it easy for users to operate and facilitate programming at the CNC turning machine. Siemens have extended their standard ShopTurn to enables STEP-NC part 21 physical file to be read and interpreted by a STEP-NC interface in the Siemens ShopTurn System. After converted through the interface the workingsteps and other STEP-NC data is processed as a standard ShopTurn program. ShopTurn supports C axis and Y axis machines together with a counter spindle, thus enabling complete machining implementations with the STEP-NC have only been reported for standard rotational parts [13].

Authors of the paper [14] have developed a process planning system (PPS), Fig. 4. This system consists of five modules: program reader; process planner; STEP-NC CAD viewer; STEP-NC viewer and program writer. In the module of process planner, project optimization is achieved by adjusting specific parameters and workingstep sequences, etc. Process planning has numerous criteria that can affect on the implementation of the process (e.g. minimum processing time, costs, etc.). To limit the significance of this research, the surface roughness has been chosen as the object of optimization. By using a mathematical model, users compare the different machining strategies with different parameters (e.g. feeds, tool selection, etc.). The required toolpath of the machine is generated by the toolpath generator. The planned toolpath can be shown and evaluated in the STEP-NC CAM viewer. The basis of PPS consist of STEP-NC data and consequently, the system contains other function modules including program reader, program writer and the STEP-NC CAD and CAM viewers. Input in the system starting with STEP-NC Part 21 file, then the data reader checks and translates the file into an internal data format (Java Array List).

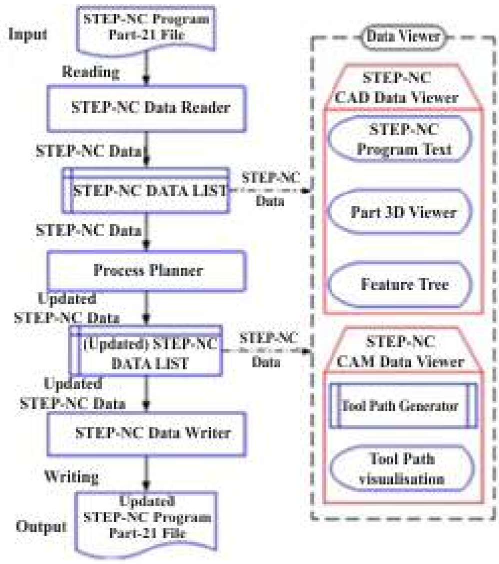

Fig. 4. Architecture of the PPS system

System G2STEP [15] was been created by joint work with researchers from National Research Laboratory for STEP-NC, POSTECH in South Korea and researchers from the university EPFL (École Polytechnique Fédérale de Lausanne) in Switzerland. This system is based on the ISO 14649 data model, the ARM model and instruction schema on G-code based on the FANUC0 series. The main proposal for G2STEP is to generate a STEP-NC part program from a G-code program with additional information related to real machining that is easily generated by skilled operators. G2STEP has been developed for 2-axis CNC Turning using the C++ language and runs on a Windows platform used a geometric modeling kernel and OpenGL for the Graphical User Interface (GUI). This system consists of four function for: pre-processor generation; machining operation generation; feature recognition and machining strategy. G2STEP was verified through the NC Virtual Software by DELMIA.

STEP compliant system for turning operations (SCSTO) was developed by the authors [16], using JBuilder 2005 and the JDataStore database. Its main tasks and functions are divided into definition of the: (i) workpiece, (ii) manufacturing features, (iii) turn/mill operations, (iv) project set-up, (v) functional/technology, (vi) manufacturing strategies, (vii) placements/lengths and (vii) tools. The implementation of SCSTO consists of three main stages: (i) representation of the information model, (ii) development of the tool database, and (iii) construction of the system application, according to Fig.5.

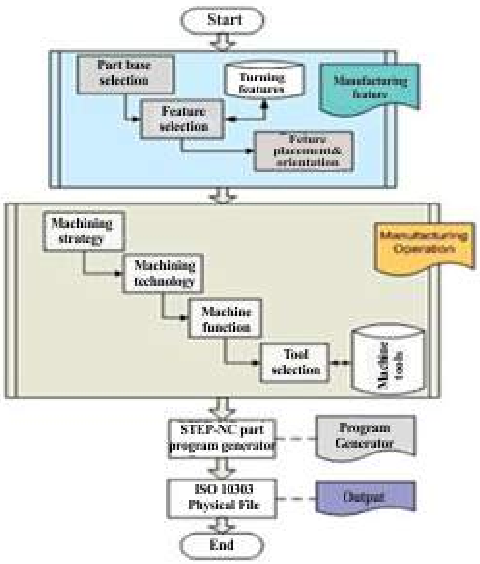

Fig. 5. Operational structure of SCSTO system

The next system applies to STEP compliant system for Turn-mill operation using XML, which was developed by the authors [17], with universities in Malaysia. This system aims to generate ISO 14649 code of feature based process plans for turning and milling operation on the basic of STEP compliant environment. Also, this system consists of STEP-AP 224 elements that define turning, milling and drilling or all 2.5D (2.5D-extruding 2D feature along third direction) manufacturing features. This system implements feature based design approach and begins with selection of workpiece by selection of 2.5D manufacturing feature, machining operation, machining strategy and finally the selection the tools. The output from this system represents a physical file complying with ISO Part 28 file. The system is developed on Visual Basic dot Net and SQL server database. It generates STEP-NC entities that defines or translate workpiece and workplan data in XML file [17].

SPAIM (STEP-NC Platform for Advanced and Intelligent Manufacturing) platform was developed by the authors of the paper [8]. It can be implemented on most of the current industrial CNC controllers and enables them to read and treat STEP-NC files that build according to ISO 14649 Norm. SPAIM platform has already been implemented and validated on high speed machining (HSM) machine tool. One such machine tool was designed by the Fatronik Company and is named “VERNE“. Machine tool has parallel kinematics architecture and is equipped with Siemens Sinumerik 849D CNC controller. Another version of SPAIM has been developed for a Hermle C30U center equipped with a Heidenhain CNC controller. Architecture of SPAIM platform is composed of a human/machine interface (HMI) and several modules for translating STEP-NC data into explicit workplan and toolpaths for each manufacturing operation [8].

The authors [18] have developed a system SNC6Kturn. System is consists of three levels: input level (in a form of the STEP-NC file), NC level and signal level. The input level consists of three elements; STEP-NC manager, shop floor programming (SFP) model, and report module. NC level represent NC-machining (NC-M) module, and the signal level represent a closed-loop servo system.

The authors [19], was developed feature based system for CAD/CAM integration through STEP file for cylindrical parts. This system consists of four major parts: creation of CAD model; extraction of feature data from STEP file; turning of parts using generated NC codes and inspection using CMM for validation.

The authors [20], was developed a system for the design of rotating parts using feature that are defined in STEP AP-224 and with automatic generation of NC code. The system consists of two main phases: phase based on the modeling feature and phase related to the development of NC generator.

Also, the authors of [21] have developed an automated system for process planning from STEP AP-203. This system consists of two modules: feature recognition and setup planning module. STEP AP-203 file defining 3D model components which are taken as input in the system. Various features are recognition using hybrid feature recognition.

There are systems that are still valid in the development, such as, design a system and database for automated machining feature recognition. Also, some authors have dealt with the development of a system for recognition features in rotational parts using STEP, where they developed algorithms to recognize various feature, such as cylindrical surface, conical surface, toroidal surface, radial holes, axial holes, and special features like threading. Some authors have dealt with methods for conversion from design feature to machining features based on STEP-NC, namely development algorithms for feature conversion manufacturing feature. All these developed systems represent the most academic research, because manufacturers are still using conventional CNC programming.

5. CONCLUSION

The application of STEP-NC in the industry has not yet received its important application. The main reason for this is the fact that manufacturers CAM system must apply an interface that write the STEP-NC data, on the other hand CNC machine tool manufacturers have to apply an interface to read data. In terms of application, the STEP standard is found and is commonly used in CAD systems. Application of STEP, namely STEP-NC in CAM systems, not so far found a wide application in industry, as is the case with STEP AP 203/AP214. In terms of CAD /CAPP/CAM systems, the biggest problem, for now, represent ways of features recognition from CAD to CAM systems, and on that single machining process on CNC systems.

REFERENCES

[1] *ISO 10303-1.“Industrial Automation Systems and Integration-Product Data Representation and Exchange Part 1. Overview and Fundamental Principles“, International Organization for Standardization, Geneva, Switzerland, 1994.*

[2] *Rosso-Jr. R.S.U., Newman, S.T., Rahimifard, S.“ The adoption of STEP-NC for the manufacture of*

asymmetric rotational components", Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 2004.

[3] *ISO/FDIS 14649-1. "Industrial Automation Systems and Integration—Physical Device Control—Data Model for Computerized Numerical Controllers—Part 1. Overview and Fundamental Principles", International Organization for Standardization, Geneva, Switzerland, 2002.*

[4] *ISO 10303-240: "Industrial automation systems and integration – Product data representation and exchange – Part 240". Application Protocols: Process plans for machined product, ISO Geneva, 2005.*

[5] *Hardwick, M. Et al." A roadmap for STEP-NC-enabled interoperable manufacturing", Springer-Verlag, London 2013.*

[6] ISO 10303–238: "Industrial automation systems and integration—product data representation and exchange—Part 238", application protocols: application interpreted model for computerized numerical controllers, 2004.

[7] Lukic, D., Todic, V., Zeljkovic, M., Milosevic, M., Vukman, J., Jovicic, G. "The possibility and significance of application STEP-NC standard in the integration CAD/CAPP/CAM and CNC szstem", 11th International scientific conference, Novi Sad, 2012.

[8] Rauch, M., Laguionie, R., Hascoet, Jean-Yves, Suh, Suk-Hwan, "An advanced STEP-NC controller for intelligent machining proccess", Robotics and Computer –Integrated Manufacturing, 2012.

[9] ESPRIT, "Project 8643, Optimized preparati on of manufacturing information with multi-level CAM – CNC coupling (OPTIMAL)", final report for publication, 1997.

[10] Yusof, Y., Newman, S., Nassehi, A., Case, K." Interoperable CNC System for Turning Operations", World Academy of Science, Engineering and Technology, 2009.

[11] Yusof, Y., Nurul, Z.Z.T, Kassim, N." ISO14649 Code Generator for Intelligent Manufacture for STEP-NC Compliant Machining", APIEMS, 2009.

[12] Heusinger, S. "ISO 14649 STEP-NC; Data model and implementation for turning in Germany", 2002.

[13] Yusof, Y., Rosso-Jr., R.S.U., Case, K., Newman, S.T. " The design of a STEP-NC compliant CAD/CAPP/CAM system for the manufacture of rotational parts on a CNC turning centre", http://www.joinville.udesc.br/portal/professores/roberto/materiais/03_imc23p55.pdf; available 27.08.2013.

[14] Zhang, X.; Liu, R.; Nassehi, A.; Newman, S.T. "A STEP-compliant process planning system for CNC turning operations", Robotics and Computer Integrated Manufacturing, 2011.

[15] Shin, S.J., Suh, S.H., Stroud, I."Reincaration of G-code based part programs into STEP-NC for turning applications", Computer Aided Design, 2007.

[16] Yusof, Y."STEP-NC-Compliant Systems for the Manufacturing Environment" World Academy of Science, Engineering and Technology, 2009.

[17] Gizaw, M., Rani, A.M.B.A., Yusof, Y. "Design of a STEP-compliant system for Turnmill Operations using XML" Journal of Applied Science, 2011.

[18] Habeeb, S., Xu, X. "A novel CNC system for turning operations based on a high-level data model", Int J Adv Manuf Technol., 2009.

[19] Sivakumar, S.. Dhanalakshmi, V. "A feature-based system for CAD/CAM integration through STEP file for cylindrical parts", Indian Journal of Engineering and material science, 2013.

[20] Akkuş, K. "Design of rotational parts using step ap224 features with automatic NC code generatio"; PhD thesis, 2011.

[21] Rameshbabu, V., Shunmugam, M.S., "Hybrid feature recognition method for setup planning from STEP AP203",Robotics and Computer Integrated Manufacturing, 2009.

Acknowledgement: This paper is part of a research on project "Modern approaches to the development of special bearings in mechanical engineering and medical prosthetics," TR 35025, supported by the Ministry of Education and Science, Republic of Serbia.

35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
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ANALYSIS OF MACHINING STRATEGIES USING COMMERCIAL CAD/CAM SOFTWARE

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Abstract: *The choice of CAD/CAM software has a profound effect on efficiency, and therefore cost of production. Commercial CAD/CAM softwares have possibility to choose of machining strategies. The paper presents the analysis of the strategy of machining of the same part to define criteria by which to be exercised in selecting the most most adequately optimization strategy and a comparison of a given software with previous versions.*

Key words*: CNC machining*

1. INTRODUCTION

Machine parts with free form surfaces often appear in the engineering practice as a result of functional and aesthetic requirements. The machining of such parts is mostly done by milling. Precision and surface quality and productivity mainly depends of tool path which designed the main task of CNC machining. Due to the increasing competition in the market, it is crucial reduced processing time and cost without sacrificing the quality of the machine part. Machining of the free form surfaces is timed and expensive process, and the process of finishing may represent up to 75% of the total cost of machining. In the case of this machining it is necessarily use a CAD/CAM software how to the surface defined analytically, on the ground that generate the appropriate tool path. As one of the criteria for the selection of machining strategies might be cutting forces, with the aim for minimizing the machining time without violate required tolerances and quality of machined parts. Special attention represent machining with ball mills. Ball mill is not the best choice because they are changing the machining parameters, and there are times when the cutting speed is zero, which is reflected in the cutting process and surface quality [4].

Fig. 1 shows the 3D models of the parts on which examples will make an analysis of the election strategy of machining. To create CAD models and to create NC code it is used a software package Creo Parametric 2.0. The upper part is used for analytes machining strategy, while the other two used for comparison with the previous version of the software. The analysis includes only 3–axial machining.

2. DEFINING THE PROBLEM

If we analyze the geometry of the parts, and taking into account that the machining performed ball mill is easy to see where the problems occur, or that places can not be machined. In fact, if the want to machined a sharp edge at that location will remain the fillet radius of the cutter. For convenience this is shown on Fig. 2 where we have shown details which can be occurs an machining error. Detail marked with A can not be machined with cutter larger than 10 mm because the holes diameter is equal 10 mm, and detail marked B is unable to machining with ball mill.

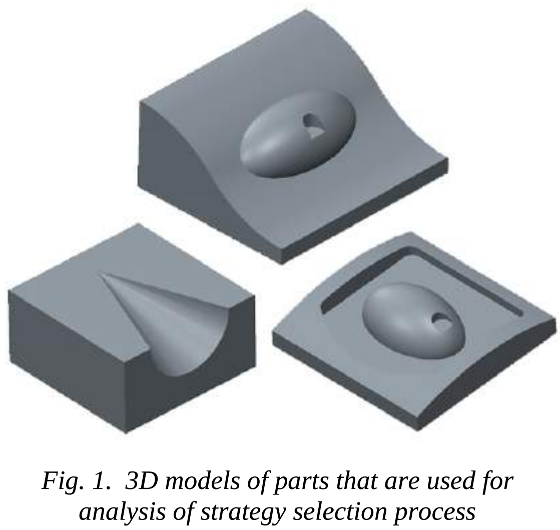


Fig. 1. 3D models of parts that are used for analysis of strategy selection process

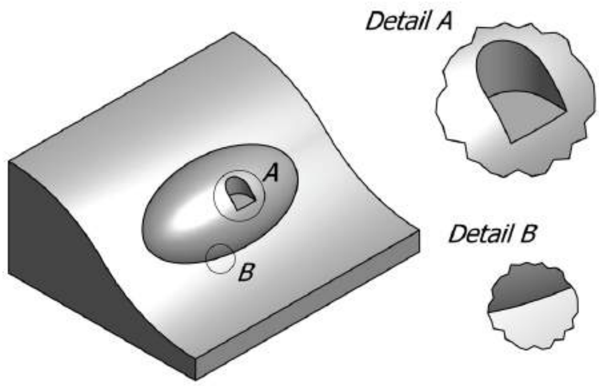


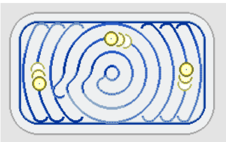
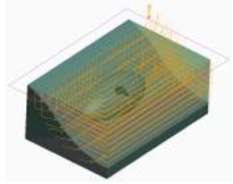
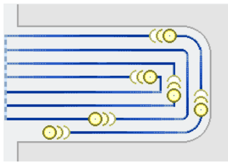
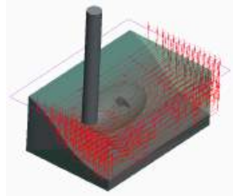
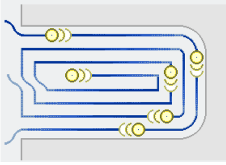
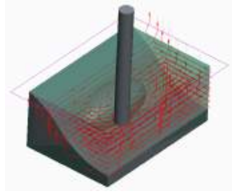
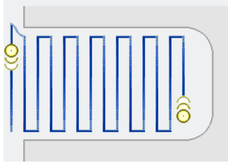
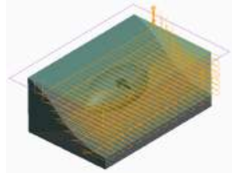
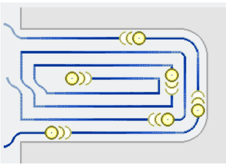
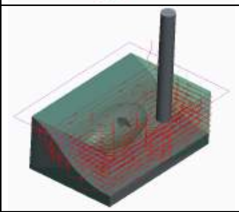
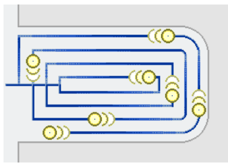
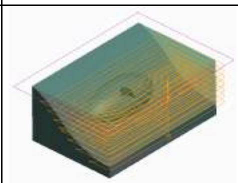
Fig. 2. Places that can not be machined with chosen tool and strategy.

As the problem is defined, it is now to analyse capabilities of the chosen CAM software. There will be variations of machining strategy and also the tool diameter. It is necessary to mention that is not impossible to machining given part as required, but it's suggested analysis of ball mill and 3–axial machining so that the analysis is limited to this case of machining.

3. ANALYSIS OF MACHINING STRATEGY

Here is an analysis of the strategy of machining for machine part from Fig. 2, using the software package Creo Parametric 2.0. Given software has a choice of machining strategies, such as volume milling, trajectory milling, rounghing, surface milling, holemaking, etc. For a start will be made rounghing that will work by end mill with 12mm diameter with diferent machining strategies. Table 1 shows the different machining strategies with drawings of scan type and machining times. Parameters for this analysis was: cut feed 80mm/min, step over 5mm, max_step_depth 5mm, spindle_speed 1000 o/min. Appendix for finishing was 0.5 mm.

Table 1. Variation of roughing strategies

N^0	Scan type	Toolpath	Time [min]	N^0	Scan type	Toolpath	Time [min]
1	 constant_load		263.65	4	 follow_contour		285.52
2	 maintain_cut_dir		143.87	5	 type_3		177.60
3	 maintain_cut_type		146.73	6	 type_spiral		149.77

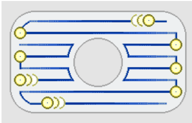
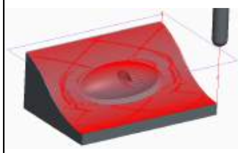
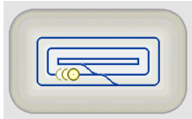
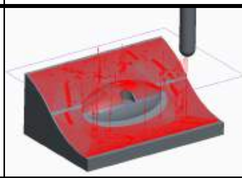
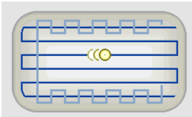
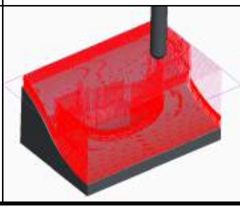
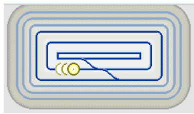
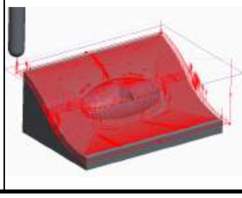
Based on the data from Table 1 can be clearly seen that with the same tool and cutting parameters, we obtain different machining times for different machining strategies. Analyzing the roughting of machine part can be concluded.

- Selecting the strategy of constant cutting force ($N^0$1) obtained greater machining time.
- Selection strategy follow_contouur ($N^0$4) get something smaller machining time, but higher than the minimum time because the tool after one pass must be drawn to the retract planeand after that must further re-pass the contour.
- Also, the choice of strategy type_3 ($N^0$5) where cutter movement is parallel to a plane of the coordinate system of the machine gets bigger machining time than minimum time. because after the tool pass of mentioned planes tool must eventually pass the whole contour.
- The shortest machining time is obtained by selecting a strategy maintain_cut_dir ($N^0$2) that follows the cut direction where no case as in the previous strategy that the tool finally pass the whole contour because he did it in the first pass.
- The other two strategies ($N^0$3 and $N^0$6) provide a bit larger machining time than the minimum time.

For fine machining strategy it is used a method of SURFACE MILLING ($N^0$1) and the FINISHING ($N^0$2–4) with a variation of machining strategies. The results are shown in Table 2 where can see the tool path obtained with processing times. Parameters for this analysis was: cut feed 80mm/min, step over 0.5mm, spindle_speed 1200 o/min. The tool was in all cases ball mill with 10mm diameter.

Looking at the results shown in Table 2 may be conclude the following: Depending on what's the criteria for machining, that is what we claim as our objective. If for example the request is the minimum machining time would then be chosen strategies numbered $N^0$1. The difference between this strategy and the other three ($N^0$2–4) is that because surface miling strategy requires hand-selected area that we want to machining, while in the finishing strategy overhang software to calculate the tool path based on defined mill window. Choice of strategy surface milling in parts with many surfaces can lead to difficulties for manual selecting surfaces that we want to machining.

Table 2. Variation of finishing strategies

N⁰	Scan type	Toolpath	Time [min]	N⁰	Scan type	Toolpath	Time [min]
1	 type_3		241.88	3	 shallow_cuts		241.34
2	 straight_cuts		975.22	4	 combined_cuts		393.7

4. COMPARISON WITH PREVIOUS SOFTWARE VERSION

Analyzing machining of the remaining two parts from Figure 1, which is described in [3] can be concluded: new version of the software allows selection strategy shown in Figure 3, in which the main machining time gets 54.92min which is less than the previous strategy described in [3] for the same machining parameters, which is shown in Table 3.

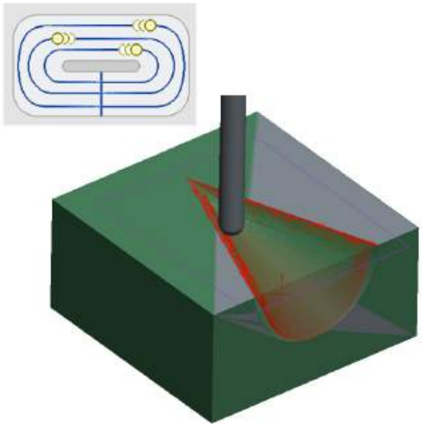
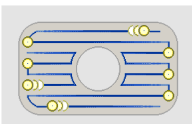
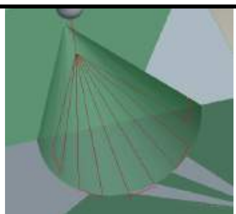
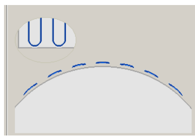
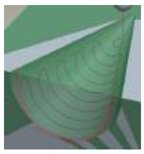
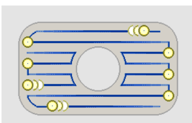
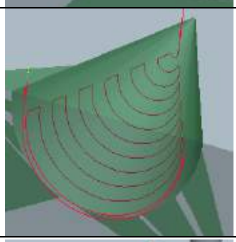
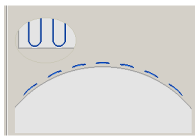
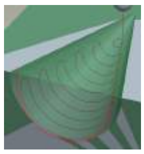
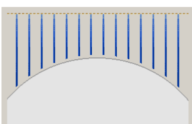
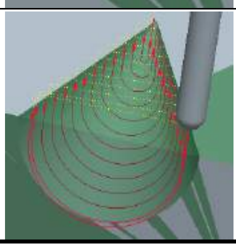


Fig. 3. The machining strategy and obtained tool path.

Table 3. Variation of finishing strategies for part two

N⁰	Scan type	Toolpath	Time [min]	N⁰	Scan type	Toolpath	Time [min]
1			69.9	4			55.1
2			55.4	5			65.3
3			129.72				

The difference between the strategy N^{0}4 were was used cutter 10mm diameter, and in strategy N^{0}5 cutter 6mm diameter and therefore is greater machining time because the tool diameter is smaller so it takes more time to pass the whole contour. For all strategies parameters was: cut feed 100mm/min, step over 0.5mm, spindle_speed 1000 o/min.
Based on the analysis of machining strategies applied to the third part from Figure 1 has not been a strategy with shorter machining time which was described in [3].

5. CONCLUSION

The paper presents analysis possibilities of CAD/CAM software on the example of machininh three parts. It was analyzed the rough and fine machining. Based on the results of the simulation process, it was concluded that the choice of machining strategy significantly affect the precision of production, and the total machining time. In the selection strategy was necessary to choose a strategy in which the tool does not occur to "cut air" because it increases the total machining time. They are also given different machining times for the tools movement in different directions. When talking about the choice of tools should be noted that this choice greatly affects the precision of machining which implies a degree of match of machined part with predefined etalon, in this case the 3D model. That the greater match is achieved by using a cutter with smaller diameter which leads to a reduction in machining parameters, and therefore increase the total machining time. Therefore it is necessary to analyze part and wherever possible choose a cutter with larger diameter. It should be noted that some disadvantages described in the paper can be avoided by using 5–axis machining.

REFERENCES

[1] P. Bojanić: Generisanje putanje alata pri obradi skulptorskih površina na 3 – osnim CNC mašinama loptastim glodalom. Zbornik radova XXXIII Savetovanje proizvodnog mašinstva Srbije, Beograd 2009.

[2] P. Bojanić, G. Mladenović: Generisanje putanje alata po kriterijumu izohrapavosti pri obradi skulptorskih površina na 3 – osnim CNC mašinama . Zbornik radova 36. Jupiter konferencije, Beograd, 2010.

[3] Mladenovic G., Analiza strategija obrade korišćenjem komercijalnih cad/cam softvera", Zbornik radova 37. Jupiter konferencije, Beograd, 2011.

[4] T. Chen, S. Zhiliang, A tool path generation strategy for three-axis ball-end milling of free-form surfaces, Journal of Materials Processing Technology, Vol. 208, 1–3, 2008, pp. 259-263

[5] http://creo.ptc.com/

Rapid prototyping and reverse engineering

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INFLUENCE OF A BUILDING PARAMETARS ON THE ACCURACY OF THE SHAPE AND DIMENSION OF PARTS PRODUCED BY SLS

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Abstract: *Selective laser sintering (SLS) is one of the additive technologies which are used in the Rapid prototyping technologies (RPT), capable of producing durable and functional parts from a wide range of prototype materials. The functional prototypes are wear resistant, durable and chemical resistant. These parts can be made to bend, snap or bolt together and form a flexible hinges. However, parts produced by SLS are poor in terms of accuracy due to the various errors accumulating from data preparation stage to finishing stage. One of the main sources of the size and shape variations of the part is shrinkage during processing of cooling and non-uniform temperature field during parts building. This paper presents the influence of building parameters, part orientations as well and part volume on the accuracy of the size and shape of the parts produced by SLS from polyamide PA2200.*

Key words**:** *Selective laser sintering, Dimensional Accuracy, Shrinkage, Exposure strategy compensation.*

1. INTRODUCTION

Rapid prototyping (RP) is an additive manufacturing process layer by layer. These parts can be made out of common engineering thermo-plastics such as polyamides, ABS, polycarbonate, polyphenylsulfone (PPSF) to metal parts such as titanium, stainless steel and tool steel [1]. Since the delivery of the first commercial machine in 1988, RP has grown as integral part of the new product development process. The use of RP has reduced time to market a product, cut trial costs, and improved product quality by giving design and manufacturing professionals a tool to quickly verify and fine-tune designs before committing these too expensive tooling and fabrication. RP also has some challenges that must be improved upon before it becomes rapid manufacturing (RM) for producing parts in small batches or customized parts. One of the main challenges is part accuracy. This is main concern of industries such as aerospace and bio-medical which would like to use RP technology for producing directly usable products. The capability to produce a part in hours without any tooling is a powerful advantage for many industries. With the stronger plastics and even metallic materials used in some of the RP processes, parts can be produced that will withstand reasonable amount of stress and higher temperature ranges. However the parts produced tend to warp and/or shrink from its given dimensions, forcing the user to run several trials of a part to reach its ideal dimension or settle for a slightly inaccurate part [2]. In order to improve the accuracy of the part, the shrinkage behavior of parts during manufacture needs to be better understood. The work presented in this paper was carried out to investigate the shrinkage behavior of parts produced by one of the RP process namely selective laser sintering (SLS).

2. CHARACTERISTICS OF THE SLS PROCESING

SLS is a powder based RP technology that allows generating complex 3D parts layer by layer. A CAD model, created in any solid modeler, is first tessellated and sliced into layers of 0.02–0.1 mm thickness to get contour information of each layer. This information is used to sinter the selected areas of each layer while producing parts. SLS uses fine powder which is spread uniformly by a roller or a recoater on the machine bed and scanned selectively by a laser of power 25–100W such that the surface tension of the grains is overcome and they are sintered together. At the start of the building process, the building platform is moved to its start position and a bottom layer of plastic powder applied to the building platform. Then the machine is warmed up.

Machine bed with powder is heated to a temperature below the melting point of the material by heaters to minimize thermal distortion and to facilitate fusion to the previous layer. Once the warm up phase is complete, the automatic building process starts. Laser power is adjusted to bring the selected powder areas to a temperature just sufficient for the powder particles to get sintered. After allowing sufficient time for the sintered layer to cool down without causing significant internal stresses, the part bed moved down for one layer thickness to facilitate new powder layer to be spread by a recoater. By exposure using a computer-controlled laser beam, the plastic powder is solidified to suit the calculated part geometry data. Than the building platform is moved down for one layer thickness and a new layer of plastic powder is applied. This process is repeated continuously to produce the part lying in the loose plastic powder. The sintered material forms the part, while the non sintered powder remains in its place and acts as a support for the subsequent layers and may be cleaned away and recycled once the build is complete. SLS processing are shown in Fig.1.

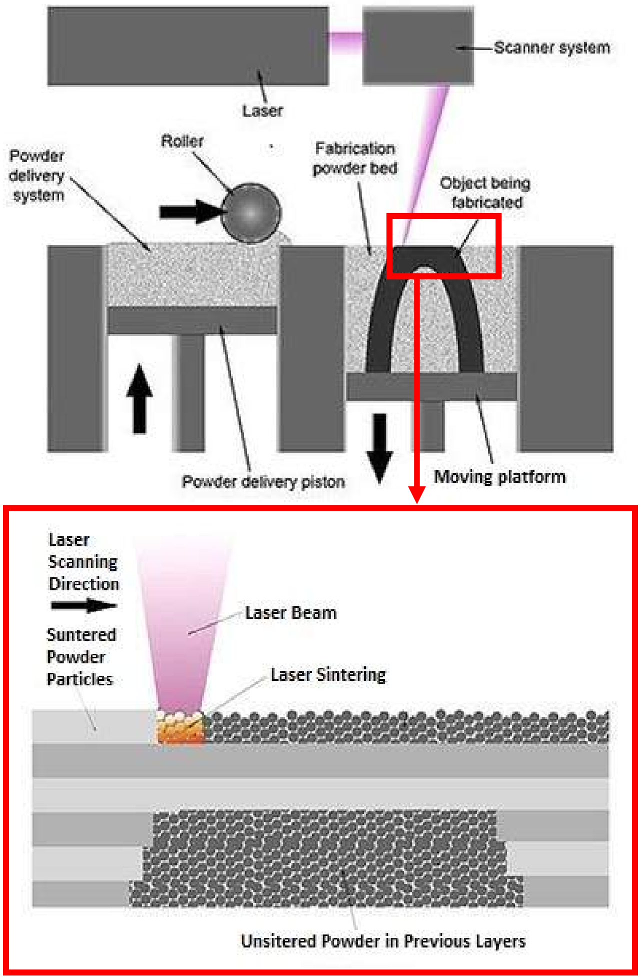


Fig. 1. SLS Building process

SLS is one of the few RP processes capable of producing durable and functional parts from a wide range of prototype materials. The functional prototypes are wear resistant, durable and chemical resistant [3]. One of the main sources of size and shape variations of the part is shrinkage during processing. The following paragraphs present some of the previous work carried out by researchers to study shrinkage in SLS process.

2.1 Factors that affect the laser sintering processing

The laser sintering process is affected by the many factors: process-related effects (shrinkage, distorsion), building temperature, ambient conditions and exposure.
To ensure the sintered part meets the quality requirements, these factors must be taken into account on setting the machine parameters, material parameters and exposure parameters.
In this study it was estimated influence of the different building strategy change of the volume and implementation skin-core parameters on the shrinkage and distortion (Process-related effects).

2.2. Shrinkage

Shrinkage is strongly influenced by the laser parameters, build chamber temperature, cooling rate and geometry. The total shrinkage in SLS process is due to material shrinkage, process shrinkage and thermal shrinkage [5]. During crystallization, the molecules arrange themselves and occupy less volume thus leading to material shrinkage. The shrinkage behavior in the exchangeable frame is shown on Fig 2.

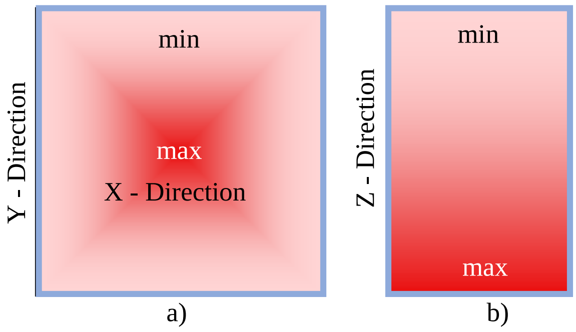


Fig. 2. Shrinkage behavior in the exchangeable frame in a) *X/Y direction;* b) *Z direction*

During processing, the powder particles fuse together to produce dense parts, leading to a decrease in porosity and volume. During heating, the part expands due to the coefficient of thermal expansion and then shrinks during cooling. The crystalline shrinkage which occurring during cooling phase, may be highly non-uniform along each direction due to high temperature gradient inside the powder bed. There can be expansion–shrinkage behavior during the time history of sintering [6]. A particular layer can shrink non-uniformly due to its position, i.e., high or low temperature regions [7]. Moreover, there is a directional effect considering the direction in which laser scanning takes place and the direction normal to it. It is evident from the review of the literature that understandings developed in variations of shrinkage due to process parameters are useful in finding an optimum set of process parameters for producing accurate parts. In most of these studies, a standard test specimen is used with the assumption that shrinkage is independent of geometry and is a constant value [8].
The assumption that shrinkage compensation factors remain unchanged with geometry and build conditions is one of the major limitations in producing accurate parts. In reality, shrinkage of parts is susceptible to changes in geometry and is heavily influenced by building strategies.

2.3. Distortion

Distortion occurs in the case of large thermal differences during the building process or during cooling after the end of the building process and results in warped parts Fig 3. The distortion is equally dependent on the part geometry and the material used [9].

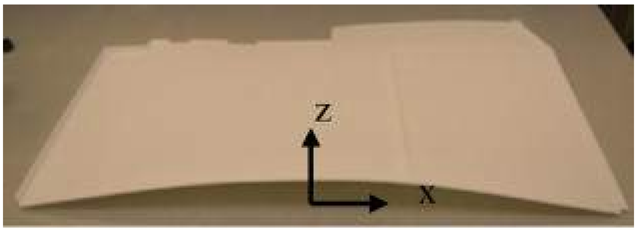


Fig. 3. Distortion (warpage)induced on the fabricated PA part (axis showing the build orientation)

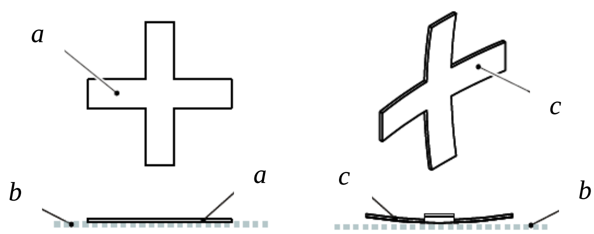
During the process the following types of distortion can occur:

➢ Distortion during the building phase
Due to excessively quick cooling of the individual layers in the process chamber there can be fluctuations in the application of the powder. If, e.g., too little plastic powder is applied at the outer edges, the part lacks material in this area.

➢ Distortion during the cooling phase
Failure to comply with the recommended cooling time, removing the exchangeable frame too soon or premature opening of the removal chamber door will result in the overall job cooling down too quickly. For physical reasons, the part cools down unevenly from bottom to top and from the outside inwards, which can result in the distortion of the part in the layers at the bottom.
For parts that are critical in relation to distortion, powder generously regenerated with new powder should be used.

2.4. Building temperature

A prerequisite for a trouble-free laser sintering process is the optimum building temperature. The recommended building temperature is listed in the *Parameter sheet* for the machine and is dependent on the machine type and the plastic powder used.
At an excessively low building temperature, the outer areas of a layer roll upward. This behavior is called curling. The building temperature must be increased in steps until curling no longer occurs.



a- Straight test corner with optimum building temperature
b- Bed of powder
c- Curled test corner with building temperature that is too low

Fig. 4. Temperature effects

The consequence of incorrectly chosen temperature is deformation of parts Fig 4. In the case of low or high temperatures, will receive the parts as shown in Figure 4c. When used, which is the optimal temperature of 170-173 degrees is obtained as a part of the Figure 4a.
With an excessively high building temperature, in the worst case all the plastic powder in the building area may melt. Even before this situation is reached, soiling of the recoater blade, recoating with stripes and the tearing out of parts will occur. The building temperature should be decreased in steps until the effects no longer occur.

3. DETAILS OF THE EXPERIMENT

The experimental study presented in this paper aims at the investigation of shrinkage and distortion behavior of polyamide material (PA2200) sintered using EOS FORMIGA P100 laser sintering machine.
The SLS process involves a large number of process parameters that are carefully controlled by the operator. Most of the process parameters are decided by the knowledge and experience of the machine builder and machine operator .

3.1. Process parameters

FORMIGA P100 has equipped with CO2 laser with maximum power of 30 W. In the building process 25 W of the laser power is usually used. All parts are produced with layer thickness of the 100 μm on temperature of building chamber of 172.5 ºC. The temperature of building chamber in the process of production as well and heat dissipation during the cooling process has big influence on part warping and curling [11]. In order to avoid temperature influence, all parts are produced on same temperature of building chamber and leave in the machine to cool down to room temperature.

3.2. Material

Specimens used in the study were fabricated using polyamide PA2200 powder which is a modified nylon 12 developed for use in SLS machines by EOS GmbH, Germany.
In production process by SLS it is very common to use a mixture of the new and used powder. This mixture of the powder has introduced for two reasons:

- To decrease the price of the parts produced by SLS,
- To decrease the parts curling and warpage. Uses of only new powder in SLS production may lead to more carling and warpage of the part [12].

3.3. Parts

In this study the influence of the three parameters, on warpage and curling, has been carried out: the volume of the parts, skin-core building strategy and height of parts. All parts are oriented in same direction in building volume, where bigger dimension of the part is oriented in *x* direction, as it is shown in Fig. 4.
The part notated as *Part 1* is fabricated as full density part with height of the 30 mm.
The part noted as *Part 2* has reduced height, which leads to reduced volume of the part. With decreasing of the part volume the total energy for part productions is reduced for 1/3.
The third part noted as *Part 3* has created using skin-core building strategy with part height of 25mm. The skin-core building strategy has been shown in Fig. 5. Using the

skin-core building strategy the outside surfaces of the parts has created with thickness of the 5 mm. The inner volume of the parts has created as web with thickness of the 2 mm, as it is shown in Fig. 5.

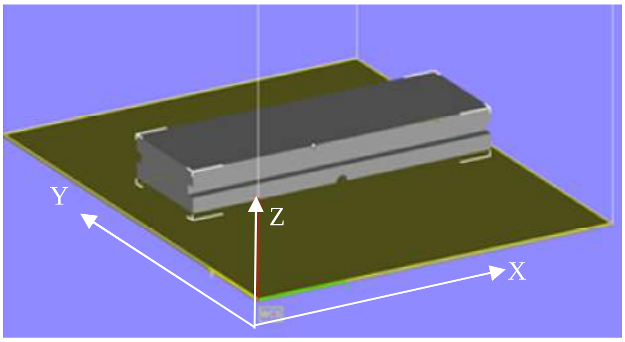


Fig. 5. Parts orientation (Isometric view)

Unsintered powder has trapped inside the web. However, taking into account that powder has twice lover density, total weight of the part is reduced. Also, the amount of energy used to fabricate the part with skin-core strategy is lowest, comparing to *Part 1* and *Part 2*.

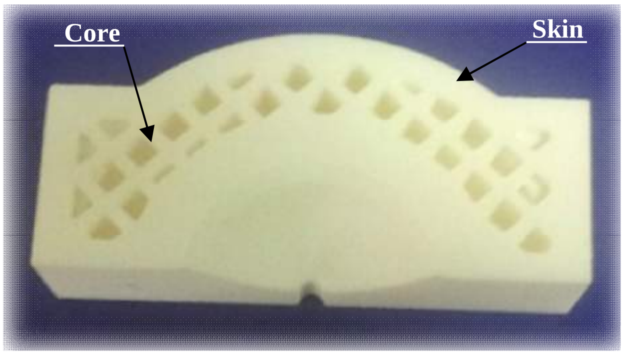


Fig. 6. The *skin-core building strategy*

4. MEASUREMENTS

The measurements are performed in the Laboratory for reverse engineering and additive manufacturing of Faculty for Mechanical and Civil Engineering in Kraljevo were scanned by 3D scanner "ATOS Compact Scan 5M" Fig. 6.

The scanner has two cameras with resolution of 5 megapixels and a projector with the blue light. The measurement area is 150x110x110 mm with distance between points spacing 0.017 - 0.481 mm.

The obtained 3D scans were compared to CAD model of the parts using software package "ATOS Professional".

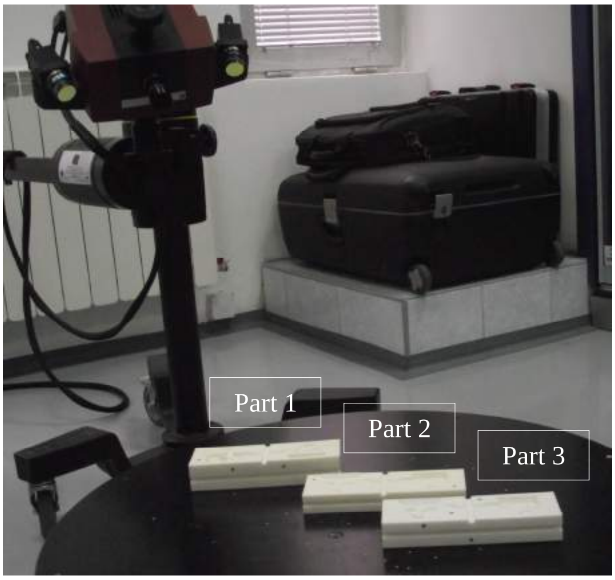


Fig. 7. Parts produced by SLS

5. RESULT AND DISCUSSION

The maximum deviation of parts per side (Front side, Rear side, Top side, Bottom side, Right side and Left side) has been shown in Fig. 8. The part 3, denoted by green color, has highest deviations. The part 2, denoted by orange color has middle deviations and part 1, denoted by blue color, has smallest deviations, as it is shown in Fig. 7.

Obtained scan data for each part has compared to designed CAD geometry. In order to analyze the influence different building strategies on accuracy and warpage of the part the deviation of each side and deviation in 8 different points has been analyzed, as it is shown in Fig. 8 and Fig. 10. The influence of the building strategy on accuracy is estimated on the basis of the deviation of fabricated parts compared to CAD geometry on all surfaces (Left, Right, Front, Rear, Top and Back side), as it shown in Fig. 8. The deviations of all parts from corresponding CAD geometry has plotted in Fig. 9. Lowest deviation from CAD geometry has *Part 1*, which means that reduction of the volume-mass of the part and introduction of the skin-core building strategy lead to higher deviation from designed CAD geometry.

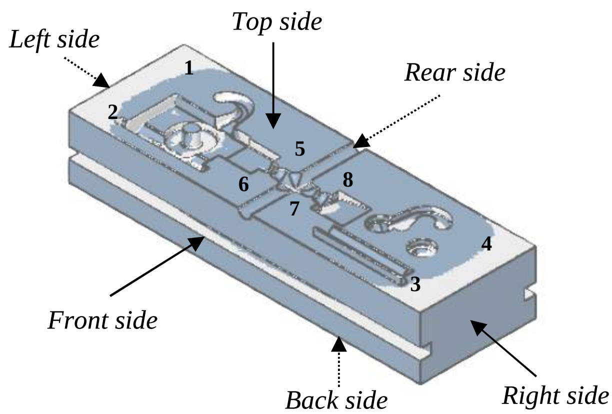


Fig 8. Orientation of the consider sides on the parts

Maximum deviation per side (mm)

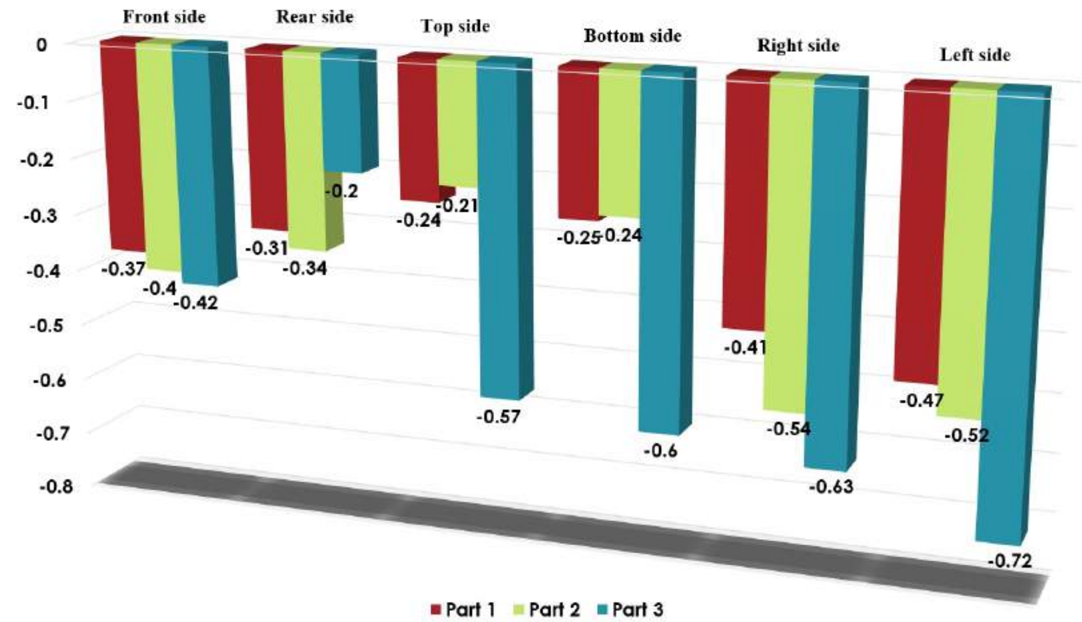


Fig. 9. Maximum deviation per side

Maximum deviation per point (mm)

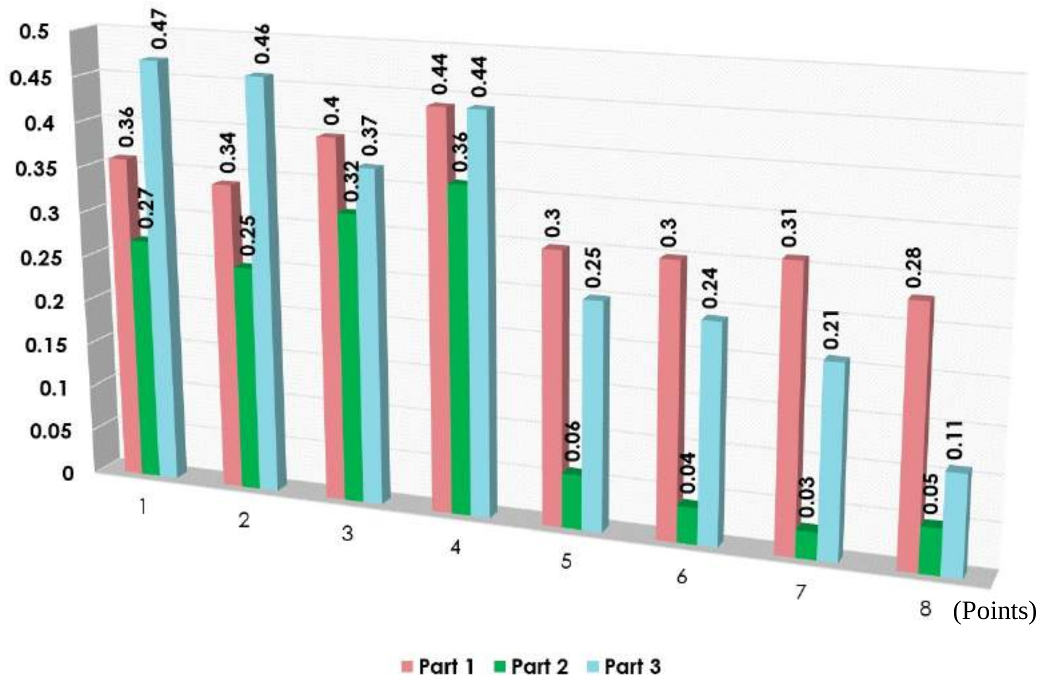


Fig. 10. Maximum deviation per point

The warping of the parts has been estimated by comparison of the deviation in vertical direction in 8 points on top side of the parts, as it is shown in Fig 8. The point are divided in two sections in order to create two zones. The points from 1 to 4 creating the first section and points from 5 to 8 creating the second section. The warping of the parts has estimated by comparison of the deviation between this two sections. The higher deference in deviation between two sections means higher warping of the parts.

From Fig.10. it can be seen that all parts has higher deviations in the first section compared to the second section. The Part 1 has lowest deference between first and second section, which means that Part 1 has lowest warpage. The Part 3 has slightly higher deference in deviation between two section and the Part 2 has the highest deference in deviations between two sections, as it is shown in Fig. 10.

From obtained results the best combination of the low deviation from designed geometry and low warpage has *Part 1*- the full density part with height of the 30 mm. Decreasing the volume of the part leads to lower deviation from designed geometry and higher warpage of the part. Introduction of the skin-core building strategy has produce high deviations and high warpage of the part.

6. CONCLUSION

Our overall research goal is to understand the nature of shrinkage occurring in SLS process to improve the accuracy of the parts. This paper focused on the shrinkage and distorsion parts which are changed with volume parts and skin-core parametars. Certain compensations, other than shrinkage factors, are needed to get accurate estimate of the shrinkage. Moreover, exposure strategies and part orientation are found to influence the accuracy of the part to be produced.

In this paper has shown the influence the mass and type the building strategies on the part accuracy and warping of the part produced by selective laser sintering.

Contrary to the expected the best combination of the low deviation from designed geometry and low warpage has heighest, full density part with. The reduction of the height and mass of the part leads to lower production time and lower price of the parts but the deviationos from designed geometry and especialy warpage of the parts are significantly expressed.

Future research should be aimed to better understanding of the temperature field insade the building volume. Also, the introduction of a dummy parts in order to slow down the cooling process in critical zones, should be considered in the futer research.

Acknowledgement: The authors wish to express their gratitude to Ministry for education, science and tehnology of Republic of Serbia for support throught research grant TR35006.

REFERENCES

[1] Chua CK, Leong KF, Lim CS. Rapid prototyping:principles and applications. 2nd ed. Singapore: World Scientific; 2003.

[2] Chua CK, Leong KF, Lim CS. Rapid prototyping:principles and applications. 2nd ed. Singapore: World Scientific; 2003.

[3] Noorani RI. Rapid prototyping: principles and application. USA: Wiley; 2006.

[4] Hopkinson N, Hague RJM, Dickens PM. Rapid manufacturing: an industrial revolution for the digital age. USA: Wiley; 2006.

[5] Shi Y, Li Z, Sun H, Huang S, Zeng F. Effect of properties of polymer materials on the quality of selective laser sintering parts. IMechE Pt L: J Mater Des Appl 2004;218:247–52.

[6] Lu PK, Li W, Lannutti JJ. Density gradients and the expansion–shrinkage transition during sintering. Acta Mater 2004;52:2057–66.

[7] Venuvinod PK, Ma W. Rapid prototyping – laser based and other technologies. London: Kluwer Academic; 2004.

[8] Influence of building strategies on the accuracy of parts in selective laser sintering, K. Senthilkumaran, Pulak M. Pandey *, P.V.M. Rao: Materials and Design 30 (2009) 2946–2954

[9] Training manual, Basic training, Formiga P100 http://www.eos.info/

[10] Wang RJ, Wang L, Zhao L, Liu Z. Influence of process parameters on part shrinkage in SLS. Int J Adv Manuf Technol 2007;33:498–504.

[11] Venuvinod PK, Ma W. Rapid prototyping – laser based and other technologies. London: Kluwer Academic; 2004.

[12] Jain PK, Pandey PM, Rao PVM. Experimental investigations for improving part strength in selective laser sintering. Virt Phys Prototyping 2008;3(3):177–88.

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TOWARD REVERSE ENGINEERING OF HIP BONE

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The objective of this study is to create preliminary 3D model of human hip bone, using the method of anatomical features. Input data, obtained with Toshiba MSCT scanner Aquillion 64 from real hip bone, were converted to a polygonal model, which represents initial model for further modelling in CAD program. Taking into account the complexity of the hip bone to obtain a valid model, it was necessary first of all to identify and define the anatomical and morphological characteristics which correspond to the referential geometric entities. These reference geometric entitieswere used to create planes of intersection and axes, resulting in the sets of curves and splines.By use of CAD programs, from these splines complex surfaces were created. Finally, merging of these complex surfaces gives 3D surface model. The obtained model can be used for further improving the reverse engineering process, for simulation and training in orthopaedists, creating customized bone implants, as well as for obtaining parametric model of the human hip bone.

Keywords: reverse engineering, hip bone, 3D surface model, CAD.

1. INTRODUCTION

In orthopaedicsurgery, but also in all other sub-branches of surgery, where the need for creation of customized osteo-fixation materialsexists, there is a specific requirement for knowlwdge of the exact geometrical model of the human bone. Therefore, it is very important to create geometry of the bone rapidly and accurately. Usually, the techniques of reverse engineering (RE) are used to define the exact geometrical model of the bones, [15]. With an increasing popularity of Computer-Aided Design (CAD) it is common to reverse-engineer objects or systems through 3D virtual models, [6]. The virtual geometry can be obtained using several scanning techniques:CT, MRI or 3D laser methods, [6,7]. CAD, with the help of medical imaging and rapid prototyping (RP) technologies, has the capability to create anatomicalmodels. In general, activities in anatomical modelling, analysis and simulation need to be carried out in a topology-based modelling environment, such as using a CAD system and CAD-based solid modelling, which is usually represented as "boundary representation" (B-REP) and mathematically described as Non Uniform Rational B-Spline (NURBS) functions, [1]. Based on 3D models of anatomical structures, there are many medical applications designed for surgical training and simulation, preoperative planning and post-operative analysis, medical diagnostic and rehabilitation procedures, as so as for implant design and implant fabrication (for example typical personalised medical products, such as implants for bone reconstruction, dental implants and prosthetics, scaffolds for tissue engineering, patient-specific contact lens etc.), [3, 9,5].
This paper is a continuation of previous studies [2,12], which were the beginning of our work at the hip bone. In this study we describe a methodology ofRE for generation the first version of 3D surface model of the human hip bone in CAD software. Unlike the modelling of the most human bones, the creation of an accurate 3D model of the hip bone has not been a simple task, because the hip bone has free-form shape with a hole in the middle, a large cup-shaped cavity on the lateral aspect of the bone and the areas with high form curvature. It represents very complex morphological entity, resulting from the fusion of three separate bones: ilium, ischium and the pubic bone, [8,12].
The reverse engineering on geometric modelling of the human hip bone is based on method of anatomical features(MAF) [7]. Process consists of the following steps, similar to that one which are presented in the previous publications [4,10,11,12,13,14,15,16]:

- Data acquisition and pre-processing,
- Formation of polygonal model, healing and smoothing of bone,
- Identification and selection of the anatomical-morphological landmarks needed to build model on each bone (Referential Geometrical Entities - RGEs**)**,
- Creating sets of B-splines and
- Creating a surface model.

2. ANATOMICAL AND MORPHOLOGICAL CHARACTERISTICS OF THE HIP BONE

The hip bone (lat. os coxae) is a paired, massive bone, irregularly shaped, whichresembles a plane propeller or windmill wing (Figure 1). It consists of three parts: 1. ilium (lat.os illi); 2. pubis (lat.os pubis); and 3. ischium (lat.os ischii). On the outer side of its middle part (Figure 1) is a deep socket named acetabulum. A large aperture, the obturator foramen(lat. foramen obturatum) is below of the acetabulum.

A detailed description of the anatomical and morphological characteristics of the hip bone is given in our previousstudy: "Morphometric Analysis of the Hip Bone as the Basis for Reverse Engineering" [12].

The main parts of the hip bone and its anatomical landmarks are shown at Fig. 1.

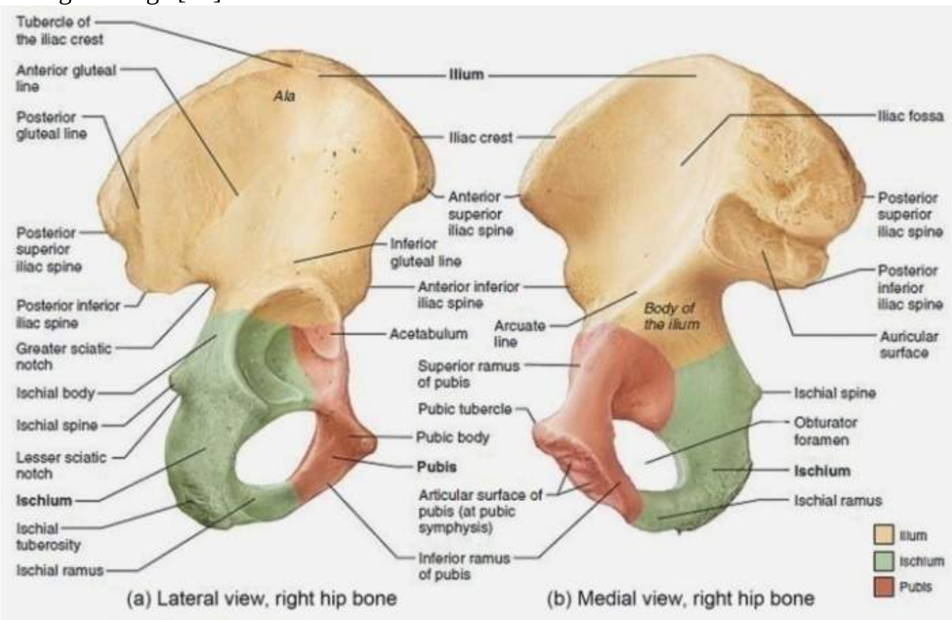


Fig. 1.Hip bone [8]

3. DATA ACQUISITION AND PRE-PROCCESING

The primary source of RE data for present work was obtained from CT scans. Hence at the first stage of the modelling we have collected input data. Our region of study involved the CT images obtained from a female hip bone with Toshiba MSCT scanner Aquillion 64. Slice images were obtained each of 0.5mm sliced segmentation, written in the form of the DICOM format. After completing the segmentation, CT data are translated into the appropriate standard format (STL – STereoLitography) for transferring into CAD program.

4. REVERSE ENGINEERING OF 3D SURFACE MODEL OF THE HUMAN HIP BONE

This initial "point cloud" was imported in RE software package for some pre-processing involving cleaning of some outliers (disconnected points) and curvature-based decimating of the data, which is to facilitate the following modelling procedures. Later on it was triangulated.
Model is suitable for further processing according to following steps:

1. Determination of Referential Geometrical Entities (RGEs) on initial model at all 3 constitutive parts of the hip bone(ilium, ischium and pubis), which correspond to their anatomical landmarks;
2. Creating the curves of higher order;
3. Creating the 3D surface model of the bone;
4. Verification of the 3D surface model.

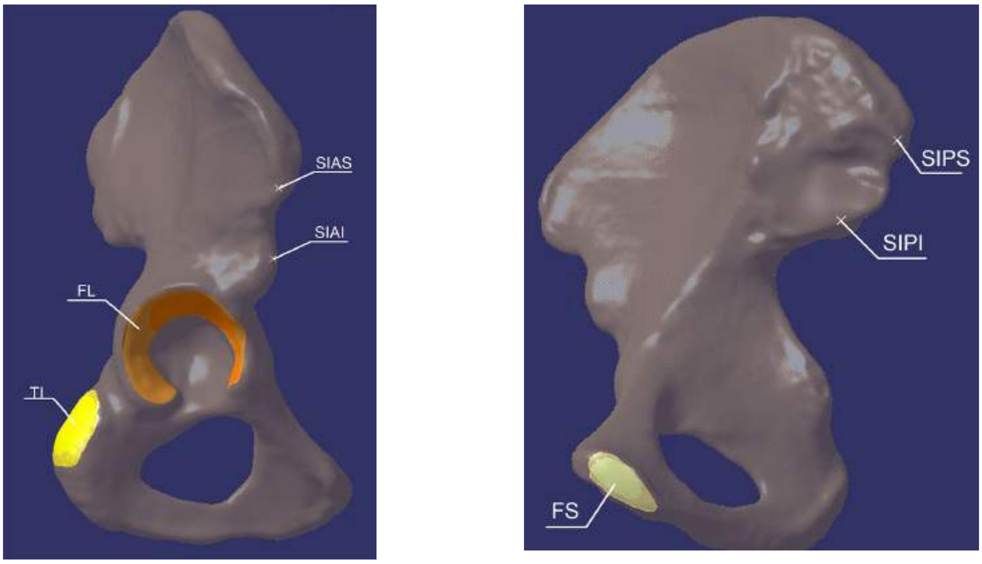
4.1 Determination of RGEs on Initial Model

After anatomy description of the bone, the procedures to identify and define anatomical landmarks (reference characteristics) are carried out. These characteristics are defined for a given bone only once and are important for creating axes of rotation and planes of intersections.
For research purposes, we have selected the following RGEs, [12], as it is shown at the Figure 2:

- FL (lat.facies lunata) - the lunate articular surface in acetabular fossa,
- FS (lat.facies symphysialis) - articular symphyseal surface at the body of pubis bone,
- TI (lat.tuber ischiadicum) - the tuberosity of the ischium at the body of ischium bone,
- SIAS (lat.spina iliaca anterior superior) - the anterior superior iliac spine at the ilium bone,
- SIAI (lat.spina iliaca anterior inferior) - the anterior inferior iliac spine at the ilium bone,
- SIPS (lat.spina iliaca posterior superior) - the posterior superior iliac spine at the ilium bone,
- SIPI (lat.spina iliaca posterior inferior) - the posterior inferior iliac spine at the ilium bone.

4.2 Creating the Curves of Higher Order

Different parts of the polygonal model were intersected with planes based on the RGEs defined in previous section. The intersections of the planes and the parts of the polygonal model produced contour curves, so called cross sections contours. We used these curves to define points on them. The selected points were used to obtain spline curves. The body and the parts of the superior and inferior ramus of the pubis bone (at polygonal model) wereintersected with 9 planes that are perpendicular to the axis which connects the centre of FS and FL.
At the part of the pubic bone (at polygonal model), that is limited by the obturator foramen, an arc line was constructed. In the centre of this line we set the plane that is parallel to the previous planes. By cutting this part of the polygonal model of the bone to the given planes,two



a) *b)*

Fig. 2.Selected RGEs at the right hip bone a) lateral view, b) medial view

intersection curves were obtained: the first one at the superior and the second one at the inferior ramus. The selected points at these curves were used for setting the planes which are perpendicular to the curves. Sections with these planes and this part of the polygonal model were made (36 in total). At the curves of intersection the appropriate points were selected. These points have been used for constructing the splines. By using loft and blend functions a part of 3D surface model of the pubis bone was created (shown at Fig. 3).

At the part of the polygonal model which corresponds to the inferior ramus of the pubis (lat. ramus inferior ossis pubis) which meets with the ramus of the ischium (lat. ramus ossis ischii), 12 sections were defined using the planes parallel to the plane which passes through the boundary curve of the surface described at the previous section. At the superior ramus of the pubic bone (at polygonal model) 9 sections were made (up to the acetabulum)with the planes perpendicular to the line which connects centres of the FS and FL, resulting with 9 curves obtained on that way. For the part of the acetabulum (at polygonal model) which forms the superior ramus of the pubic bone up to the end of inferior gluteal line (lat. linea glutea inferior), toward the anterior border of the ilium, 16 planes perpendicular to the last curve at the superior ramus were used.

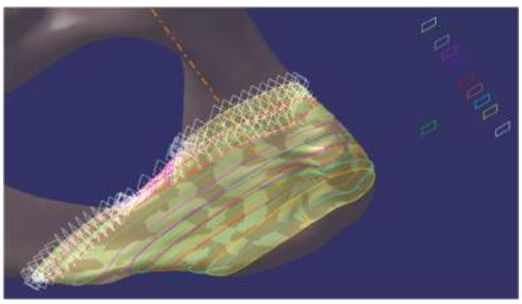


Fig.3. Surface and splines at the body and the parts of the superior and inferior ramus of the right pubicbone

Curves obtained in cross-sections span the acetabulum and the part of the ischium, including a part of the iliac crest (lat. crista iliaca), Figure 4.

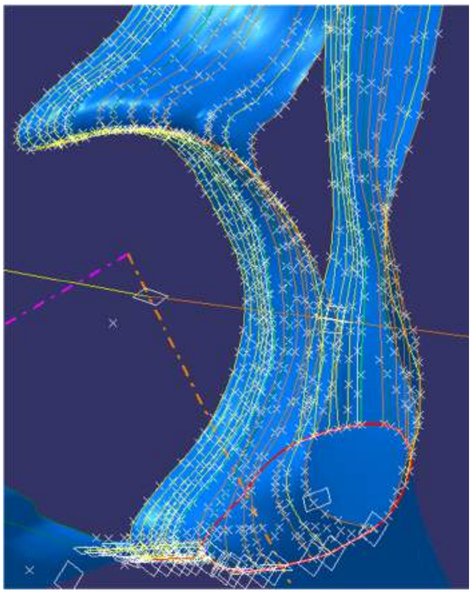


Fig. 4. Splines at the part of the acetabulum

At the part of the polygonal model on the superior ramus of the pubic bone where few bony elements are present: iliopectinal eminence (lat. eminentia iliopubica), the oblique groove (lat. pecten ossis pubis) and the orburator crest (lat. crista orburatoria)), 12 sections were made with the planes that are parallel to the plane defined by two lines - the first one which connects SIAS and SIPS and the second one which connects SIAI and SIPI. At the part of the ala (lat. ala ossis ilii) toward the anterior border, including the part of the anterior border, at polygonal model, 39 sections were made. In this case we used the planes parallel to the previous planes. At the all curves, points were selected and splines were constructed. By use loft and blend functions part of 3D surface model of the bone was created as it is shown at figure 5.

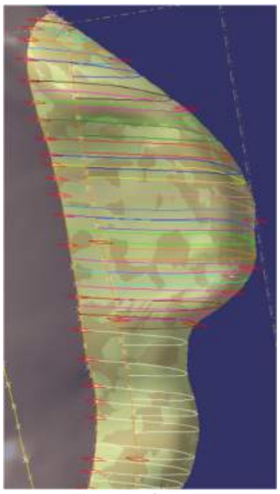


Fig. 5. Splines at the part of the anterior border of the hip bone

At the border point of the arc constructed at the part of the orburator foramen limited by the ischium, the plane perpendicular to the line which connects the centre of TI and the centre of the arc line at the orburator foramen was set. Cutting the inferior part of the body of the ischium bone (at polygonal model) with this plane and the planes parallel to it, leaded to 12 sections. The polygonal model of the ischial ramus was sectioned with the 15 planes. For the superior part of the body of ischium (at polygonal model) the plane determined by three points: the farthest and the nearest point from the centre of TI, and the centre of TI,was used [8]. This plane was rotated for the angle of 90^0(for the axis of rotation is used the line which connects the centres of TI and FS). So, for this part of the polygonal model 17 planes parallel to the previously mentioned rotated plane which leads to 17 curves,were used. Points at these curves were used for spline constructing.

For the acetabular notch (lat. incisura acetabuli) at polygonal model, we used 11 planes perpendicular to the line which connects the border point from previous sections and the lowest point in acetabulum (at the outer side of the bone). For the part of the ischium which builds a part of the acetabulum (at polygonal model) we used 7 parallel planes. At the curves of intersections we have also selected points and got the splines.

At the part of the acetabulum (at polygonal model) built from ischium and ilium,the sections with 11 planes parallel to the plane defined by two lines (SIAS-SIPS and SIAI-SIPI) were made. These sections also included a part of the posterior border, till to the end of the arc line constructed at the greater sciatic notch (lat. incisura ishiadica major).

In the medial part of the ala at the polygonal model,the sections with 27 planes perpendicular to the border curve obtained at the part of the surface at superior ramus of the pubis bone,were made, while the part of the ala toward the posterior border (including posterior border of the hip bone) above and below, SIPI was cut with 7 planes parallel to the plane defined by the two lines (explained above). The area near SIPS and toward superior border was sectioned with 14 parallel planes (Figure 6). At all curves of the intersections the appropriate points were selected. These points were used for obtaining splines, and finally from these splines by use CAD functions (loft and blend) the last part of 3D surface model was obtained.

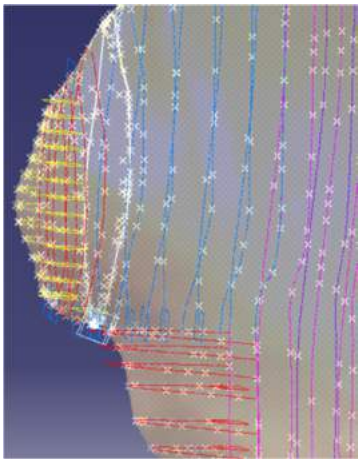
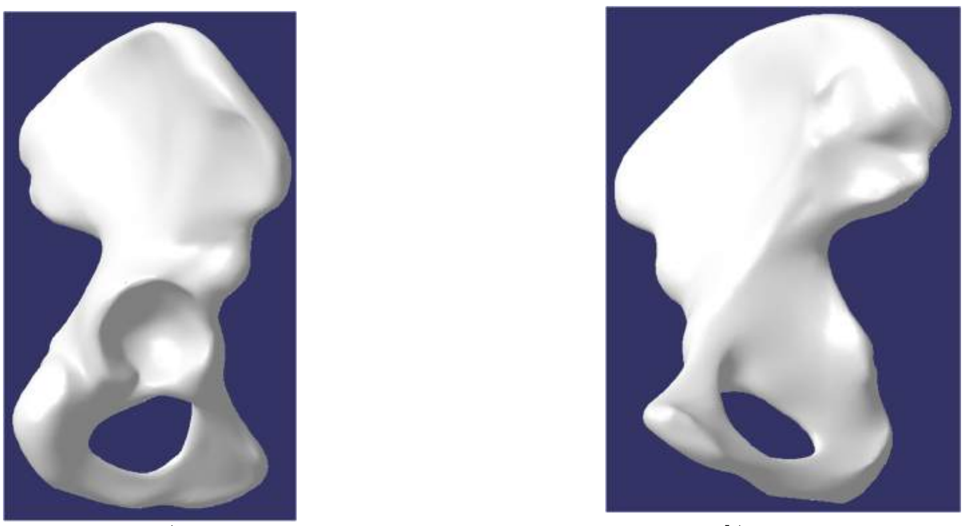


Fig. 6. Curves of intersections and points at the part of the ilium

4.3 Creating 3D Surface Model

With the help of CATIA V19 modules, by merging all parts of the right hip bone (merging distance 0.001mm) 3D surface model of the right female hip bone is created. This model is shown at the Figure 7.



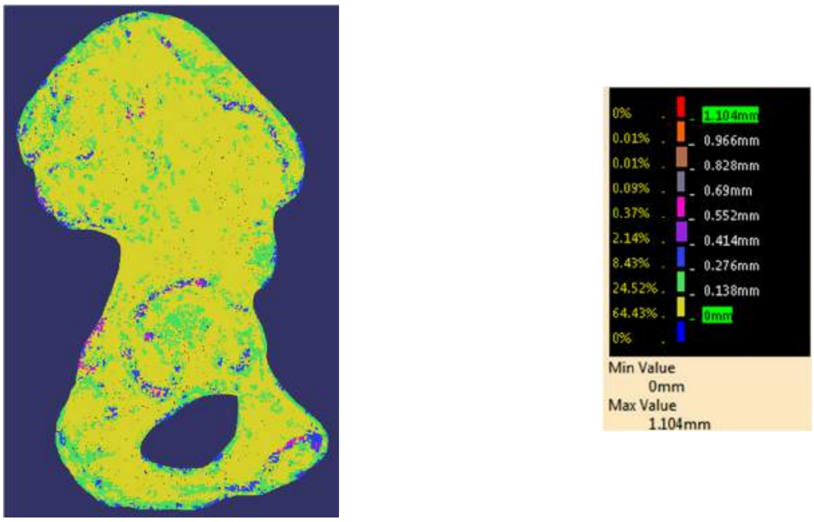
a) *b)*

Fig. 7.3D surface model of female hip bone: a) lateral view; b) medial view

4.4 Model Verification

In the final stage of modelling, the final polygonal 3D model was created in order to implement accuracy of our CAD model. The distancein perpendicular direction, without modifying elements, between the initial polygonal model (reference model), obtained from the point clouds (from CT scan), and final polygonal model, using CATIA Shape modulewas analysed.

The results from this 3D comparison are presented in terms of colour coded map (by use of min/max option) of distances as shown in Figure 8, proving that most of the area of the model has been built within 0 - 0.138mm, which can be considered as a relatively good result.



a) *b)*

Fig. 8.Verification of the model by analysis of the distance: a) colour coded map; b) statistical results of verification

Deviation analysis between theinitial surface model (created at initial polygonal model) and our final CAD surface model is presented at Figure 8. These deviations are from -2.54 to1.8mm.

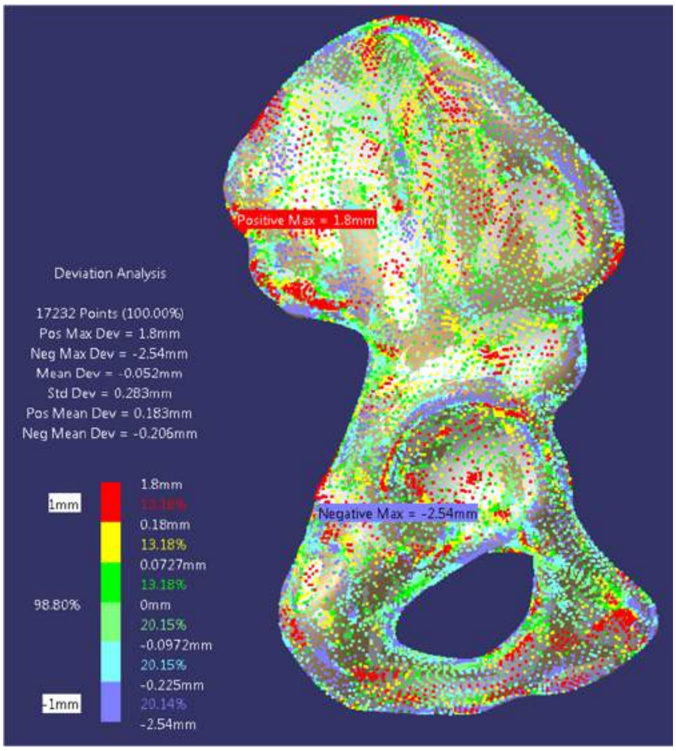


Fig. 8. Deviation analysis between initial and final CAD surface model

5. CONCLUSIONS

The presented RE methodology to generate 3D surface models of the hip bone provides satisfactory results due to geometrical and morphological characteristics of the hip bone. The quality of the obtained surface is directly related to the number of the selected sections and selected RGEs. The results of this study can be considered as preliminary, because based on the results of verification (analysis of distances and deviations) some improvements of the model are possible: at the posterior border (around SIPI and ischial spine), at FS, as so as at the part of the iliac crest at the superior border of the hip bone . These improvements could be implemented by increasing the number of RGEs and by increasing the number of the sections in order to obtain the high-quality surface models in the RE process, which will be the main topic in our future work. However, the authors are aware of the fact that the increase in the number of RGEs and sections necessarily leads to an increase in the time required to generate the model.

The obtained model can be used for further RE process, for creating and prototyping of customized bone implants, as well as for the training and virtual simulation in orthopaedics. Also, this model will be used in our study for obtaining parametric model of the human hip bone.

Acknowledgment: This paper is part of project III41017 Virtual human osteoarticular system and its application in preclinical and clinical practice, funded by the Ministry of Education, Science and Technological development of Republic of Serbia, for the period of 2011-2014.

REFERENCES

[1] Hacene Ameddah and Mekki Assas, "Bio-CAD Reverse Engineering of Free-form Surfacesby Planar Contours", Computer-Aided Design & Applications, 8(1), 2011, pp 37-42

[2] Stojanka Arsić, Dragana Ilić, Milorad Mitković, Milica Tufegddžič, Sonja Janković, "The Study of Morphological Paramerers of Human Acetabulum Significant for Hip Arthroplasty", The 2nd International Conference, Mechanical Engineering in XXI century, June 20-21, 2013, Niš, Serbia, Faculty of Mechanical Engineering, Proceedings pp 115-120

[3] Amba D. Bhatt and Ravi M. Warkhedkar, Reverse Engineering of Human Body: "A B-spline based Heterogeneous Modeling Approach", Computer-Aided Design & Applications, 5(1-4), 2008, pp 194-208

[4] Nikola Korunović, Miroslav Trajanović, Jelena Milovanović, Miloš Stojković, Nikola Vitković, "Bone modelling for structural analysis using FEM", Proceedings of The International conference Mechanical Engineering in XXI Century, Niš, 2010, pp 205-208

[5] C.H Le, M.I Okereke, V.H Nguyen, V.D Dao, S Soe, N Zlatov, T.H Le, "Personalised Medical Product Development: Methods, Challenges And Opportunities", The Romanian Review Precision Mechanics, Optics & Mechatronics, 2011, No. 40, pp 11-20

[6] André Lupi, Zdenka Sant, "Reverse engineering applied to a lumbar vertebra", Malta Medical Journal Volume 20, Issue 04, December 2007

[7] Vidosav Majstorovic, Miroslav Trajanovic, Nikola Vitkovic, Milos Stojkovic, "Reverse engineering of human bones by using method of anatomical features", CIRP Annals - Manufacturing Technology 62 (2013) 167–170

[8] Marieb N. E., Wilhelm B. P., Mallatt J., "Human Anatomy", Sixth Edition Media Update, 2010, Pearson education, Inc., San Francisco

[9] I. POPOV and S. O. ONUH, "Reverse engineering of pelvic bone for hip joint replacement", Journal of Medical Engineering & Technology, Vol. 33, No. 6, August 2009, pp 454–459

[10] Milos Stojkovic, Jelena Milovanovic, Nikola Vitkovic, Miroslav Trajanovic, Nenad Grujovic, Vladimir Milivojevic, Slobodan Milisavljevic, Stanko Mrvic, "Reverse modeling and solid freeform fabrication of sternum implant", Australasian Physical & Engineering Sciences in Medicine: Volume 33, Issue 3 (2010), pp 243-250, DOI: 10.1007/s13246-010-0029-1

[11] M. Stojkovic, M. Trajanovic , N. Vitkovic, J. Milovanovic, S. Arsic, M. Mitkovic, "Referential geometrical entities for reverse modeling of geometry of femur", Computational Vision and Medical Image Processing - VipIMAGE 2009, Porto, Portugal, 14.-16. October 2009

[12] Miroslav Trajanović, Milica Tufegdžić, Stojanka Arsić, Dragana Ilić, "Morphometric Analysis of the Hip Bone as the Basis for Reverse Engineering", The 2nd International Conference, Mechanical Engineering in XXI century, June 20-21, 2013, Niš, Serbia, Faculty of Mechanical Engineering, Proceedings, pp 107-110

[13] Trajanović, M., Tufegdžić, M., Arsić, S., Veselinović, M., Vitković, N., "Reverse engineering of the human fibula", 11th International Scientific Conference MMA 2012 - Advanced Production Technologies, Novi Sad, 2012, Proceedings pp 527-530,

[14] Miroslav D. Trajanovic, Nikola M. Vitkovic, Milos S. Stojkovic, Miodrag T. Manic, Stojanka D. Arsic, "The morphological approach to geometrical modelling of the distal femur", SEECCM 2009, 2nd South-East European Conference on Computational Mechanics An IACM-ECCOMAS Special Interest Conference M. Papadrakakis, M. Kojic, V. Papadopoulos (eds.) Rhodes, Greece, 22–24 June 2009

[15] Marko Veselinovic, Nikola Vitkovic, Dalibor Stevanovic, Miroslav Trajanovic, Stojanka Arsic, Jelena Milovanovic, Milos Stojkovic, "Study on Creating Human Tibia GeometricalModels", *Proceedings of the 3rd International Conference on E-Health and Bioengineering - EHB 2011*, 24th-26th November, 2011, Iasi, Romania

[16] Nikola Vitković, Miroslav Trajanović, Jelena Milovanović, Nikola Korunović, Stojanka Arsić, Dragana Ilić, "The geometrical models of the human femur and its usage in application for preoperative planning in orthopedics", ICIST 2011, 1st International Conference on Internet Society Technology and Management, Kopaonik 2011, Serbia.

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EXPERIMENTAL DETERMINATION OF ABRASIVE WATER JET CURVATURE AND ITS MODELING USING THE GENETIC PROGRAMMING

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One of many characteristics of abrasive water jet, used for material machining, is its curvature respectively lag in jet shape between the upper and the lower edge of machined material. For this paper experiments were conducted and the influence of cutting parameters on shape of abrasive water jet during machining is measured. Steel was used as a workpiece material while water pressure, cutting speed and quantity of abrasive were varied. After mapping of abrasive water jet shape, genetic programming was used for modeling of jet curvature. Conclusion was that this type of evolutionary algorithms presents very effective method for predicting the curvature of abrasive water jet during machining with respect to material type.

Keywords: *abrasive water jet machining, jet curvature, genetic programming*

1. INTRODUCTION

Water jet machining is one of the most versatile machining there is. It can be applied, theoretically, on every type of material. With this kind of potential and by optimization of process parameters could be made as a very economical means of machining.

Observing the edges of machined material inside the kerf, it is well known that jet traces are visible in the form of lines (Fig. 1). By closer examination it is discovered that lag is present between the upper and the lower portion of the line. That lag is the indicator of process optimality. If the line is too straight, process is underrated, while arched line reveals, to some extent, selection of optimal parameters. But one must be careful not to overdo it, in means of jet curvature, because there could be the case where jet is unable to cut through the material. For this paper experiments were carried out varying process input parameters while jet curvature is measured. Those data are then used to artificially construct simulation function and to determine the influence of input parameters on jet trajectory curvature.

In the past, papers regarding abrasive water jet (AWJ) shape have been published. Simple empirical correlation for the kerf profile shape, under different traverse speed, has been developed in [1]. Description of abrasive water jet quality through the relationship of declination angle and cutting wall quality is realized in [2]. Empirical model for predicting the shape of profile cut in industrial cutting processes has been developed and applied to abrasive water jet cutting in [3]. Empirical model for calculation of the cutting head tilt angle with respect to ability of the jet to penetrate material, is presented in [4]. Numerical simulation and analysis of abrasive water jet cut surface topography, using the trajectory of jet, is described in [5]. Estimation of cutting speed by waterjet cutting is presented in [6.]

Although the presence of jet shape analysis is recorded, only arithmetical solutions are found.

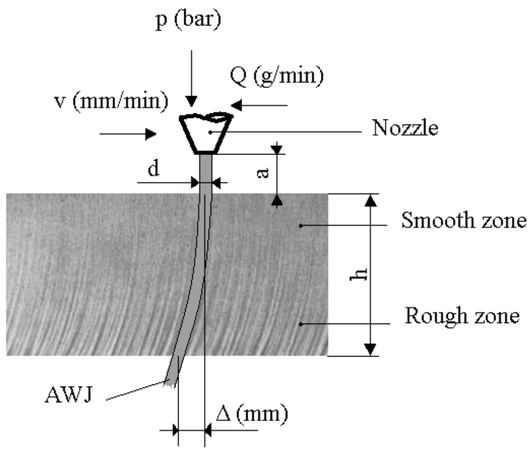

Fig. 1. Surface topography by AWJ machining

In these days all trends are heading to ever increasing use of computational assistance in solving various tasks. Artificial intelligence, as a tool for analysis and dependence development is gaining ever more popularity and commercial use. Being aware of this fact and realizing that no work covers this subject it is decided to support the scientific community and present the novel approach in abrasive water jet analysis and simulation.

Realizing the complexity of presented challenge, only very flexible system could successfully live up to that task. Having previous success with genetic programming in other areas [7, 8] it is speculated and assumed that mentioned success will once again be achieved. Genetic programming is one of the most used evolutionary algorithms subcategory. Its main feature is the ability to construct function which will most vividly model assigned function.

2. EXPERIMENTS

Experiments were carried out on the machine for water jet cutting by manufacturer STM from Austria. Cutting was done with sapphire nozzle of dn=0,3 mm in diameter, focus tube df=0,9 mm in diameter and h=1 mm distance of nozzle from workpiece. Sand was used as abrasive with 0,1 mm grain size. Regular steel S235 JRG2 (Č0361) was used as the workpiece, because of its general application and wide prevalence. Thickness of steel plate was a=15 mm.

During the experiments three process parameters were varied: fluid pressure p (bar), traverse cutting speed v (mm/min) and the quantity of abrasive Q (g/min). While one parameter was varied the others were held constant. For every combination of parameters new sample was machined and jet curvature was measured. Five different instances were used for each parameter. Pressure was varied between 1600 bar and 3200 bar with the step of 400 bar. Traverse speed was varied between 40 mm/min and 80 mm/min with 10 mm/min step. Abrasive quantity for the case of 400 g/min and 350 g/min did not leave any visible strains, but those were visible for 300, 250 and 100 g/min.

For every piece nine depths were selected to take measurements of jet curvature. In Table 1, characteristic example of abrasive water jet measured curvature, is shown. Cutting conditions for this case were p=3200 bar, v=60mm/min and Q=400 g/min.

Table 1. Example of measuring results

Pressure *p* (bar)	Traverse cutting speed *v* (mm/min)	Abrasive quantity *Q* (g/min)	Measuring depth *k* (mm)	Curvature of jet Δ_{exp} (mm)
3200	60	400	0	0,0000
			2	0,0000
			2,45	0,0000
			4	0,1619
			6	0,3911
			8	0,5997
			10	0,9084
			12	1,1712
			14	1,5923
			15,2	1,8221

On Fig. 2, Fig. 3 and Fig. 4, values of measured jet curvature with respect to pressure, cutting speed and abrasive quantity change are graphically shown. For the last one only three samples could be identified because only there, stream lines were visible.

3. MODELING PROCEDURE

In this work, genetic programming was employed to construct a function that will, as much as possible, mirror the actual shape of jet inside the kerf. As every evolutionary based algorithm, genetic programming is also based on principles of evolution. Solutions are shown as individuals and through fitness function their quality is evaluated. Than it is up to a process of evolution simulation to decide what to do with each individual. Those with highest fitness will be most probably placed inside the mating pool from where they will be mated with another individual. The task of crossover process, as it is called, is to combine properties of two individuals and make new offspring, desirably with same or even better properties than their parents had. Process of mutation is also employed to refresh the population with new genetic material. This helps the algorithm to increase the possibility of finding the global optimum rather than being stuck in the local optimum. Within the procedure of modeling, as mentioned above, membership functions are generated. On the beginning of the process six constants are randomly generated from the range of 0-10. These constants could be used by the system in function creation process. Each generation consisted from 500 individuals where each individual is one possible solution respectively one function. Probability for crossover to take place is 0,7, mutation 0,05 and reproduction 0,2.

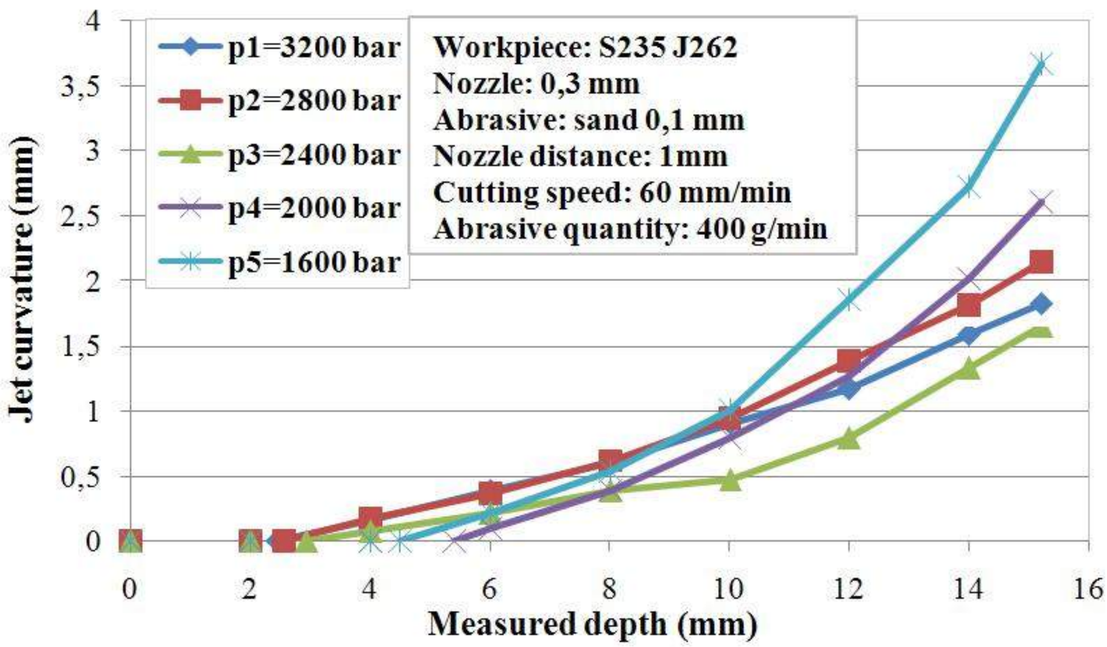

Fig. 2. Influence of fluid pressure on jet curvature

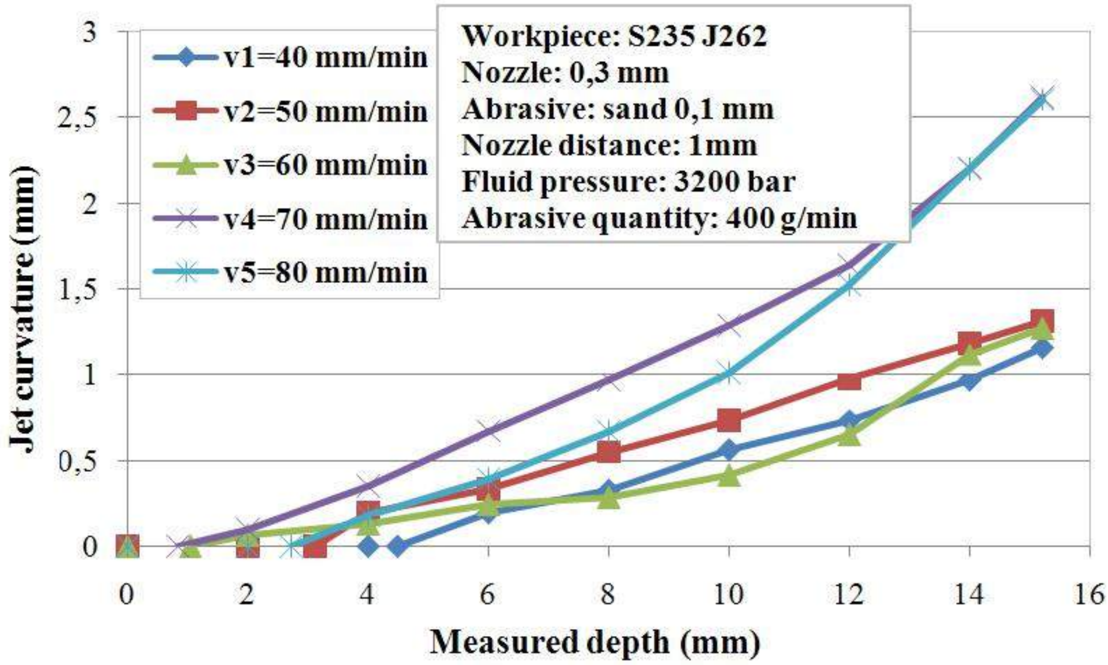

Fig. 3. Influence of traverse cutting speed on jet curvature

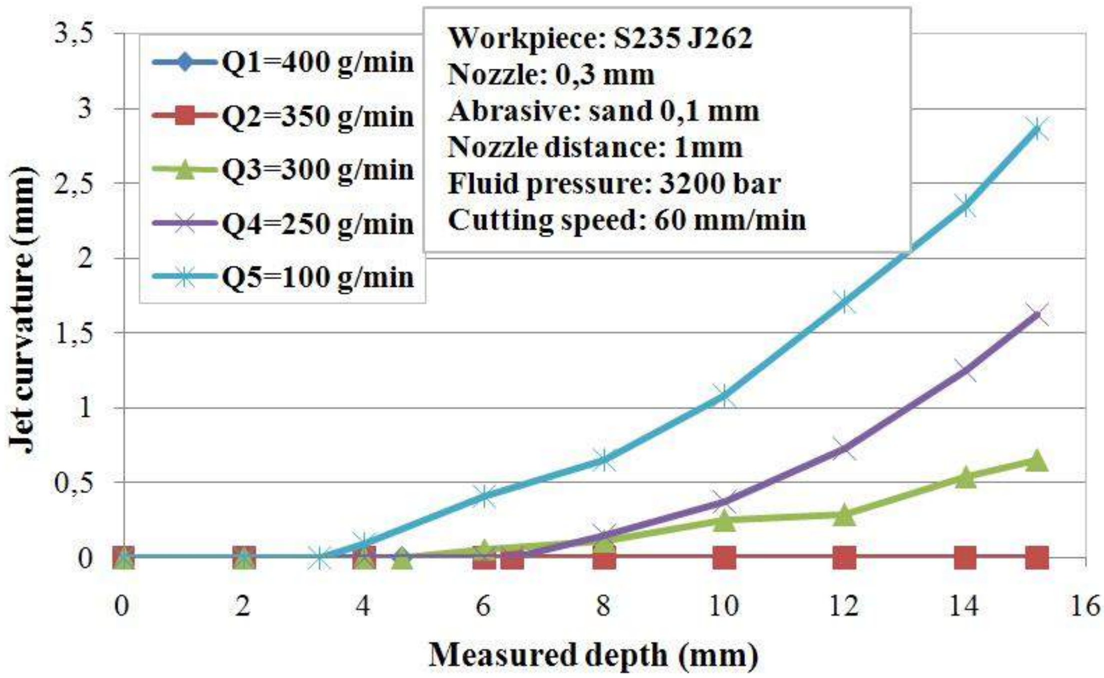

Fig. 4. Influence of abrasive quantity on jet curvature

In each generation 10 most highly quoted are marked as elite individuals resp. are automatically transferred to the next generation. Fitness function is selected to be mean square error, because it is fairly easy to find minimum for this function with high probability that it will be the global minimum. For function construction only basic (arithmetical) mathematic operators are used; +, -, * and /. Common function is generated which means that it incorporate all available measured data. First five regions are related to pressure variation part, next five regions for cutting speed variation and last three regions for abrasive quantity part.
As mentioned before for abrasive quantity only three samples could be visually measured.

4. RESULTS

In Table 2. an example of modeled results for abrasive water jet curvature, by genetic programming, is shown. These results are for previous data shown in Table 1. (p=3200 bar, v=60 mm/min and Q=400 g/min).

Table 2. Results of modeled abrasive water jet curvature

Measuring depth k (mm)	Curvature of jet - measured Δ_{exp} (mm)	Curvature of jet - modeled Δ_{mod} (mm)	Relative error (%)
0	0,0000	0,000000	0,00
2	0,0000	0,015081	0,00

2,45	0,0000	0,024402	0,00
4	0,1619	0,078560	51,48
6	0,3911	0,205132	47,56
8	0,5997	0,397897	33,65
10	0,9084	0,649258	28,53
12	1,1712	0,961379	17,91
14	1,5923	1,342996	15,66
15,2	1,8221	1,611132	11,58

Taking in consideration complexity of the function, final result is relatively simple but is still robust and is not shown here. Resulting function is available from corresponding author on request. On Fig. 5 graphical representations of results is shown. Comparison between modeled and measured data is presented. Third line in graph is showing relative error of modeled deviation from measured data.

5. DISCUSSION

Analysis of experimental results revealed that most impact on abrasive water jet curvature has traverse speed *v*. Increase of cutting speed increases the jet trajectory curvature. On the other hand decrease in abrasive quantity also increases jet curvature. Increasing the fluid pressure causes the abrasive grains to breakup which leads to more smother surface and automatically leads to disappearance of jet traces.

As can be seen from Fig. 5, modeled results replicated measured data with great credibility. Relative error is the largest in the beginning of the jet curvature resp. top of the material. Data from this area is to be taken with reserve because it is the most delicate area and measurement error is easily to occur. Also it is the area in which precision of jet trajectory curvature doesn't matter as much as at the bottom of the material. Main disadvantage of evolutionary algorithms in general is that they require some amount of experience in modeling procedure. Overall they are very flexible tool to use for this type of challenge. They offer great flexibility and employ relatively small amount of computational time. Results yielded in this work offers satisfaction because potential for future and deeper use in this area is discovered.

Acknowledgement: Authors would like to thank Serbian Ministry of Education, Science and Technological Development which supported this work in form of project no. TR 35015.

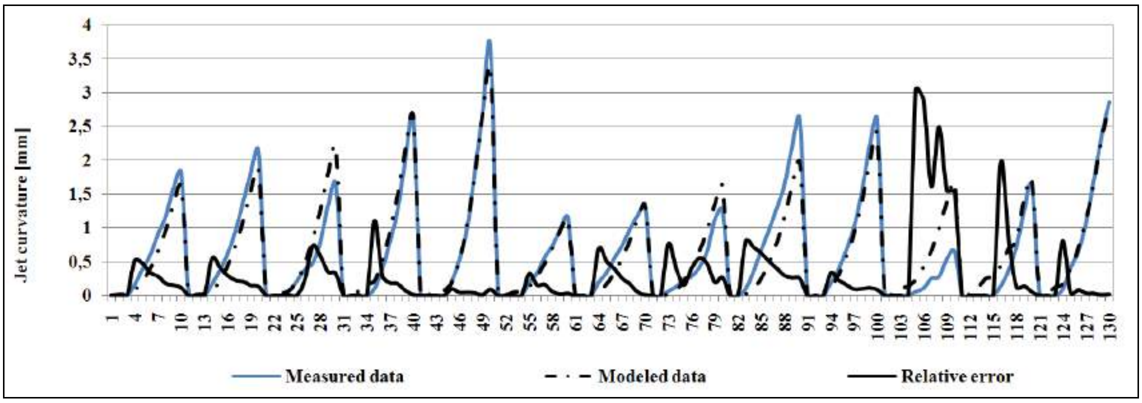

Fig. 5. *Graphical representation of experimental and modeled results of jet curvature*

REFERENCES

[1] Ma, C. And Deam, R.T. "A correlation for predicting the kerf profile from abrasive water jet cutting", Experimental Thermal and Fluid Science, 30, pp 337-343, 2006.

[2] Hlavac, L.M., Hlavacova, I.M., Gembalova, L., Kalicinsky, J., Fabian, S., Mestanek, J., Kmec, J. and Madr, V. "Experimental method for the investigation of the abrasive water jet cutting quality", Journal of Materials Processing Technology, 209, pp 6190-6195, 2009.

[3] Deam, R.T., Lemma, E. and Ahmed, D.H. "Modelling of the abrasive water jet cutting process", Wear, 257, pp 877-891, 2004.

[4] Hlavac, L.M. "Investigation of the abrasive water jet trajectory curvature inside the kerf", Journal of Materials Processing Technology, 209, pp 4154-4161, 2009.

[5] Vikram, G. and Ramesh Babu, N. "Modelling and analysis of abrasive water jet cut surface topography", International Journal of Machine Tools & Manufacture, 42, pp 1345-1354, 2002.

[6] Radovanovic, M. "Estimation of Cutting Speed by Waterjet Cutting", The 31st Internationally Attended Scientific Conference Modern Technologies in the XXI Century", Bucharest, Romania, pp. 8.196-8.203, 2005.

[7] Gostimirović, M., Pucovsky, V., Kovač, P., Rodić, D. and Savković, B. "Modeling of Discharge Energy in Electrical Discharge Machining by the use of Genetic Programming", Journal of Production Engineering, 15 (2), 2012.

[8] Kovač, P., Pucovsky, V., Palkova, Z., Nagy, L. and Savković, B. "Solar Energy Dependence Modeled With Evolutionary Algorithms", Engineering for Environmental Protection TOP, Časta – Papiernička, Slovak Republic, 2013.

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NEURAL EXTENDED KALMAN FILTER FOR STATE ESTIMATION OF AUTOMATED GUIDED VEHICLE IN MANUFACTURING ENVIRONMENT

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Abstract: *To navigate autonomously in a manufacturing environment Automated Guided Vehicle (AGV) needs the ability to infer its pose. This paper presents the implementation of the Extended Kalman Filter (EKF) coupled with a feedforward neural network for the Visual Simultaneous Localization and Mapping (VSLAM). The neural extended Kalman filter (NEKF) is applied on-line to model error between real and estimated robot motion. Implementation of the NEKF is achieved by using mobile robot, an experimental environment and a simple camera. By introducing neural network into the EKF estimation procedure, the quality of performance can be improved.*

Key words*: Automated Guided Vehicles, monocular SLAM, extended Kalman filter, feedforward neural network.*

1. INTRODUCTION

The problem of Visual Simultaneous Localization and Mapping (VSLAM) assumes a mobile robot that moves through an unknown environment, uses information from camera to infer its position and orientation, and simultaneously determines the position of characteristic objects [1-4]. This paper presents the extended Kalman filter (EKF) coupled with neural network [5,6] as a state estimator for VSLAM of the mobile robot. Neural extended Kalman filter (NEKF) is trained on-line in order to approximate an error between the theoretical motion model and the actual motion of an object; NEKF for SLAM problem is an adaptive technique that uses neural network's ability to model functions in order to capture dynamics not contained a priori in the mathematical motion model of the mobile robot [1].

1.1. NEKF for monocular SLAM

NEKF is a recursive state estimator that combines two steps in estimation: prediction and update [1-4]. In the prediction step of NEKF the state vector and the state covariance are propagated using standard state propagation equations [1-3].

$$\hat{\mathbf{x}}_{k|k-1} = \begin{bmatrix} \hat{\mathbf{x}}_{v(k|k-1)} \\ \hat{\mathbf{x}}_{w(k|k-1)} \\ \hat{\mathbf{x}}_{m(k|k-1)} \end{bmatrix} = \begin{bmatrix} \mathbf{f}_M(\cdot) + \mathbf{x}_{vNET} \\ \hat{\mathbf{x}}_{w(k|k-1)} \\ \hat{\mathbf{x}}_{m(k|k-1)} \end{bmatrix}. \quad (1)$$

$\mathbf{f}_M(\cdot)$ stands for theoretical motion model, $\mathbf{x}_{vNET} = \mathbf{g}(\hat{\mathbf{x}}_{v(k-1|k-1)}, \hat{\mathbf{x}}_{w(k-1|k-1)}, \mathbf{u}_{k|k-1})$ is network output, $\hat{\mathbf{x}}_{v(k-1|k-1)}$ is an estimate of the robot state at $k-1$, and $\mathbf{u}_{k|k-1}$ is the control vector that initiates motion of the robot from state $k-1$ to state k. The main difference between NEKF and EKF SLAM in the first step can be seen in the state prediction where the output of neural network $\mathbf{g}(\cdot)$ is introduced. As in standard EKF, update step is then performed in the same manner [1-3]:

$$\begin{aligned} \mathbf{S}_k &= \mathbf{H}_k \mathbf{\Sigma}_{k|k-1} \mathbf{H}_k^T + \mathbf{R}_k \\ \mathbf{K}_k &= \mathbf{\Sigma}_{k|k-1} \mathbf{H}_k^T \mathbf{S}_k^{-1} \\ \hat{\mathbf{x}}_{k|k} &= \hat{\mathbf{x}}_{k|k-1} + \mathbf{K}_k (\mathbf{z}_k - \hat{\mathbf{z}}_k) \\ \mathbf{\Sigma}_{k|k} &= (\mathbf{I} - \mathbf{K}_k \mathbf{H}_k) \mathbf{\Sigma}_{k|k-1} \end{aligned} . \quad (2)$$

$\hat{\mathbf{x}}_{k|k-1}$ and $\mathbf{\Sigma}_{k|k-1}$ are predicted joint state vector and its covariance; $\mathbf{H}_k$ is the Jacobian of the measurement model; $\mathbf{S}_k$ is the innovation covariance, $\mathbf{R}_k$ is the measurement covariance matrix and $\mathbf{K}_k$ is the filter gain. $\hat{\mathbf{x}}_{k|k}$ and $\mathbf{\Sigma}_{k|k}$ represent the updated values of the joint state vector and its covariance. The reader is kindly referred to [1] for further background information related to EKF, NEKF, SLAM, extracting image features from monocular camera and other concepts used to solve the initial problem.

2. EXPERIMENTAL RESULTS

Experiments were conducted in a laboratory model of a manufacturing environment with Khepera II mobile robot and the simple USB web camera on top of it (Fig. 1). NEKF algorithm for state estimation within monocular SLAM framework is implemented in Matlab environment, which is used to control the robot as well. A desktop computer (AMD Athlon on 2.20 GHz; 1 GB of RAM) was used as a central control unit achieving communication via standard RS232 cable with the robot and via USB cable with the camera.

Fig. 1. The laboratory model of a manufacturing environment and the mobile robot Khepera II with USB camera

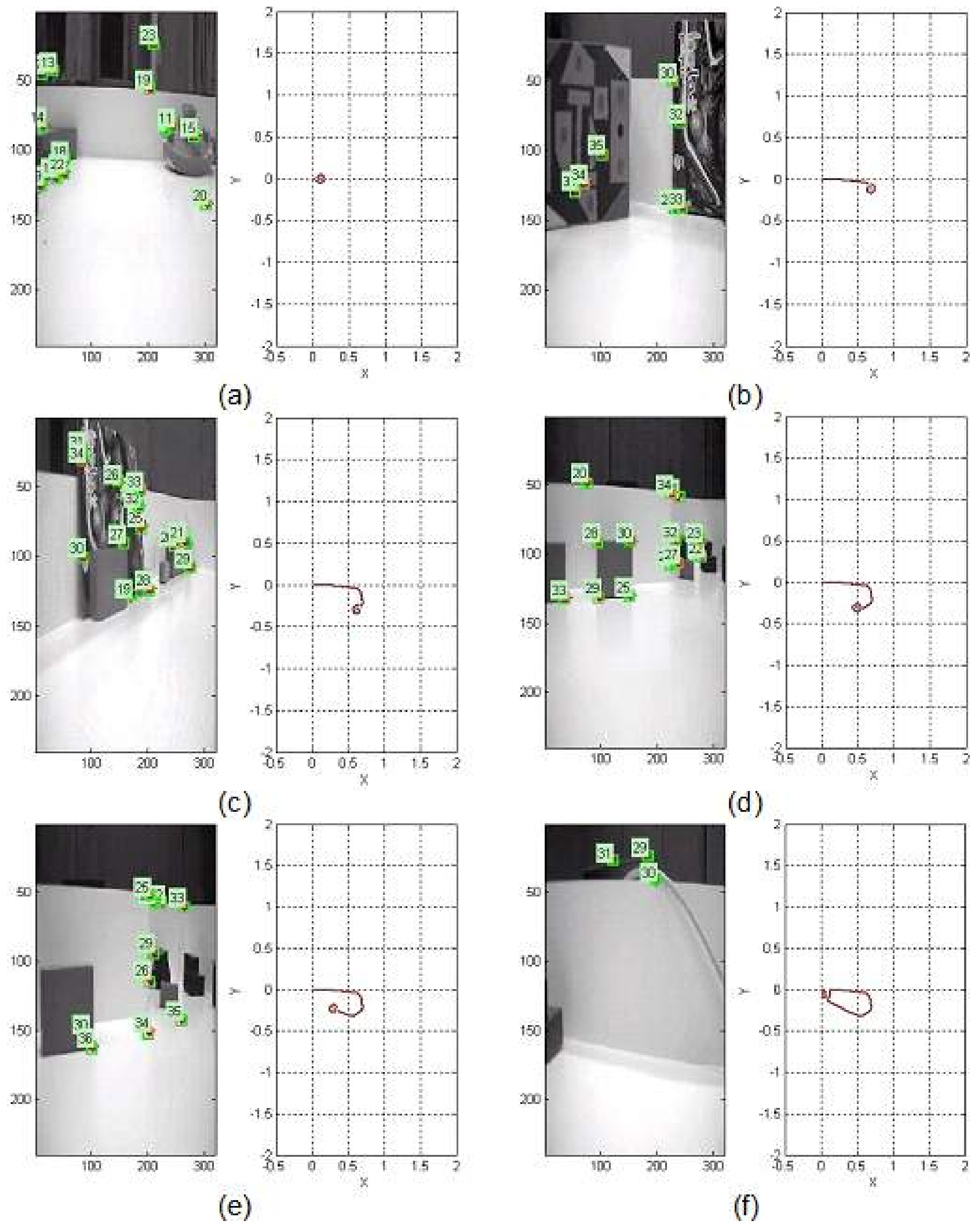

Fig. 2. Chosen frames during experimental run. The figure is formed by an image from the camera (on the left hand side) and the estimated path of NEKF (the right hand side)

The path consists of multiple translations and rotations with a total length of approximately 1.9 m. To compare NEKF path estimates a simple procedure is applied: each time the mobile robot performs incremental motion, the experimentator manually labels current pose of the mobile robot with the pen on the surface in the laboratory model. When the mobile robot reaches end point, the path can be easily reconstructed by reading of coordinates of manually labeled positions of the mobile robot. Euclidian distance between manually labeled path and the robot positions is chosen as an error measure (path error):

$$e = \sqrt{(\mathbf{r}^{w}_{nekf} - \mathbf{r}^{w}_{labeled})^{T} (\mathbf{r}^{w}_{nekf} - \mathbf{r}^{w}_{labeled})} \, . \quad (3)$$

$\mathbf{r}^{w}$ denotes the path with respect to the world coordinate system. Table 1 shows the results, while Fig. 2 shows results of typical experimental run.

Table 1. Path error, Mean Absolute Error and maximum error for five repetitions of experiment

	NEKF	EKF	Odometry
Path error [m]	0.4002	0.4258	0.800
MAE [m]	0.0155	0.0166	0.0369
Maximum Error [m]	0.0636	0.0675	0.1044

Experimental results revealed that while performing the translation motion there are more successful feature matches than during rotation. On average, the number of matched features drops while robot performs rotation. This is a direct consequence of lighting conditions; much attention is given to this issue with "artificially" increased diversity in the environment by introducing multicolored objects (Fig. 2).

Fig. 3 shows path estimates of NEKF, EKF and odometry plotted versus manually labeled path. During the first steps of motion, both NEKF and EKF recognized a situation when the robot drifts away from the designed path. Odometry fails to recognize this and its path estimate is far from the real one. This odometric error is propagated through the forthcoming steps, which makes odometry estimated path unreliable.

As the robot keeps on moving, the rotation induces an error in NEKF and EKF estimates due to decreased number of features (there are less features for the update step). As the number of successfully matched features increases, the path estimates are getting closer to the actual path. It takes a number of steps for the NEKF and EKF to adapt to the rotation of the robot. Although the difference between NEKF and EKF path estimates are visible from the first rotation (Fig. 3), NEKF starts diverging from EKF during the fourth translation. The difference is especially visible at the very end of the fourth translation, during the fourth rotation and during final motion - the fifth translation. On line modification of connecting weights of neural network imposes a number of estimation steps in order to learn unknown dynamics. As the final outcome, NEKF produces path estimate closer to the real path than EKF (Fig. 3) [1].

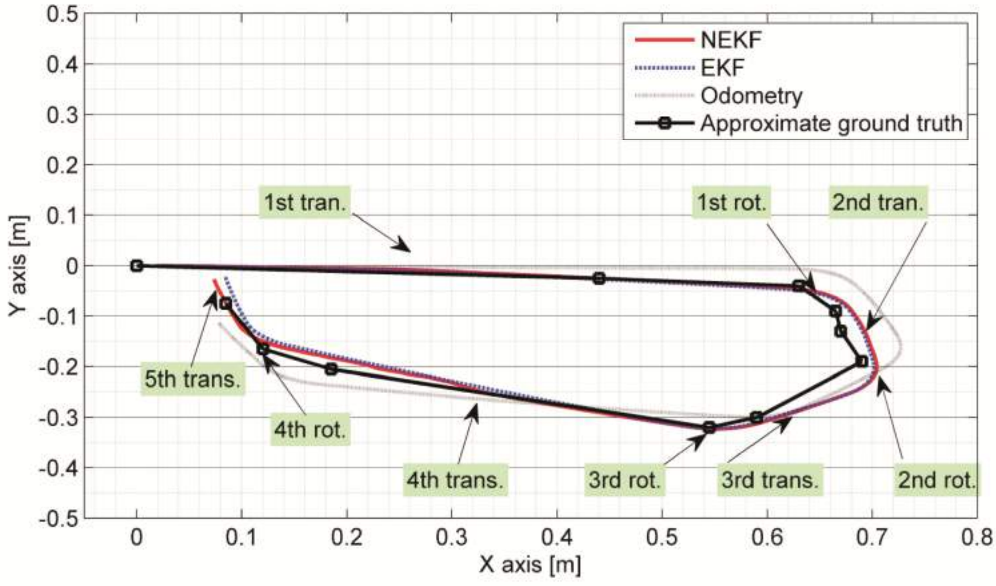

Fig. 3. Path estimates of NEKF, EKF, odometry and approximate ground truth (manually labeled)

3. CONCLUSION

The implementation of neural extended Kalman filter is achieved in terms of the monocular SLAM problem: multi-layer perceptron neural network is coupled with EKF to improve the state transition model. The main advantage of NEKF is the ability of the neural network to learn a model of the system on-line [6]. The paper showed that the introduction of neural network has resulted in higher accuracy of NEKF than a "standard" extended Kalman filter implementation for monocular SLAM. Multiple repetitions of experiment are performed, and experimental results indicate that NEKF outperforms EKF and odometry in terms of accuracy [1,2,4].

Future work could be extended through implementation of other Gaussian filters (Unscented Kalman Filter or Extended Information Filter) and different types of feedforward neural networks (Radial Basis Function or maybe even Hyper Basis Function [6]). To achieve real time performance of 30 [Hz] additional hardware is necessary. Finally, through experiments with the mobile robot and simple USB web camera, we have showed that this approach can be applied but we are looking forward to implement it in the real manufacturing environment and assess its performance.

Acknowledgments: This work is supported by the Serbian Government - the Ministry of Education, Science and Technological Development under grant *TR35004*.

REFERENCES

[1] VUKOVIĆ, N. "Machine Learning of Intelligent Mobile Robot Based on Artificial Neural Networks". *Ph.D. dissertation* (In Serbian). University of Belgrade – Faculty of Mechanical Engineering, 2012.

[2] MILJKOVIĆ, Z., VUKOVIĆ, N., MITIĆ, M., BABIĆ, B. "New Hybrid vision-based Control approach for automated guided vehicles". Journal: *International Journal of Advanced Manufacturing Technology* 66(1-4): 231-249, 2013.

[3] BABIĆ, B., MILJKOVIĆ, Z., VUKOVIĆ, N., ANTIĆ, V. "Towards Implementation and Autonomous Navigation of an Intelligent Automated Guided Vehicle in Material Handling Systems", Journal: *Iranian Journal of Science and Technology - Transactions B: Engineering* 36(M1): 25-40.

[4] VUKOVIĆ, N., MILJKOVIĆ, Z., MITIĆ, M., BABIĆ, B., LAZAREVIĆ, I. "Autonomous navigation of Automated Guided Vehicle using monocular camera", *Proceedings of 11th International Scientific Conference MMA 2012 – Advanced Production Technologies*, University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia, 2012.

[5] MILJKOVIĆ, Z., ALEKSENDRIĆ, D. "Artificial neural networks—solved examples with theoretical background" (In Serbian). University of Belgrade-Faculty of Mechanical Engineering, Belgrade, 2009.

[6] VUKOVIĆ, N., MILJKOVIĆ, Z. "A Growing and Pruning Sequential Learning Algorithm of Hyper Basis Function Neural Network for Function Approximation", Journal: *Neural Networks*, 46C:210-226; DOI: 10.1016/j.neunet.2013.06.004, 2013.

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PREDICTION OF ROBOT EXECUTION FAILURES USING NEURAL NETWORKS

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In recent years, the industrial robotic systems are designed with abilities to adapt and to learn in a structured or unstructured environment. They are able to predict and to react to the undesirable and uncontrollable disturbances which frequently interfere in mission accomplishment. In order to prevent system failure and/or unwanted robot behaviour, various techniques have been addressed. In this study, a novel approach based on the neural networks (NNs) is employed for prediction of robot execution failures. The training and testing dataset used in the experiment consists of forces and torques memorized immediately after the real robot failed in assignment execution. Two types of networks are utilized in order to find best prediction method - recurrent NNs and feedforward NNs. Moreover, we investigated 24 neural architectures implemented in Matlab software package. The experimental results confirm that this approach can be successfully applied to the failures prediction problem, and that the NNs outperform other artificial intelligence techniques in this domain. To further validate a novel method, real world experiments are conducted on a KheperaII mobile robot in an indoor structured environment. The obtained results for trajectory tracking problem proved usefulness and the applicability of the proposed solution.

Keywords: *Neural networks, mobile robot, execution failures, prediction method*.

1. INTRODUCTION

Nowadays, one of the most desirable features of every robotic system is the ability to adapt to the real world changing conditions. This is especially important for robots working in the hazardous and dangerous surroundings where unwanted events frequently interfere in task accomplishment. Likewise, failure prediction is equally important in these environments in which repairs are often infeasible and failures can have disastrous consequences [1]. In industrial robotics, failure prediction and fault tolerance are helpful in reduction of a system down-time in the following manner: by tolerating failures robot’s lifespan is increased, and by identifying faulty components or subsystems to speed up the repair process [2]. Also, the reliability of a product manufacturing and increased human safety is ensured by implementing fault tolerance and failure prediction unit in the robotic system.

Neural networks (NNs) are a well-known tool used as a solution for various engineering problems [3]. They can understand the relationship or mapping between input and output variables during the training process using different learning algorithms. In robotics, this artificial intelligence technique is often applied for control of a mobile robot [4], or a robot manipulator [5]. For failure problems, the NNs are usually employed in the assembly tasks, prediction of failure rates of large number of the centrifugal pumps or in the robust scheme for robot manipulators. However, despite various mentioned applications, the robot failure prediction based on the soft computing methods has not been reported in the literature so far. This study delivers a novel approach using multilayer feedforward neural networks as a solution for this problem, and also presents performance comparison of different learning algorithms and architectures. In addition, the original prediction method is successfully implemented and tested on a real mobile robot in indoor environment for solving trajectory tracking problem.

2. PROBLEM STATEMENT

The problem treated in this study refers to the failure detection in a robot system; more specifically, this work treats the robotic failure prediction problem using neural networks and a set of recorded sensor measurements. Consider a robotic system working in a structured or unstructured environment exposed to severe conditions such as: increased working hours, changeable working demands, possibility of collision with known/unknown objects, and/or presence of human workers near the robot workspace. In these cases it is crucial to ensure maximum safety and smallest deviation from the nominal operating mode by recognizing irregularities in robot behaviour. In this study, the recorded sensor measurements (forces and torques) memorized during the execution of failed tasks, such as collision and obstruction during robotic assembly, are used in order to predict future unwanted behavior of the robot. The NNs are then trained with this data (and also with nominal sensor measurements), in order to distinguish good and bad robot behavior. Finally, trained NNs are used to predict the future undesirable conduct of the system in hand.

In order to successfully predict execution failures, some sort of safety unit must be employed in the robotic system. In this case, the NNs are used in the control system as an element for predicting misbehaviour based on the corrupted internal/external measurements. In this paper, trajectory tracking problem is solved by employing the

NN-based unit that is used to predict irregular behaviour in wheel control domain. Consider that mobile robot wheels command unit is not working properly all the time, and that in certain control iterations it gives unexplainable large/small commands for tracking the specific trajectory. In this case, NNs can predict these irregularities, with the aim to invoke a nominal control value in the command dataset. In this manner, the bad wheel command is replaced with the desired (calculated) value, and the robot motion is continued without difficulties.

3. METHODS

The data used in this study is obtained from a real system, and refers to the evolution of forces (F) and torques (T) during execution of a specific task. In order to correctly evaluate and compare various NN algorithms and architectures, the failures in approach to grasp position are considered. Each feature in the dataset represents a force or torque value measured immediately after failure detection. Total number of instances is 88, and each instance consists of 15 sensor measurements (i.e. samples) collected at regular time intervals. Three values of forces and torques are founded in each sample; therefore, one instance has 90 different features (i.e. the values of F and T). This data is available via well-known machine learning repository:
http://www.ics.uci.edu/~mlearn/MLRepository.html.
In the failure dataset, 4 different robot situations (i.e. data classes) can be identified: normal, collision, obstruction and front collision with the distribution of 24%, 19%, 18% and 39%, respectively.

In this study 24 different architectures were investigated, including the networks with one, two or three hidden layers. The network structure marked as 8-4-2 means that there are 8 neurons in the first hidden layer, 4 in the second hidden layer, and 2 in the third hidden layer. As mentioned, the NN input and output are single column vectors since they represent scaled values of recorded sensor measurements and corresponding robot situations. Employed network architectures are listed in table 1.

Table 1. NN architectures tested in experiments

No.	NN Arc.	No.	NN Arc.	No.	NN Arc.	No.	NN Arc.
1	1	7	1-1	13	2-2-2	19	3-3-3-3
2	2	8	2-2	14	3-2-2	20	4-3-3-3
3	3	9	3-2	15	4-3-2	21	5-4-3-3
4	5	10	5-2	16	5-3-2	22	8-5-4-3
5	8	11	8-4	17	8-3-2	23	10-8-4-3
6	10	12	10-4	18	8-4-2	24	10-8-5-4

4. EXPERIMENTAL RESULTS

The verification of NN prediction performance is conducted using Intel® Core™ 2 Duo 2.1 GHz processor laptop computer with 2.96 GBs RAM on Windows XP platform. The Matlab 2009a (v. 7.8.0.347) is employed for algorithm implementation and testing. In order to find optimal NN, all architecture and algorithms are tested several times, and the best performance is presented in this study.
The testing results in terms of Mean Squared Error (MSE) for Elman NN and feedforward NN with Bayesian Regularisation [6] algorithm are given in Fig. 1 and Fig. 2, respectively.

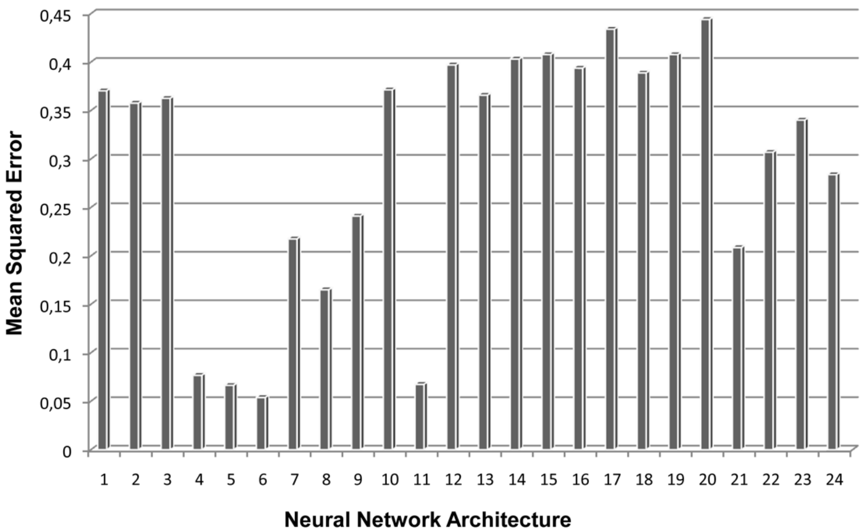

Fig. 1. Results of Elman NN testing

The identification of particular class is based on the values and/or relationships between measured forces and torques

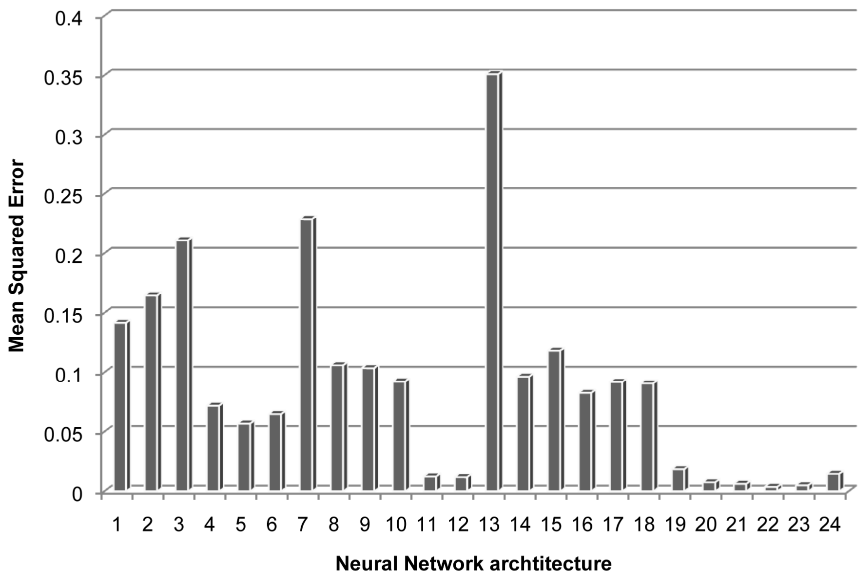

Fig. 2. Results of feedforward BR NN testing

As it is obvious from Fig.1 and Fig.2 the BR NN showed overall better results. Smallest MSE was reported for NN No. 23 in Table 1, so this one is implemented for trajectory tracking.

One can consider the case in which the robot wheels command unit is not working properly, i.e. the situation in which several control commands have unwanted values regarding tracking the particular trajectory. If the wheel command in every control iteration is not as expected (calculated), the mobile robot could make a significant error or even completely mis-track the desired trajectory.

Input to the network are scaled right and left wheel commands, while the output represent successful or incorrect failure prediction. We tested *M-shaped* trajectory several times, and the results of one test is presented in Fig. 3 (the red line denote the robot orientation in every control iteration) and Fig. 4. The experiments confirmed the usefulness of the proposed approach: in more than 99 percent of the cases, the network successfully predicted the failure prediction. In addition, in order to successfully track chosen trajectory, failed values are replaced with the desired information. The result shows that the mobile robot is able to track each trajectory, and that robot poses do not significantly differ from the wanted ones in every time instant [7].

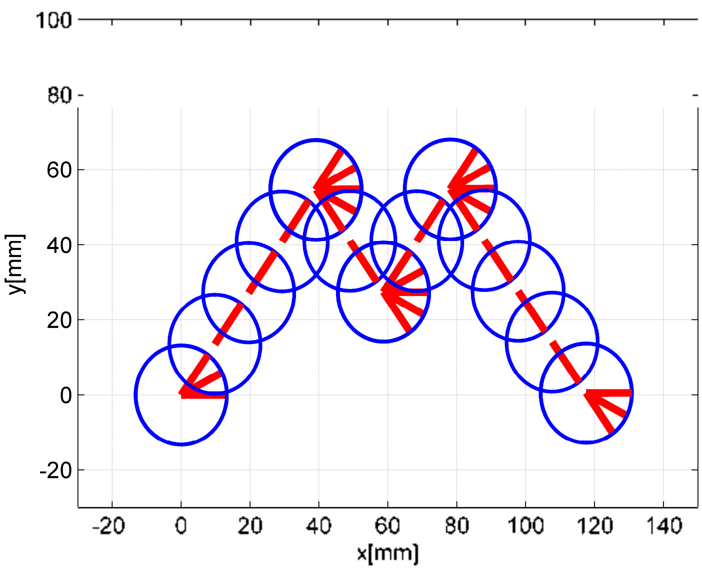

Fig. 3. *M-shaped trajectory tracking*

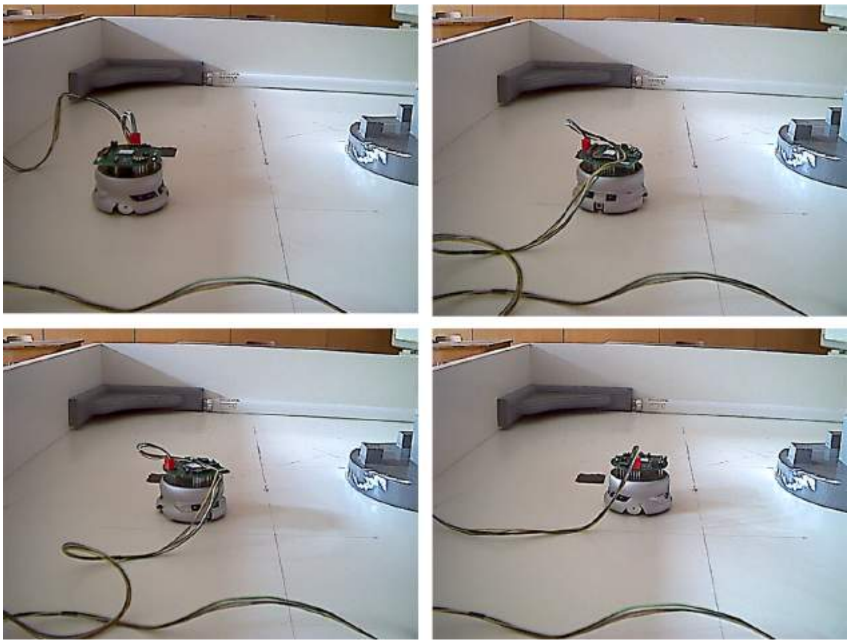

Fig. 4. *Real world experiment in a manufacturing environment using KheperaII mobile robot*

5. CONCLUSION

In this paper, a novel approach for robot failure prediction based on the neural networks (NNs) is presented. A successful mapping from the execution forces and torques to the 4 possible cases that correspond to the particular input (normal, collision, obstruction or front collision) is developed using NNs. The training dataset consists of a real robot data that is recorded immediately after the system failure during the execution of the specific task. In order to fully show the robustness of the proposed approach, several real world experiments for trajectory tracking are conducted on a *KheperaII* mobile robot. Results show usefulness and the applicability of the proposed approach [7].

Acknowledgments: This work is supported by the Serbian Government - the Ministry of Education, Science and Technological Development under grant *TR35004*.

REFERENCES

[1] Dixon, W., Walker, I., Dawson, D., et al. “Fault detection for robot manipulators with parametric uncertainty: A prediction-error-based approach”. Journal: *IEEE Trans Robot Autom* 16(6): 689–699, 2000.

[2] Visinsky, M., Cavallaro, J., Walker, I. “Robotic fault detection and fault tolerance: A survey”. Journal: *Reliab Eng Syst Safety* 46(2): 139–158, 1994.

[3] Miljković, Z., Vuković, N., Mitić, M., Babić, B. “New Hybrid vision-based Control approach for automated guided vehicles”. Journal: *Int J Adv Manuf Technol* 66(1-4): 231–249, 2013.

[4] Vuković, N., Miljković, Z., Mitić, M., Babić, B., Lazarević, I. “Autonomous navigation of Automated Guided Vehicle using monocular camera”, *Proceedings of 11th International Scientific Conference MMA 2012 – Advanced Production Technologies*, University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia, 2012.

[5] Miljković, Z., Mitić M., Lazarević, M., Babić, B. “Neural network reinforcement learning for visual control of robot manipulators”. Journal: *Expert Syst Appl* 40(5): 1721–1736,2013.

[6] Miljković, Z., Aleksendrić, D. “Artificial neural networks—solved examples with theoretical background” (In Serbian). University of Belgrade-Faculty of Mechanical Engineering, Belgrade, 2009.

[7] Diryag, A., Mitić, M., Miljković, Z. “Neural Networks for Prediction of Robot Failures”. Journal: *Proc ImechE Part C: Journal of Mechanical Engineering Science* (ISSN 0954-4062), Article in press, Sage, United Kingdom, http://pic.sagepub.com/content/early/2013/10/09/0954406213507704.abstract (first published on October 10, 2013 as DOI: 10.1177/0954406213507704).

Education in the field of manufacturing engineering

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SWOT ANALYSIS AS A TOOL FOR TEACHING ENGLISH

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Abstract: *This paper presents SWOT analysis in a different context. SWOT is a general tool designed to be used in the preliminary stages of decision-making. It takes into account Strengths and Weaknesses as the factors that exist within an organization and Opportunities and Threats as the factors that exist outside of the organization. This paper shows how this technique can be used in an English class, with a group of ESP students. SWOT itself can inspire students to participate in communication and at the same time help them learn or improve their grammar and vocabulary. The subject of SWOT analysis can be determined together with the students, and the class may result in a lot of fruitful ideas. Such a novelty in class contributes to the use of communicative approach in teaching English.*

Key words*: SWOT analysis, English language, ESP students*

1. INTRODUCTION

The SWOT analysis is a strategic planning method, i.e. an analytical tool designed to be used in the preliminary stages of decision-making [1]. It was created by Albert Humphrey in the 1960s. This technique is as useful now as it was at that time. Although it can be used for personal objectives, SWOT is commonly performed at the level of an organization. It may serve as a simple icebreaker helping people get together to "kick off" strategy formulation, or in a more sophisticated way as a serious strategy tool [2].
SWOT is sometimes confused with possible strategies. To clarify this confusion, it can be said that SWOTs are descriptions of conditions, while possible strategies define actions.
This paper deals with the SWOT analysis as a useful tool for teaching English, especially in a class of ESP students who may already have been introduced to this technique. The author suggests the grammatical points and terminology which can be revised or taught.

2. SWOT ANALYSIS

The acronym SWOT stands for Strengths, Weaknesses, Opportunities and Threats. These four factors are categorized into Internal and External Factors. For this reason the SWOT Analysis is sometimes called Internal-External Analysis, and its result, SWOT Matrix, is sometimes called an IE Matrix.
The mentioned matrix has the form of four quadrants dedicated to the four factors. Bullet points may be the best way to organize the ideas in the matrix.
The SWOT analysis begins by conducting an inventory of strengths and weaknesses in an organization. The first quadrant contains its ***Strengths***, i.e. its characteristics understood as an advantage if the organization is compared to its competitors. Strengths include the positive attributes of the employees, their knowledge, backgrounds, education, contacts, reputations, skills, etc. Strengths also include tangible assets, such as available capital, infrastructure, equipment, established customers, existing channels of distribution, copyrighted materials, patents and other valuable resources. The talk about Strengths is an opportunity to remind the participants in SWOT of the values existing within the organization. Strengths are internal, which means that they are within the control of the organization. They must continue to be developed, maintained and defended.
The notes organized through bullet points in the first quadrant should answer the questions such as:

- What do you do well?
- What advantages does your organization have?
- What do you do better than anyone else?
- What do others see as your strengths?
- What resources do you have?

Objectivity is always required while answering, and modesty should be avoided. Each variable in the matrix should be kept short, concise and clear, without unnecessary details.
Weaknesses are the limitations that hinder the progress of the organization or the characteristics that place the organization at a disadvantage relative to others. Like Strengths, they are under control, but for a variety of reasons, are in need of improvement to effectively accomplish the objectives set by the organization. The more accurately you identify your weaknesses, the more valuable the SWOT will be. You ought to be realistic and face any unpleasant truths as soon as possible. Weaknesses may include negative images or bad reputation, poor quality products, poor financial management, poor delivery, incompetent personnel, etc. All these characteristics need to be remedied or stopped.
Possible questions that could be posed here are as follows:

- What could you improve?
- What should you avoid?

- What are some of the “out-dated” or inefficient equipment?
- What are others likely to see as your weaknesses?
- Where do you have fewer resources than others?

Opportunities refer to any favourable situations or chances outside the organization. Being external, they are not under control. They are on the positive side of the SWOT matrix and therefore the organization should try to use them as wisely as possible. Prioritization and optimization of Opportunities can make them potential future Strengths. The skill to discover new opportunities is certainly helpful and should be constantly strengthened. Opportunities may cover positive demographic and economic trends, e.g. reduction of unemployment, then political and governmental stability, technological changes, changes in government policy or legislation related to the organization, lifestyle changes, development of the local community, social and cultural aspects, etc.

These are the questions that should be answered in the third quadrant dedicated to Opportunities:

- What might be possible or may happen in the near future?
- What trends could you take advantage of?
- Who might you want to work with?
- What financial/governmental/legislative changes can benefit you in the near future?
- How may new technologies change your practices?

Threats are external, i.e. beyond the control of the organization. They are negative environmental factors that can cause troubles and hinder the organization in achieving its objectives and goals. It may be valuable to classify threats according to their “seriousness” and “probability of occurrence”. Threats need to be properly managed or minimized. The better the organization is at identifying potential threats, the more likely it can position itself to respond to them. Awareness of Threats resulting in plans to address them if they should occur is the first step toward the elimination of the possibility for them to become future Weaknesses. The factors that can cause harm to the organization may include new government regulations with negative impacts on the organization, emergence of new technology with an unfavourable influence on the financial performance and business operations, trends in the same branch of industry which the organization cannot cope with for various reasons, etc.

The fourth quadrant should be filled in with the answers to this type of questions:

- What obstacles do you face?
- What trends could harm you?
- What are “rival” organizations doing?
- Are there any new regulations that may be barriers to your development?
- Will new technologies affect your activities?

Weaknesses and Threats must not be hidden or underestimated. If they are ignored now, they may cause a lot of problems at a later stage, when they are forgotten or least expected.

When the participants in SWOT recognize and analyze Strengths, Weaknesses, Opportunities and Threats, they may also address some well designed “cross” questions, such as:

- How can the organization use its Strengths to take advantages of its Opportunities?
- How can the organization use its Strengths to overcome its Threats?
- What does it need to overcome its Weaknesses in order to take advantage of its Opportunities?
- How will the organization minimize its Weaknesses to overcome its Threats?

The SWOT analysis is defined as situation analysis, but evaluation of the present situation runs the risk of being useless and ineffective if it does not lead toward subsequent actions for accomplishing an objective. Having identified its Strengths, Weaknesses, Opportunities and Threats, the organization can use the obtained framework to start crafting a strategy that helps it distinguish itself from its competitors, so that it could compete successfully in the market.

3. SWOT AND TEACHING ENGLISH

The SWOT analysis is taught within some subjects dealing with business, management, engineering, etc. However, it can also be used as a tool for teaching English, particularly in a class of ESP (English for Specific Purposes) students. The students may already have become familiar with the SWOT analysis in their mother tongue, so another form of exploitation of this topic can build on the knowledge they have gained and unobtrusively flavour it with some grammar and specialized terminology.

The suggested size of the initial group that should be gathered to carry out a SWOT is small, normally 4 to 10 persons [3]. Ideally, it should be a cross-functional team or a task force that represents a broad range of perspectives. For example, a SWOT team in an organization may include an accountant, a salesperson, an executive manager, an engineer, etc. As for a class of ESP students, this condition cannot be satisfied if the SWOT analysis is to be carried out with large groups of students. It is also clear that for such a task the students’ knowledge of English should be at a higher level.

Judging by the experience of the author of this paper, the optimum time envisaged for a SWOT analysis in a class of ESP students should be 90 minutes. Small amounts of time are not enough to cover the theoretical part about SWOT, explain the grammatical points and necessary vocabulary and finish the class with a short test SWOT analysis. A time period exceeding 90 minutes or possible continuation of the SWOT analysis after a couple of days could be too demanding. The purpose of carrying out a SWOT in a class of ESP students is, actually, to realize a successful English class, inspiring and innovative, and not the SWOT analysis itself. The students should leave the classroom with a feeling of increased self-confidence because they have been involved in an unusual kind of discussion and because they have expressed their ideas and opinions openly and for the benefit to a wider group.

It is up to the teacher to carefully choose the topic, i.e. the subject of their SWOT analysis, and thus motivate the students to participate actively and freely in the conversation. If the topic is hard to deal with or if it does not coincide with the students' interests, then the SWOT analysis cannot result in fruitful ideas and a relaxed atmosphere in class. The communicative approach to the teaching of foreign languages here proves its advantages.

The class should begin with some introductory notes about the SWOT analysis to make the students feel at home because it is just a revision of what they have already been acquainted with. But, this time the theoretical speech about SWOT is not in their mother tongue – it is in English. As the class goes on, the students become slowly aware that they start refreshing their memory, correcting their mistakes and acquiring new vocabulary. The continuation of this paper suggests some grammatical points that could be revised, with examples, and the vocabulary that could be introduced.

3.1. Word formation

Word families and word formation are sometimes neglected in teaching foreign languages. Words are often learnt by heart and forgotten easily if they are not frequently repeated. Students should be taught how to play with words, how to add suffixes in order to make a noun an adjective, etc. The precondition for the success in this play is the fairly good knowledge of their mother tongue, i.e. its grammar. In other words, if they are apt to "juggle" words in their own language, they will be able to do the same with foreign words.

While introducing the SWOT analysis and its quadrants with Strengths, Weaknesses, Opportunities and Threats, the teacher can take some time to draw the students' attention to the mentioned nouns. The students will be reminded that *strength* is a noun which makes a word family with the verb *strengthen*, the adjective *strong* and the adverb *strongly*. Then, there are *weakness* and *threat*, which can also invite students to think of the verbs or adjectives with the same root. A table can be drawn and whenever an interesting word for this "juggling" arises, the students can be asked to enter its form in the corresponding column. They should not feel obliged to fill all columns for every word. Sometimes a word will not have all of the forms, or they are rarely used.

Table 1 shows ten examples that will most probably be encountered while talking about the SWOT analysis.

Table 1. Word families

noun	**verb**	**adjective**
strength	strengthen	strong
weakness	weaken	weak
threat	threaten	threatening
efficiency	-	efficient
competition	compete	competitive
vulnerability	-	vulnerable
success	succeed	successful
achievement	achieve	achievable
accomplishment	accomplish	accomplished
sustainability	sustain	sustainable

If the students are taught how to manipulate parts of speech in a sentence, they will increase their vocabulary by e.g. three words instead of one. It is beneficial to advise students to create their own tables that can be added with new word families.

3.2. Antonyms

Antonyms in a foreign language should be learnt as pairs of words with opposite meanings. If, from the first occurrence of a new word, students are told its antonym, and if illustrative examples of their usage are immediately presented, the antonyms will be remembered more easily. The SWOT analysis is built of contrasts and therefore full of antonyms that can be exploited in class.

Students are always encouraged to guess the antonym of a word if they are not sure what the correct answer is. The easier examples are used for the students who are shy, reserved or unwilling to take part in the discussion because they feel that their knowledge of English does not allow them to take a more active part in the conversation. The more they participate, the more they become interested in the common task. The students' confidence in the method is largely in the hands of the most important factor affecting intrinsic motivation – the teacher [4]. It is up to the teacher to prepare a range of various questions for their students in advance. Easy tasks, such as *What is the antonym of the word **external**?* or *What is the antonym of the word **low**?* will be assigned to the students with poorer knowledge of English and this approach will constantly keep them "awake" and responsive. The acronym SWOT as the core of the whole topic contains the first two pairs of antonyms. Another table can be created and the students will add new rows as they discover new opposites.

Table 2 lists ten antonyms that can be mentioned while dealing with the SWOT analysis. The list is added depending on the chosen topic and the words required.

Table 2. Antonyms

strength	weakness
opportunity	threat
external	internal
low	high
simple	complex
out-dated	modern
subjective	objective
increase	decrease
narrow	wide
short-term	long-term

Antonyms in the English language can be formed with negative prefixes or the negative suffix *–less*. A large number of them appear in the SWOT analysis, so their revision can be done either as a separate topic within the class or it can be done parallel with the ongoing discussion. Whichever manner of revising is chosen, the students should never have the impression that they are burdened with too much grammar.

Table 3 with the words that are likely to be treated in the SWOT analysis is another suggestion in this paper. It reminds of seven negative prefixes and the negative suffix *–less.*

Table 3. Negative prefixes and the suffix –less

negative prefixes/suffix -*less*	examples
DIS-	DISadvantage, DISapprove
UN-	Unfavourable, UNemployment
IR-	Irresponsible, IRregular
IM-	IMpossible, IMpartial
IL-	ILlegal, ILliterate
IN-	INefficient, INstability
MIS-	MISuse, MISunderstand
-LESS	meaningLESS, useLESS

Students remember best when they have actually done something with the words they are learning. They should be aware that words do not exist on their own but live with other words and depend upon each other. The acquisition of grammar and the acquisition of vocabulary are interdependent. That is why the teacher should always look for an opportunity to interest their students in a context [4]. The above words from Table 3 can be of better use if the students are inspired to talk about e.g. *disadvantage* of a location, *unemployment* rate, *irresponsible* employees, *impossible* deadlines, computer *illiterate* staff, political *instability*, *misuse* of equipment, *useless* meetings, etc.

3.3. Question making and modal verbs

When the teacher starts introducing the SWOT analysis and its four quadrants, the students will be faced with question making. For some of them the issue of how to make a question in the English language is difficult if they have been used only to producing answers to their teachers. The SWOT analysis gives an opportunity to the teacher to check the students' knowledge of question making and correct possible mistakes. When students know how to produce their own questions, they take greater ownership of their learning and become more engaged in searching for the answers.
Several examples of typical questions used for the quadrant Strengths could be enough to inspire the students to make correct question forms for the other three quadrants. The teacher should not stop to open a discussion or answer any of the questions posed.
The SWOT questions deal with abilities and possibilities or the lack of them and therefore often contain modal verbs. It is desirable at this point to briefly repeat the meaning and usage of at least *can, could, may, might, must* and *should*. The questions such as *What could you improve? What should you avoid? What might be possible?* repeat the same word order (question word, modal verb, subject, main verb) and the students will easily remember that formula. After the production of similar questions, which are meaningful in the SWOT context, the students will feel communicatively efficient and willing to make more complex question forms.

3.4. Vocabulary

Although grammar and vocabulary are not two straight lines without an intersection point, they are separated in this paper just for the purpose of suggesting some terminology.
The vocabulary that will be used in a class dedicated to the SWOT analysis depends to a large extent on the topic agreed or the objective set. Whatever the topic is, the teacher should have a number of previously selected words and phrases which can be an appropriate input in the process of facilitating the discussion. They can be either delivered to the students as a "finished product", i.e. the assistance provided by the teacher if the students feel the lack of the necessary terminology, or presented in a broader context to the students who will be asked to guess or describe the meanings.
The suggested terms which can be helpful for the SWOT analysis in a group of ESP students are as follows:
timeframe, time-consuming, ongoing, stakeholder, prioritize, effective, efficient, assessment, evaluation, implementation, engagement, loyalty, commitment, competitive, short- and long-term, reliability, up-to-date, state-of-the-art, demand, supply, revenue, distinctive, competent, etc.
The SWOT analysis technique was tried in a class of master's students at the Faculty of Mechanical and Civil Engineering in Kraljevo. The group consisted of six persons. The teacher gave them the task to use SWOT for making a situation analysis of the Faculty. They gladly accepted it and were easily facilitated throughout the class. A professor who is fluent in English also joined the group, which added to the success of the class. The outcome can be both the topic of another paper and a useful tool in the hands of the management of the Faculty.

4. CONCLUSION

The suggestions presented in this paper allow the SWOT analysis to be treated as a possible tool in a class of ESP students. Discussion on the subject agreed should be unobtrusively interwoven with the revision of selected grammatical points and introduction of new vocabulary.
The desired aim is to strengthen students' self-confidence for communication in a business environment.
This novelty in teaching ESP can be a spark for inventing other teaching tools that can both motivate students to get more involved in classroom activities and result in a tangible outcome like a SWOT matrix, which can be used for accomplishment of another goal.

REFERENCES

[1] BARTOL, K. M., & MARTIN, D. C. (1991) *Management*, McGraw Hill, New York

[2] NARAYANASAMY, N. (2009) *Participatory Rural Appraisal: Principles, Methods and Application*, Sage Publications, Los Angeles

[3] European Community, Civil Protection Mechanism (October 2013) *SWOT Analysis, A Short Introduction*, missionitac.pbworks.com/f/swot.pdf,

[4] HARMER, J. (1997) *The Practice of English Language Teaching*, Longman, London and New York

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35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
Faculty of Mechanical and Civil Engineering in Kraljevo

MEASUREMENT OF NON-ELECTRICAL QUANTITIES BY ELECTRICAL MEANS IN STUDENT'S EDUCATION

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Abstract: *In students' education in engineering sciences, electrical measurement of mechanical quantities can often be found. Also, it is widely used in engineering applications such as mechanical load or temperature measurements.*
This paper provides an overview of strain measurement, and introduces the concept and characteristics of virtual instruments applied for that purpose. The conjunction of strain gauge with various measuring circuits, especially in the Wheatstone bridge configuration will be explained in detail. The model of electrical measurement used for students' education will also be described. The presented model is a learning tool applied in the laboratory for measurements. Special attention will be paid to the concept of virtual instrumentation which is very important in the field of engineering today. The objectives of this paper were to provide students with practical experience about the measurements of non-electrical quantities, such as force or temperature, by electrical means.

Key words: *Measurement, Students' Education, Virtual Instrument*

1. INTRODUCTION

Very important in engineering research is the study of material properties under the working conditions since the mechanical properties of materials changes with stress application. Because of the influence of some external or internal effects, such as force, or the structural change in material, the strain of a body will be the consequence. Within the elastic limit for many materials, the relationship between stress and strain is linear [1]. Stress cannot be measured directly but strain can. Therefore, measured strain and calculated stress for a given load are combined with the other properties of the material [2].
Strain, as the deformation of material, can occur due to many reasons, for example, because of the applied force or temperature change [3]. There are numerous methods in measuring strain or deformation, which are very often described. In order to estimate some of the mechanical quantities such as force, displacement or deformation, one can use transducers, whose electrical resistance is changed as a result of a variation of dimensions. Sensing elements or transducers, called strain gauges, are designed to measure strain [4]. The main area of the strain gauges application is in experimental stress analysis, diagnosis of machines and failure analysis [4]. The strain gauge is applied in many other fields, such as clinical orthopaedics [5], biomedical studies [6], civil engineering [7], automotive and aerospace industries [8].
The most convenient and used method is the resistance strain gauge. A strain gauge is usually bonded to the surface of the sample, so that any physical strain in the material can be transmitted to the strain gauge's resistive element. This leads to a proportional resistance change which can be measured by appropriate equipment. The suitable alternative to the common resistive strain gauge can be the proposed capacitive strain gauge [9].
Electrical measurement of mechanical quantities is frequent in engineering sciences. One example for that is an experiment of force measurement. In mechanical engineering, research load sensors use strain gauges, bonded to a metal beam. The applied force induces extremely small changes in the resistance of strain gauges (range mΩ), which is difficult to measure with an ohmmeter. In order to measure strain there is a need for an electrical bridge measuring circuit. Strain gauge transducers usually employ four strain gauge elements, electrically connected to form a Wheatstone bridge circuit widely used in practice [10].
In teaching the strain gauges to students and for the purpose of laboratory activities, it is required to go through several stages, such as: the theoretical part, the computer simulation and the real measurement performed on the real force transducer model. In the theoretical part students learn about the basic properties of strain gauges and become familiar with the principles of strain gauge techniques together with a Wheatstone bridge, to measure (i.e. calculate) force or load. The experiment used in student exercise is described and the model is designed for the laboratory use.

2. THEORETICAL BACKGROUND OF FORCE MEASUREMENT

2.1. Strain and stress definition

In order to explain the theoretical basis, we will consider a wire with the original cross-sectional area of the wire (A), and the original wire length (L). A wire fixed to the top (Fig.1) stretches vertically due to applied force (F) with the appearance of stress and strain.

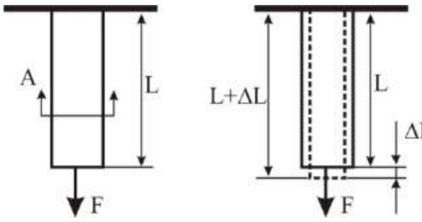

Fig.1. The wire before (a) and after force application (b)

The stress σ (called an axial stress) is defined as the material's internal resistance:

$$\sigma = \frac{F}{A} \tag{1}$$

The effects of applied force are the decrease in cross-sectional area and the increase in wire length (ΔL) (fig.1). The ratio between the original wire length and the deformation that occurs, defines the axial strain ε:

$$\varepsilon = \frac{\Delta L}{L} \tag{2}$$

For elastic materials, the relationship between stress and strain can be described by Hooke's law:

$$\sigma = E \cdot \varepsilon \tag{3}$$

where E is the Young's modulus, also called the modulus of elasticity. We will only consider the elastic stress region [1].
The length L of the material will increase to (L+ΔL) when a tensile force is applied, and the ratio ΔL/L is defined as longitudinal strain. Mechanical strain will be (-ΔL/L) if the compresive force is applied and the length is reduced to (L-ΔL). Compressed in one direction, a material usually tends to expand in the other two directions, perpendicular to the direction of compression. This phenomenon, called the Poisson effect, is characterized by the Poisson ratio (for most metals around 0.3).
The wire material of resistivity ρ, length L and cross-section area A, has the electrical resistance R:

$$R = \frac{\rho \cdot L}{A} \tag{4}$$

When the conductor is exposed to strain the resistance of a conductor changes, and this fact is important for the strain gauges application. With strain the electrical resistance of wire will be higher because it is longer and thinner.
The relationship between strain and resistance variation is almost linear, and the constant of proportionality is known as the "sensitivity factor":

$$G = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon} \; or \; \frac{\Delta R}{R} = G \cdot \varepsilon \tag{5}$$

where: G – the sensitivity factor, R – the initial resistance, ΔR – the change in resistance, L – the initial length, ΔL – the change in length. A typical value for G, known as the 'gauge factor', is around 2 for commercially available strain gauges [1].
Taking into account that ΔL<<L, ΔA<<A and Δρ<<ρ, the relationship between strain and resistance variation is almost linear. The constant of proportionality between them is known as the "sensitivity factor" (G) and can be described by the equation:

$$\frac{\Delta R}{R} = (1 + 2\mu) \cdot \varepsilon = G \cdot \varepsilon \tag{6}$$

2.2. The Wheatstone bridge

Because the resistance of a strain gauge changes proportionally to the received strain, we have to measure the resistance change. The resistance changes are very small and there is a need for the appropriate method to measure them.
Due to a very small resistance change ΔR in practice, and the ratio ΔR/R for typical strain gauges between 10^{-3} and 10^{-6} [1], it is very difficult to use an ohmmeter for direct, precise measurement of such a small resistance change. Therefore, there is a need to design an electronic circuit to measure the change in resistance, rather than the resistance itself. The most widely used electric circuit, with the ability to accurately detect small changes in resistance, is the Wheatstone bridge. Wheatstone bridge is an electrical circuit with ability to convert small resistance changes into voltage and is usually used in mechanical strain measurements.
The Wheatstone bridge circuit, which consists of four resistances arranged in a square, is fundamental to the use of strain gauges for measurement tasks. In a bridge measurement system, an excitation voltage (V_{in}) is applied across the bridge and the voltage is measured in the diagonal, between points A and B (figure 2).

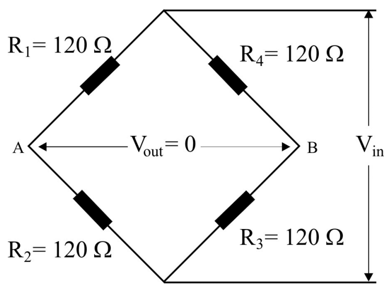

Fig.2. The Wheatstone bridge in balance

In application, one or more of the resistive elements will be strain gauges. For the bridge in balance the voltage across the center of the bridge will be zero volts (figure 2). If the stress is applied, the resistance of the strain gauge changes causing the voltage change across the center taps. The change in resistance of the strain gauge is indicated by voltage change, proportional to the mechanical strain. To explain this connection between the electrical and mechanical parameters, we calculated the voltage change detected in the Wheatstone bridge in two examples [10].
Due to the force application, the resistivity increase of R_1 and R_3 has the positive influence on the bridge output and the negative influence on the output voltage when the values R_2 and R_4 are greater (Fig. 2). The relation between input and output voltage can be given as follows:

$$\frac{V_{out}}{V_{in}} = \frac{1}{4}\frac{\Delta R}{R} = \frac{1}{4} B \cdot G \cdot \varepsilon \qquad (7)$$

where B is the Bridge factor value, depending on the strain gauge layout on an elastic element. These results and conclusions are important when we use the Wheatstone bridge for the application of strain gauges. The two most crucial factors that determine the correct strain equation are bridge configuration (quarter, half, or full) [10] and stress type (tension, compression or bending). Due to different values of parameter B in the case of quarter bridge (B=1), half bridge (B=2) and full bridge (B=4), equation 7 receives various forms.
One of the aims of this paper is the development and use of a virtual instrument system for force measurement using the Wheatstone bridge model with a strain gauge as sensor. The system made should be suitable for laboratory applications, especially in the measuring of mechanical quantities by electrical means.

3. FORCE TRANSDUCER VIRTUAL INSTRUMENT IN THE CASE OF TENSILE FORCES

The most widely used method in experimental stress analysis is the Wheatstone bridge or resistance strain measurement. In order to avoid the traditional resistance strain instruments, it is possible to use the advanced virtual instrument technology [11]. This step was the next level in strain analysis and students' education about these measurements – the introduction of the concept and characteristics of virtual instruments applied for that purpose.
In many technical fields the idea "virtual instrumentation" has been developed, allowing engineers to apply appropriate software on a computer combined with instrumentation hardware and do some measurements tests. The concept of virtual instrumentation is very popular today [12], and its benefits (high accuracy and more flexibility in scientific work) are used as an educational tool.
Mechanical quantities, such as force, can be measured using transducers whose electrical resistance is changed as a result of a variation of dimensions. On the example of uniaxial stress state, the application of a force transducer virtual instrument using the National Instruments LabVIEW software will be described, together with the Wheatstone bridge model.
LabVIEW is a graphical programming language where icons are "wired together" to form a working program. A LabVIEW program is called a virtual instrument (VI). Each VI has a "front panel" and "block diagram".
The Wheatstone bridge model is wired to a low cost, but very versatile USB data acquisition module National instrument "NI myDAQ". The schematic of the wiring diagram is presented in Fig 3.
In the LabVIEW program data will be acquired as a voltage and converted to a strain, force, or other mechanical quantity. Inside the while loop is the DAQ Assistant. It is configured to read a single value from the myDAQ two analog input terminals, one to measure V_{in}, and the other to measure V_{out}. Then the ratio of V_{out}/V_{in} is calculated and displayed on the front panel.

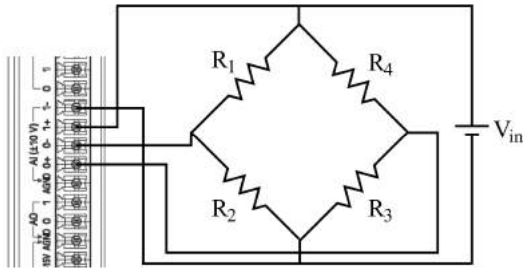

Fig.3. Wiring diagram

Tensile force F, acting on a rod, leads to the elongation of the rod in the direction of the load. At the same time, normal stress appears in the rod material (σ). The stress values cannot be measured, but they can be calculated from the strain.
To measure the value of tensile strain, and reject possible bending strain, we should bond four active strain gauges to the surface of the rod (two in the direction, and two perpendicular to the direction of the force). They are electrically connected to form a full Wheatstone bridge, as shown in the literature. For the configuration where two strain gauges (R_1 and R_3) are elongated, and other two (R_2 and R_4) compressed, the value of Bridge factor B is 2.6.
Strain value is based on both, known and measured, electrical quantities:

$$\varepsilon = \frac{V_{out}}{V_{in}} \frac{4}{G} \frac{1}{B} \qquad (8)$$

For a known value of the strain, material type (E - Young's modulus) and cross-sectional area, force can be calculated by the formula:

$$\frac{F}{A} = E \cdot \varepsilon \rightarrow F = A \cdot E \cdot \varepsilon = A \cdot E \frac{V_{out}}{V_{in}} \frac{4}{G} \frac{1}{B} \qquad (9)$$

3.1. Practical use of the laboratory model

In order to build the physical model, linear slider resistors with maximum resistance of 1kΩ are used. On the model, shown in Figure 4, the initial position of the slider of the potentiometer on the scale is marked with zero. It is a position corresponding to the unloaded state, when the resistance of strain gauges is equal to their nominal value. In this example, all four resistors have the resistance of 400 Ω in the initial position. Depending on the direction of the external loads (forces), there may be either the contraction or the elongation of the strain gauges, which respectively leads to a decrease or increase in their resistance. Marks on the scale, next to the resistors, indicate an increase (+1 and +2) or decrease (-1 and -2) in resistance. It was chosen that each mark on the scale corresponds to an equal change in resistance of 100 Ω.
The resistors are connected in a Wheatstone bridge. Bridge input voltage (V_{in}) of 8 V is provided by a standard 220 V adapter to 12/24 V, using voltage stabilizer 7808CT and 7805CT. The output voltage is measured with a digital voltmeter. In order to facilitate the

balancing of the bridge in the unloaded (initial) state, parallel with resistors R_3 and R_4, another variable resistor is connected. Its maximum resistance is 10 kΩ and its fine adjustment is possible by a 15-turn gear drive.
After the theoretical part, with the aim to learn about stress/strain and the Wheatstone bridge, one example is described. First, results were obtained using a computer simulation by LabView and after that, real measurements were carried out with the real laboratory model, shown in Figure 4.

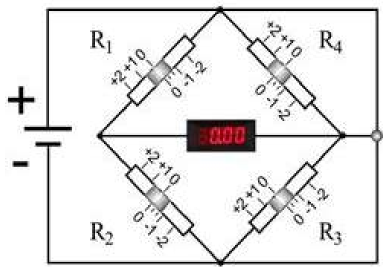

Fig.4. Model of the Wheatstone bridge

Assume that an unknown force (F) causes the rod elongation of ε = 0.1. Under the load and according to a Wheatstone bridge configuration in Figure 5, the following layout is set on the model: resistances R_1 and R_3 are higher (position +1), while the values of resistance R_2 and R_4 are smaller (position - 0.3), compared to nominal (unloaded condition). In the case of such a given load condition, the bridge output (V_{out}) value can be read - 1.3V. Substituting the values in equation (9) for $A = a^2 = (10\ mm)^2 = 100\ mm^2$, $E = 2{,}1\cdot10^5\ N/mm^2$, G = 2,5, B = 2.6, V_{in} = 8 V, V_{out} = 1,3 V, follows:

$$F = 2.1\cdot10^4\ N = 21\,kN \tag{10}$$

Force transducer VI, according to the measured value of V_{out}, divided by the V_{in}, together with the electrical characteristics of the Wheatstone bridge (V_{in}, G, B), and mechanical characteristics of the rod (A, E), is used for the calculation of strain and force values. Finally, results are displayed as numeric indicators on the front panel (Fig. 5).

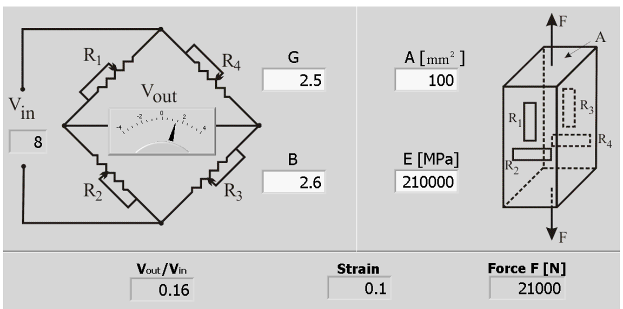

Fig.5. Force transducer VI front panel

4. CONCLUSION

The objectives of this paper were to provide students with practical experience about how the Wheatstone bridge is used in strain measurements and virtual instrumentation. For that purpose, a very simple model was made, in order to calculate the non-electrical quantities, such as force by measuring electrical quantities, such as voltage.
The greater interest of virtual instrumentation lies in improving teaching in a real laboratory. In this example we included only the simulation of the real force transducer that students will encounter in a laboratory.
The additionally presented virtual instrument introduces several functions in the measurement procedure, such as the ratiometric calculation of the strain gauge bridge deformation, digital filtering of the measurement results, calculation of the other measurement values, based on the calculated deformation (the strain and the force at the measurement transducer), and numerical presentation of the measurement results.

Acknowledgment: This paper is part of the technological project TR35034 at the University of Niš, Faculty of Mechanical Engineering, and was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia

REFERENCES

[1] CIMBALA, J. M.. (2011) *Stress, strain and strain gauges*, Penn State University, USA.
[2] PACKARD, H. *Practical strain gauge measurements*, Application note 290-1
[3] Wheatstone bridge and strain gauge, MIME 2000, 2005, report
[4] HOFFMANN, K., (2001) *Applying the Wheatstone bridge circuit*, *HBM Company*
[5] PRATT, DJ. (1979) *Load measurement in ortopaedics using strain gauges*, Journal of Biomedical Engineering, Vol. 1, Issue 4, pp. 287-296
[6] CORDARO, N M WEISS, J A SZIVEK, J A. (2001) *Strain transfer between a CPC coated stain gauge and cortical bone during bending*, Journal of Biomedical Materials Research, vol.58, number 2, pp. 147-155
[7] SKELTON, J. R. (2006) *A transducer for measuring tensile strains in concrete bridge girders*, Experimental Mechanics, *46*, pp. 325-332
[8] SCHUSTER, S. A. *Testing the Structural Integrity of the Boeing 777*, Sensors Magazine.
[9] RODERICH Z, THOMAS F., JURGEN W. *Development and testing of capacitive strain gauges* , University of Freiburg-IMTEK, Department for Microsystems Engineering Laboratory for Assembly and Packaging Technology, Freiburg, Germany
[10] HOFFMANN, K. (1989) *An Introduction to Measurements using Strain Gauges*, Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany
[11] DJUKIC S, JANKOVIC P., MANOJLOVIC J. (2013). *A LabVIEW based virtual instrument force transducer*, Mechanical Engineering in XXI century, pp. 293-296
[12] ZAIMOVIC-UZUNOVIC, N., LEMES, S., PETKOVIC, S. (2001) *Virtual instruments-A chance to teach engineering at a distance*, International Conference on Engineering Education, Oslo, Norway

35th INTERNATIONAL CONFERENCE
ON PRODUCTION ENGINEERING

25 - 28 September 2013
Kraljevo - Kopaonik
Faculty of Mechanical and Civil Engineering in Kraljevo

EDUCATION OF PRODUCTION ENGINEERS FOR DIGITAL MANUFACTURING

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Abstract: *The global economic crisis has led to the start of the transition process of manufacturing organizations in most developed countries of Europe, the Far East and North America. The basic aim is to reduce all costs (manufacturing, non-production), and the aim is to develop new, innovative products, and to generate new services for customers. They (innovative products) require complex technologies and processes, especially new knowledge and skills, as well as in the field of engineering, and in the field of management. The University has a key role in these processes, because in the generation and transfer of knowledge must accompany these changes. It is believed that high technology will play a key role, but their diffusion depend exclusively on the willingness of (knowledge) of young engineers to use them. The paper provides an analysis and synthesis of the strategic directions of research and education production engineers today and in the immediate future, based on joint CIRP reseraches – ePRODE Project.*

Keywords: *Production Engineering, Education, Research, Development*

1. INTRODUCTION REMARKS

Production of the beginning industrial revolution enabled the creation of a consumer society, increasing the richness and variety of goods, mostly products and then services. Industry was and initiator of these activities, because it only allows you to increase the standard of living and general well-being, which is particularly evident in developed as well as countries that are under intense economic development - so called, BRIC countries. However, in Serbia, the retrograde stage process - industry has been destroyed and nothing can take that it is " alive " [5].

One of the key factors, if not most, of the newly developing industrially Serbia's engineering education, especially production engineers. Why? Because production engineers, design, planning, produce, control, assembled and tested, the machines produced by other machines- "machine tools", and also manufacturing plan, produce and control the production of other engineering products (cars, planes, railway, boats, etc.). Therefore, they constitute the basis of the entire industry, not just the metal working industry, as it is more often thought.

Data for the EU, which relate to 2011.year, according to production activity provides 23.5% of GDP, includes 21% of the jobs of the employees, or in numbers: 28.1 million people employed in this field work in 309,000 enterprises with 20 or more employees. However, if we look at production in the broad sense of the word, then the data is even more important: the production includes more than 76% of GDP and more than 71% of employees. Detailed analysis shows very similar data for the U.S. and Japan [2,4,9].

All sectors of the economy face the challenges of the technological revolution in particular industries, which are based on production technologies. The fact is that some segments of these industries based on the use of high-tech, generate large profits. Others do not apply, you will surely affect the organization and its business in the future. ICT technologies are the main subject of today's technological revolution. However, the positive side of this process is that ICTs are most of the applied production engineering, in relation to any other area. These trends have led to production engineering at the forefront of demands for new systems (machine tools, robots, measuring machines) that generate innovation in products, from design, manufacturing, quality control and logistics. Europe and the EU, especially Germany, France and Spain, using ICT technologies contribute most to changing every aspect of production in Europe.

Industrial production increased wealth of society and brings new jobs. These trends contribute to the development of service activities, particularly through the supply chain. Services and manufacturing are inextricably linked, so that high-automated production means more demand for additional services, particularly in the field of ICT. Innovation and product development intensively contribute to the development of these processes, in which to develop knowledge and potential for practical application and development of innovative products additional value.

All of the above facts should be the basis for the development of today's models of production engineers, where innovation is the driving force for the present industry and not just for high-tech industries. For example, in the areas of materials, 70% of today's materials installed in the car ten years ago did not exist.

Or, for example, shipbuilding, where ten years ago, the production of large tankers and cruise ships from Europe and the Americas relocated to the Far East, is now flourishing again at the old place, but now the production of boats and yachts (value added innovative products, based on new materials and design). Similar examples can be given in other areas.
Leading scientific, educational and professional institutions and organizations of North America, Europe and the Far East in the middle of the first decade of the twenty-first century, defined platform for the development of production engineering: Manu*future* Intelligent Manufacturing Systems (IMS) [3]. Basic elements Manu*future* platforms: products and services with new added value, new business models, advanced manufacturing engineering, manufacturing technology and border science, engineering education.
IMS platform, which contains similar elements: sustainable production, industrial integration based on ICT, manufacturing, interoperability and standards, production technology and engineering education. We conclude that engineering education is one of the key elements in both platforms.

2. CHANGING THE CONCEPT OF PRODUCTION

During the last years of the twentieth century, with the development of the Web, there is a business development via the Internet - Business-to-Business (B2B) concept, which included engineering design and machining technology. Today's industrial production is characterized by the following factors [6-8]: *globalization, production chains and production networks, digital business and innovation*.
Market globalization has existed for decades. In the beginning it was characterized in finding markets around the world for its products. In the second phase, it was reflected in the development of off-shore production the American car is produced and sold in Europe.
The latest phase of globalization has been developed thanks to ICT technologies - production and supply chains around the world. This phase of globalization has led to the production moved to low-wage economies, where production is cheaper. Type of production that is suitable for off-shore production, determined by two main factors: the cost of additional services. Costs include direct and indirect costs, energy costs, and taxes. Price of clothes, for example only defines the nature of these costs, because the industry has high off shore potential. Additional services include additional factors such as quality, time losses, uncertainty of delivery, customer orientation, the level of knowledge among staff, etc.
Today production emphasis from the technical and technological approaches to increase productivity, moving in the direction of increasing the efficiency of business processes. The focus is directed to the *supply and distribution chains*, where they explore opportunities to create additional value for the customer, but also in production., So that it creates a network economy that includes: the supply chain, manufacturing, supply chain, operation and maintenance, and phase-out and recycling. Chain and distribution are service intensive activity, the resource-intensive production, and the last two activities (operation and maintenance, and phase-out) are service-intensive activities. It is important to note that basically every area intensively supported the use of ICT.
Reply manufacturing companies in today's dramatically changing business environment is the guidance on quality, costs and production technology in order to achieve competitive advantage. Also, special attention is given and the supply chain, where there was a large change, using the concept of digital business. Supply chains include research and optimization of the process links between organizations (manufacturers, suppliers and distributors), creating a network economy. In this concept creates an expanded range of additional value-added products that includes additional services from the supply chain. For example, in the 2009 year, total revenue in the automotive industry consists of 26% of production, 29% of suppliers, 45% of after-sales service.
Digital business has become an effective tool in the fight for competitive advantage. Modern production is based on digital modeling and transfer product data, digital and digital production logistics management, thus creating a digital model of the factory. Digital business supply chains and networks of the economy (digital network model of the economy) is based on application of advanced ICT technologies in every link of the model, while reducing costs and optimize processes, leading to increased profits. Digital business, integrating Internet and digital factory model (network economics) perform fundamental transformation of business processes, strategies and techniques. Thus we come to the business model for knowledge management, which drastically changes the static procedure-oriented business model in the new - the dynamic business model virtual network economy based on knowledge.
Innovation is the process of bringing something to change, the ushering in of a new - makes its basic definition. In this paper, we consider aspects of innovation in manufacturing, where innovation is related to a product, process or service. Innovation in manufacturing is the most frequently used model of continuous improvement, as well as the concept and implementation of six sigma quality standards (ISO 9001). But innovation can also be a radical change in the product, process or service. Then there is the application of new technologies and innovation process is changing and resources in production, which means that there is a change in machines, processes and specifications, especially in knowledge and levels of organizational change. Between production and innovation is made symbiosis, in a way that made the transformation "customer orders and raw materials into products and services, using available resources and product specification".
Innovation processes in manufacturing (machining, quality control, assembly) and innovation processes in the supply chain are fundamentally different. Innovative processes include performance measurement, ideas and creativity, projects and project portfolio management teams and innovation. Innovation focused on the use of high technology, it is easier and faster to implement parent companies in relation to the offshore organization to be a part of innovation should we transform knowledge

workers. Innovation and application is the essence of the knowledge economy.

3. THE ROLE OF EDUCATION IN DIGITAL MANUFACTURING

All the above mentioned facts about the digital business is based on expert engineering skills, which are key to the implementation of new technologies and achieve competitive advantages of organizations. Another key element of the company's knowledge of the managerial knowledge, together with engineering skills are integrated. Because of this there is a clear need to build a solid relationship between industry and the University.

Universities can do innovation in their educational programs in accordance with the requirements of industry and digital business. However, the universities, especially in Serbia, exploring the needs and demands of the industry for engineering education , so that rule does not reflect the real needs of the industry. New types of knowledge and skills that are required for digital production, make the organization more agile in the field of intellectual capital, and engineers capable of continuous adaptation of their knowledge. Increasingly, the digital production require little flexible (project / problem- oriented) teams of engineers with multidisciplinary knowledge and skills in engineering and management. This will require the University to build flexible engineering education models that will follow the new requirements of digital production.

This means that the university must change education strategy and the "prediction" educational needs of industry on the basis of the development of science and technology, go to "mutually beneficial relationships with industry" as required by the concept of digital production in delivering education of engineers.

Further expansion of the global economy, both at the level of demand (request for new products added values) and in the plane of supply (network economics), requires new engineering skills in various aspects of production. So today is a specialist engineer in various fields of design / planning / production system integrator, but in certain areas there is adequate depth of knowledge needed to manage the project, the use of ICT.

4. EDUCATION PROGRAM FOR DIGITAL MANUFACTURING

Today there are a number of strategies and programs of education production engineers in the EU, and even a joint program of the EU, derived from the CIRP project - be extended. All of these programs are derived from the pre-defined key knowledge and skills should have a manufacturing engineer. Common to all these models is that they have a basis for their design were models of the manufacturing engineers with the ETH Zurich, the program - leaders in the manufacture of MIT and Production Leaders - a program of Cambridge. Seven fields of knowledge, education key to manufacturing engineers [4, 10-12] are shown in next text.

a) *Product development of additional value* - Development with a combination of physical characteristics of products and services in order to improve its position of the market. Teach students to understand what it is - the product concept additional value. To train him to use of tool for product development. Teach students about the business aspects of the product and service.

b) *Digital business in the supply chain* **-** Business information system for e-business using the supporting technologies, expanded the business activities from design, production, delivery and servicing of products, including in this way and the suppliers and customers. Teach students what is the concept of supply chain management. Give students extensive knowledge of e-commerce and application of the concept of supply chain management.

c) *The product life cycle and phase-out* **-** Development and application of techniques, methodologies and tools to support decision making in the product lifecycle and the withdrawal from service (repair, replacement, recycling products, components, materials) based on economic, social and environmental criteria. To introduce students to contemporary environmental and recycling practices. Training students to make decisions for the exclusion of the use of the product and its recycling in terms of technological, economic, business, humanities characteristics.

d) *Operations and competitive strategies* **-** An explanation of how the organization works, its interaction with competitors and its market, tracking performance over time (benchmarking).The development of all aspects of competitive strategy and building roads sensitive model for the development of the organization in the future. To train students to think about the modern concept of productivity and competitiveness. Teach students to make business decisions and to manage projects, to manage quality and human resources.

e) *Intelligent manufacturing processes* **-** Explanation of application techniques for handling complex production conditions, the vague and changing conditions with the use of artificial intelligence and machine learning. To give students the necessary skills for the most common technologies and processes with applications in intelligent manufacturing. To train the student to choose the process according to the requirements of quality and production costs.

f) *Intelligent Manufacturing System (IMS)* **-** Tools and models the skills and knowledge of technological expertise required for intelligent machines, and equipment that produces products with little or no human intervention. To introduce students to the concept of intelligent manufacturing and integration of various aspects of the use of ICT. Training students to IMS design with technological, economic and humanistic aspects.

g) *Integrated product modeling and simulation* **-** Information on the characteristics of the product and how to develop and use computer representations exploiting structure, activities, processes, information, resources, people, environment, goals and environment, other organizations, and also products. To train students in modeling and simulation and application of IMS. To train students in the development of the model and its use for decision making.

From the" whole" of knowledge presented in the previous paragraph, it is important to define those related to innovation processes, which are specific in that they can be used in all fields of engineering, and not just in manufacturing engineering, which is the subject of this paper . These are issues related to strategic planning, performance measurement, laws, standards and regulations, ideas and creativity, product development, project management, project portfolio management. Knowledge related to ITS, in this domain includes: BSC, lean and six sigma organization. These bodies of knowledge are part of the content that is closely related to the professional education of the manufacturing engineers.

4. CONCLUSIONS

Education plays a key role in the business success of manufacturing organizations, for today and the future growth and development of manufacturing organization depends on the knowledge of its engineers and managers. Therefore, it is extremely important that the University follows the rapid changes in technology and techniques, now based on digital engineering and knowledge-based economy and therefore adapt their curricula.

REFERENCES

[1] Chryssolouris G., D. Mavrikios, Education for Next Generation Manufacturing, Laboratory for Manufacturing Systems & Automation, Department of Mechanical Engineering & Aeronautics, University of Patras, 2012.

[2] MANUFUTURE – A Vision for 2020, Report of the MANUFUTURE ETP High Level Group, December 2013.

[3] Geyen A., et att, The Future of Manufacturing in Europe 2015-2020: The Challenge for Sustainability – Scenario Report, Joint Research Centre - EC, December, 2012.

[4] N., N., European Manufacturing of the Future – Role of Education for European Leadreship, Brussels, 2013.

[5] Majstorovic, V., Manufuture Serbia – Strategic Research Agenda 2008-2015, Mechanical Engineering Faculty, Belgrade, 2008.

[6] Wiendahl, H., Global Manufacuring – Challenges and Solutions, Institut für Fabrikanlagen und Logistik Leibniz Universität Hannover, Germany, 2011.

[7] Tolio, T., et all, SPECIES—Co-evolution of products, processes and production systems, CIRP Annals - Manufacturing Technology 59 (2010) 672–693.

[8] Tryggvason, G., Apelian, D., Re-Engineering Engineering Education for the Challenges of the 21st Century, JOM, October 2009, pp.14 – 19.

[9] Jovane, F., et all, The incoming global technological and industrial revolution towards competitive sustainable manufacturing, CIRP Annals - Manufacturing Technology 57 (2010) 641–659.

[10] Westkämper, E., Strategic Development of Factories under the Influence of Emergent Technologies, Fraunhofer Institute of Manufacturing Engineering and Automation, Stuttgart, Germany, 2010.

[11] Martinsen, K., The competitive challenge of manufacturing Some requirements for the future manufacturing strategy education, RTIM, Raufoss, Norway, 2012.

[12] Rodriguez, C., et all, Industry and University Cooperation to Enhance Manufacturing Education, *Journal of Manufacturing Systems,* Vol. 24, No. 3, pp. 277 – 287.

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AN INTERACTIVE AUGMENTED REALITY PLATFORM FOR CAD EDUCATION

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***Abstract:** Current instruction methods of teaching CAD/CAM technologies rely heavily on traditional pedagogical techniques such as in-class and in-lab instruction and coursework. Augmented Reality (AR) technology to support learning activities becomes a trend in education and AR-based methods are proven to be effective teaching aids for engineering courses. This paper presents initial results of a project aimed to transform the current learning process of CAD/CAM by designing and implementing an interactive AR learning tool to help students to develop a comprehensive understanding of features, models, spaces and processes. A webcam or smart phone recognizes the AR marker information on the page of a CAD/CAM teaching book, generates real-time three-dimensional objects and superimposes them in the camera image. Generally, we present a platform that uses AR as a medium for teaching and representation of digital 3D geometry and a process to facilitate CAD/CAM education. This AR platform should enable a faster comprehension of complex spatial problems and 2D relationships, from which the students and engineers will benefit greatly during their learning processes.*

***Key words**: Augmented Reality, Android & Desktop Platforms, CAD/CAM, Education.*

1. INTRODUCTION

Augmented reality (AR) technology is widely used to exploit computer algorithms to draw the virtual objects in a real space, fusing the virtual 3D objects or animations in real-life scenes (Figure 1). The rapid development of AR applications has contributed to its wide applications in advertising, engineering, medicine and etc. With augmented reality, CAD instructors can bring to real environment, virtual 3D elements or animations [1]. Commercial CAD/CAM software offers an overwhelming variety of complex features, models and processes in multimodular product development [2].
This article introduces the applications of AR technology in practical CAD/CAM education, and will discuss the significance of AR based learning. The core of this interactive system consists of video image processing techniques and interactive 3D model visualization.

1.1. Augmented Reality

Augmented Reality in general is the concept of enhancing the real world with additional virtual information. One of the most commonly used definitions of Augmented Reality was given by Ron Azuma [3]. Independent of specific technologies, an Augmented Reality system has to meet the following requirements:

1. Combine real and virtual worlds,
2. Augmentations are interactive in real time,
3. Augmentations are registered in 3D to the real world.

In recent years smart phones and tablets became an increasingly popular device for Augmented Reality. These combine all needed components (camera, display and processing power) for video based Augmented Reality in a small form factor.

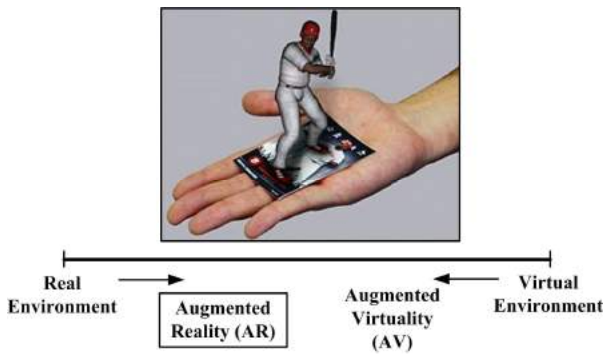

Fig. 1. Simplified representation of the Reality-Virtuality Continuum

For this reason and the fact that smart phones and tablets became widespread devices we choose to build our system as a video based Augmented Reality system for Android devices.

2. SYSTEM ARCHITECTURE

To fulfill the requirements for an augmented reality system, the foundation is to estimate the position and orientation of the camera in respect to the world or vice versa. The combination of a position and an orientation is called a pose. To do this we employ a technique called marker tracking.

2.1. Marker tracker

Marker tracking makes use of the camera image to find optical square markers and estimate their pose relative to the camera. A square marker consists of a black square with a white border. Within the square the ID of the marker is encoded. Different techniques can be used to encode the ID like template matching or the encoding as a binary number as in our case. The marker tracking pipeline is illustrated in Figure 2.
In the first step the image from the camera is converted to a gray scale image to speed up the image processing in all further steps.
Since the square markers are only black and white we can threshold the gray image in the second step to generate a binary image. This will remove noise and most of the environment from the image, which again allows a much faster processing for the next step.
The third step consists of using the binary find of all contours that are left in the binary image. Of these contours only contours with exactly four corners are selected as potential square markers for the following steps.
Using the corner positions of the rectangles from the previous step and the gray image the forth step consists of refining the corner positions of the rectangles to sub-pixel accuracy. This is realized by sampling the edges along each side of the rectangle and using this data to fit a line along each side. By calculating the intersection points of these lines the algorithm obtains the sub-pixel accurate position of the corners.

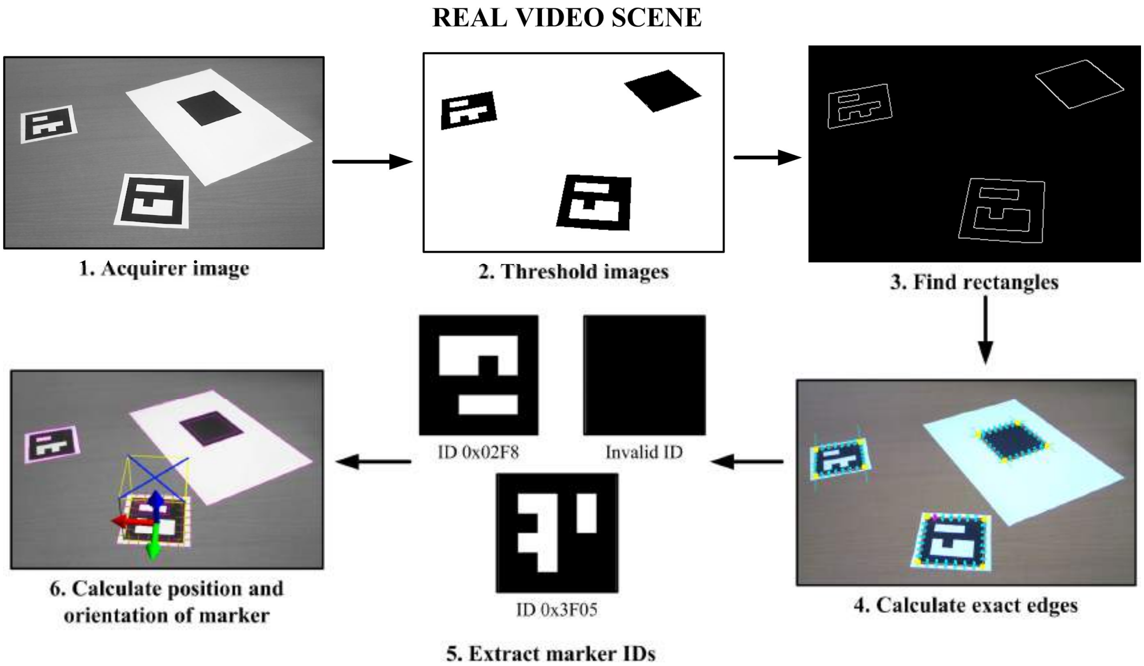

Fig. 2. Marker tracker pipeline

In step five the algorithm tries to determine whether a specific rectangle is a part of an optical square marker or a part of the environment by extracting the ID of the marker from the gray image. If a valid ID was detected then that rectangle is further processed. The ID of the square marker has the requirement to be rotation invariant. This property is needed to determine the order of the corner points, which in turn is needed to estimate the orientation of the square marker. Once a rectangle with a valid ID has been identified, the 2D corner positions from step 4 and the predefined size of the square marker are used to estimate its pose. Now we have all we need to fulfill the three requirements for an augmented reality system. By using the camera image as the background (real world) in our display and using the pose of the marker we now can superimpose the camera image with and virtual object (virtual world) as seen in figure 2. When the marker or camera is moved the augmentation stays on the marker (registered in 3D). The marker tracking pipeline is computationally inexpensive, so we can keep all interactions with the virtual objects in real time.

2.2. MagicBook

The concept of an Augmented Reality MagicBook was firstly introduced in 1997 [4]. The basic principle is that a real book is enhanced using Augmented Reality. Virtual objects are superimposed on the different pages of the book in the Augmented Reality mode. If the user is interested in a specific scene, he or she can fly into the scene by switching to the Virtual Reality mode and inspect it from the inside. This concept also included multi-scale collaboration, which enables multiple users to experience the same virtual environment. For our system we omitted the Virtual Reality mode as it is impractical for our application. We still have support for collaboration, as several users can see the same virtual model on the book page.

2.3. System description

Our system is composed of a tracking framework to provide the necessary tracking data and a game engine for rendering the virtual models and interaction with the augmentations.

As the tracking framework we are using UbiTrack[1]. UbiTrack is an open source, general purpose tracking framework for Augmented Reality developed by the „Group of Augmented Reality” group of the Technical University of Munich, published under the LGPL license. The greatest advantage of the UbiTrack Framework is the use of so called “Spatial Relationship Patterns” [5]. This leads to a component based design, which allows the easy replacement of specific hardware drivers and tracking methods, as well as a less error prone way to develop and setup more complex Augmented Reality systems. UbiTrack has been successfully ported to Microsoft Windows, Linux, Mac OS and Android.

Using a game engine for the visualization and interaction has the advantage that all the necessary groundwork for generating user interfaces, displaying 3D models, as well as an interaction pipeline for the virtual world are already build in. We can make use of high level functions like real time shadows, particle systems or physics simulations without the need to implement them. For the game engine we are using Unity3D[2] for the ease of use and its platform independency. This allows us to deploy our application to all desktop systems and Android devices without any need to change the source code of the application.

3. APPLICATION

Our application basically works like the video based augmented reality system as seen in Figure 3. Each page of the tutorial book has an embedded unique square marker associated with the CAD model.

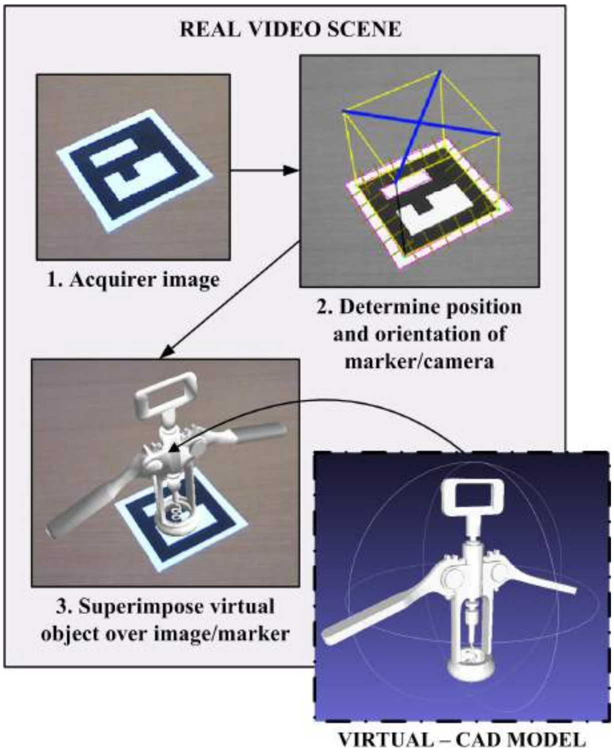

Fig. 3. Video based Augmented Reality

Employing desktop version of developed AR platform or a Smartphone equipped with a camera, students are able to go through the exercises themselves. Focusing the camera on the markers retrieve the virtual 3D objects from database and the information and graphics are then overlaid onto the screen (Figure 4).

By recognizing the ID of the square-sized marker, the application determines which CAD model to display. The interaction with the CAD model is handled by single touch rotation gestures on the touch-screen of the device or by mouse inputs in case of the desktop application (Figure 4). The 3D model database is created using educational PLM system CATIA[3].

Students can turn the pages of a tutorial, look at the problem inside the book, and finish their exercise much the way they are reading and drawing on a paper sheet [6]. The virtual models superimposed upon the real page will serve as the tip for imagining the relationship between the 3D geometry and their 2D projection.

4. CONCLUSIONS AND FUTURE WORK

The augmented reality technology can be used as a new tool to support of the teaching activities and to enhance the traditional learning experience. It emphasizes the perception of students and offers information that is not perceived directly by the use of their own senses. Besides understanding the relationship between 3D objects and their 2D representations, projections, AR Magic CAD Book aims at comprehending geometric relationships of reference lines, sides, planes, angles, developing their ability to make sense of visual information, and motivating logical thinking and cultivating logical skills.

In the future we plan to replace the standard square marker tracker with a texture/image based tracking system. This will allow using the pages of the book itself to be the marker, thus removing the need to include a specific marker on the page.

Such models can be further enhanced by integrating types of information other than just simple 3D representations. These types can include audio, text annotations, 2D images, and diagrams. As the development of the UbiTrack framework continues, we can make use of future ports of UbiTrack framework to other operating systems, e.g. Apple iOS and Windows Phone to support these devices.

Acknowledgments: This work is supported by national project “Application of Biomedical Engineering in Preclinical and Clinical Practice”, supported by the Serbian Ministry of Education, Science and Technological Development (III-41007) and TEMPUS Project, “BioEMIS” (530423 - TEMPUS), funded by European Commission.

[1] www.ubitrack.org
[2] http://www.unity3d.com
[3] www.3ds.com

a) *b)*

Fig. 4. CAD MagicBook Application – a) Android version and b) Desktop platform

REFERENCES

[1] FARIAS, L., DANTAS, R., BURLAMAQUI, "A. Educ-AR: A tool for assist the creation of augmented reality content for education", In Proc. *IEEE Int. Conf. on Virtual Environments Human-Computer Interfaces and Measurement Systems*, pp.1-5, 2011.

[2] PENGCHENG F., MINGQUAN Z., XUESONG W., "The significance and effectiveness of Augmented Reality in experimental education", In *Proc. International Conference on E-Business and E-Government (ICEE)*, pp.1-4, 2011.

[3] AZUMA, RONALD T., "A Survey of Augmented Reality", in *Presence: Teleoperators and Virtual Environments* Vol.6, No.4, pp.355-385, 1997.

[4] BILLINGHURST, MARK, HIROKAZU, KATO END POUPYREV, IVAN, "The MagicBook: a transitional AR interface" In *Computers & Graphics*, Vol.25, No.5, pp.745-753. 2001.

[5] PUSTKA, D., HUBER, M., BAUER, M., KLINKER, GUDRUN, "Spatial Relationship Patterns: Elements of Reusable Tracking and Calibration Systems". In Proc. *The 5th IEEE and ACM International Symposium on Mixed and Augm. Reality*, pp.88-97, 2006.

[6] HEEN C., KAIPING F., CHUNLIU M., SIYUAN C., ZHONGNING G., YIZHU H., "Application of Augmented Reality in Engineering Graphics Education", *In Proc. International Symposium on IT in Medicine and Education (ITME)*, pp. 362-365, 2011.

Automatisation, robotisation and mechatronics

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DEVELOPMENT OF TOOL WEAR MONITORING SYSTEM FOR TURNING

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Abstract: *In this paper is presented development a model of tool wear monitoring system with special emphasis on the module for acquisition and processing of vibration acceleration signal by applying discrete wavelet transformations (DWT) in signal decomposition. The paper presents a model of the developed fuzzy system for tool wear classification. The system comprises three modules: module for data acquisition and processing, module for tool wear classification, and module for decision-making. The selected method for feature extraction is presented within the module for data classification and processing. The selected model for the fuzzy classifier and classification in experimental laboratory conditions are shown within data classification and clustering. The proposed model has been tested in longitudinal and transversal machining operations.*
Key words*: tool monitoring, wear, feature extraction, turning*

1. INTRODUCTION

The development of tool wear monitoring systems which operate in real time and employ indirect methods, represents the mainstream in today's automated manufacturing. Intensive research in the area of cutting tool wear monitoring systems based on application of artificial intelligence (AI), have begun in the nineties of the twentieth century. The focus of research was placed on the application of multi-sensor systems and the development of AI-based tool wear classifiers able to operate with a large number of features. Although the initial results promised the design of an industrially applicable solution, such breakthrough did not happen. Numerous AI-based tool wear monitoring systems have been developed to optimize and predict tool wear condition, or control the machining processes. Development of a model and practical application of a multi-sensor tool-wear monitoring system was proposed by Dutta et al. [1] and Balazinski et al. [2]. Indirect tool wear monitoring methods based on acquisition and processing of sensor signals represent major topic in majority of current experimental investigations. Since most indirect methods are still under development and improvement, none of them represent tool wear on the level required for industrial application [3, 4].
Modern tool wear monitoring systems based on artificial intelligence, should replace and augment conventional systems, providing continuous, fast and accurate determination of tool wear. Application of such systems in industry allows:

- Increase of reliability of the machining system, which is specially important in situations when cutting is performed with tools nearing life end.
- Optimization of cutting parameters with tool life as goal function, considering technological limitations.
- Provision of required workpiece dimensional accuracy and surface quality.
- Additional rationalization of manufacturing costs.

2. TOOL WEAR MONITORING

Tool wear condition is defined as the change of tool cutting geometry. Indirect tool wear monitoring methods allow monitoring of the degree of correlation between sensor signals and the monitored phenomenon. Due to its practical applicability, the approach based on indirect method has advantage over direct methods. Through monitoring the machining dynamics, as well as the influence of the type of chip cross-section generated during machining, it is possible to gain insight into the tool wear condition [5]. Moreover, numerous researchers have employed finite elements analysis to define the influence of machining process parameters on the tool wear, using special types of finite elements. Tamizharasan and Senthil Kumar [6] evaluated the effect of tool geometries on performance measures of flank wear, surface roughness and cutting forces. They applied finite element analysis to minimize flank wear of uncoated carbide inserts during machining.
The selection of sensor system, and type and characteristics of sensors are directly related to specific features of the machining process. The variation of cutting forces directly reflects on machine accuracy and machining quality. Through force control, it is possible to directly improve machining quality and prolong tool life. Also, the changes in machining process can be identified through monitoring of variations in the structure of vibrations, which allows the correlation to the quality of machined surface and tool life to be established.

2.1. Tool monitoring systems

Majority of investigations which deal with the development of tool wear monitoring systems focus on the type of machining and the machining process to which they are applicable, rather than the types and kinds of input signals, methods and techniques of signal processing and feature extraction. Thus, they artificially limit the application range of their investigation in the domain of tool monitoring systems, especially when focusing on specific machining technologies.

Suitable for defining a multi-sensor system model are neural networks, fuzzy logic and a combination thereof, also known as the hybrid systems. Due to their feature recognition ability, these algorithms can be applied in machining to allow adequate recognition of process features. Development of tool monitoring system based on pattern recognition approach can be conducted in three characteristic steps. The first step is acquisition and processing of sensor signals, x(t), which requires noise removal by filtering. The acquired data are then grouped as the input function, used in the subsequent process. Information relevant to samples classification are extracted from the pre-processed input signal x'(t), and a vector function y(t), is formed.

2.2. Methods and techniques of feature extraction

Input sensor signals and other input data depend on the type of machining and the time-frequency decomposition of signal. Application of wavelet transformations in processing and analysis of the data acquired from the machine tool, allows efficient analysis of various dynamic and stationary signals from mechanical systems which proves its efficiency in feature extraction. It has been shown that time-frequency methods are very good for the extraction of features which would otherwise, through application of other methods, remain undetected. The area which requires father investigation is the integration of machine tool dynamics and the correlation between the cutting process and tool wear monitoring system. Little has been done to use those information within systems for tool wear monitoring. There are a number of methods which can be used to generate dynamic models of machine tools in order to allow integration of tool wear monitoring systems. Use of mathematical models has a potential to widen applicability of tool wear monitoring systems taking into consideration dynamic characteristics of machine tools [7].

Wavelet transformation is the most popular and most important method for signal analysis in the time-frequency domain. It allows analysis of signals on a local level, which is especially important when processing non stationary signals. Transformation is based on the comparison between the wavelet function of a certain width (frequency) defined by the scanning parameter (s) and the parts of signal of equal width within a defined time interval (t - kτ). The scale is inverse to signal frequency, as shown in (1):

$$\gamma(\tau,s)\frac{1}{\sqrt{|s|}}\int_{-\infty}^{\infty}x(t)\varphi^{*}\left(\frac{t-\tau}{s}\right)dt \qquad (1)$$

where τ is translation parameter, s is scale parameter, *x(t)* is the signal being transformed, γ is the frequency content of the signal *x(t)* within a time interval $k\tau$ and considering the scale *s*, while φ^* is the scaled and translated projection of the original wavelet $\varphi(t)$. When the analysis of the complete signal is performed using the original function of the defined scale, the procedure is reiterated for another scale value, i.e., time interval. If the signal contains the spectral component which corresponds to current scale value, the product between the wavelet function and the signal is relatively large at the spot where the component is located.

Parallel to the development of the model of tool wear monitoring, analyses have been performed of characteristics of various forms of wear identification parameters, to assess the quality of wear identification they allow. According to these analyses, the low-frequency signals (forces, motor currents) are most often present when extracting parameters in time domain, followed by the parameters from the frequency domain, and statistical parameters. In high-frequency signals, such as the acoustic emission or vibrations, the most frequent parameters are the parameters from the frequency domain, followed by statistical parameters and the parameters from the time domain.

3. DEVELOPMENT OF A LABORATORY SYSTEM FOR TOOL WEAR MONITORING

Current experience with the development of various AI-based models of tool wear monitoring were used in the development of the model proposed in this paper. Analysis of the existing models yielded advantages and disadvantages of particular approaches which was valuable in the development process of the novel model. Based on the stated requirements, a novel model of the system for tool wear monitoring was designed (Fig. 1). Essentially, the model consists of three modules combined into a unique system. The developed modules of the proposed laboratory system for tool wear monitoring are:

- module for data pre-processing,
- fuzzy classification module,
- decision module.

The sensor part of the data pre-processing module consists of accelerometer for the measurement of vibration acceleration which is positioned at the tool handle. Also belonging to the pre-processing module is the A/D card, NI USB 6281 18 bit, 625 kS/s, which receives analogue data from the sensor, converts them into digital format, and sends them to the measurement database on a PC. MATLAB was also used to control the card operation. The system allows selection of the sampling speed, as well as the other data acquisition parameters.

3.1. Modules for data pre-processing and fuzzy classification

The structure of the module for pre-processing of data allows realization of three basic tasks. During data acquisition task, data are collected from the sensors and filtering band is selected. The proposed system uses the flat frequency response Butterworth filter to filter various types of noises present in the measurement signal.

The second task is feature extraction. The basic goal of feature extraction is to significantly reduce the dimensions of raw data collected from the sensors in the time and frequency domain, while at the same time preserving the data relevant for tool wear condition. Spectrogram matrix *S*, of the signal *s(n)*, is composed of the columns which represent the square of the modules of discrete Fourier transformation (DFT) of the sampled signal *s(n)*.

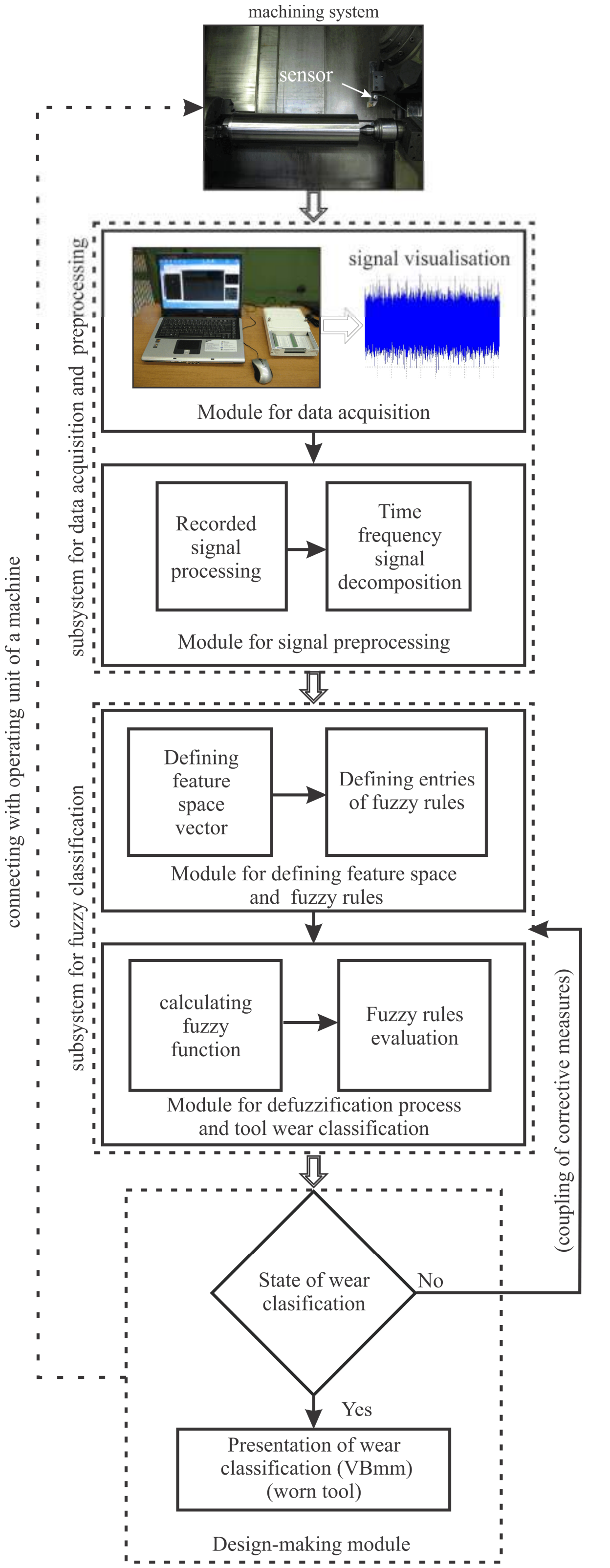

Fig. 1. Structure of the developed system for tool wear classification

Major spectrogram parameters are shape and length, as well as the degree of superposition between two neighbouring window functions w(n). Averaging of all column values from the spectrogram matrix S, yields the assessment of the signal spectral power. Since, based on conducted analyses, there was established that the signal spectral power alone is insufficient to allow discrimination of features, the spectrogram was normalized by subtracting the approximation of the signal spectral power from each column of matrix S. Once normalization is performed, following steps are executed:

- extraction of certain spectrogram ranges (~5kHz to ~45kHz),
- selected filters from the LM bank of filters are applied,
- statistical parameters are calculated based on the data extracted by filtering,
- features are formed and subsequently used for classification in the next step.

Basically, maximum number of features should be used to train the classifier. However, this is not always the best approach, since some features with less discriminative power can impact the performance of the training set. In order to improve accuracy and efficiency of classification and diminish hardware requirements, the final number of significant features is carefully considered and defined within the third segment of the pre-processing module.
Within the investigation aimed at filtering and calculation of vibration signal spectrum, "Leung-Malik" (LM) set of filters was used as a multi-scalar and multi-oriented bank with 48 filters are shown in Fig. 2.

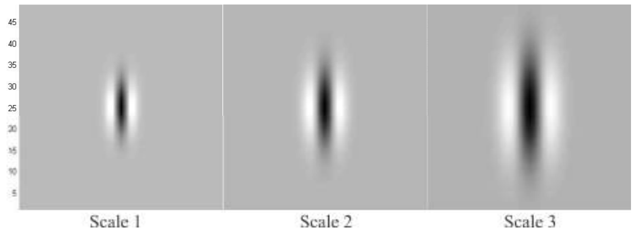

Fig. 2. Images of the selected vertically oriented filters used for signal processing during feature extraction

The selected filters with vertical orientation at particular scales were applied to the high-frequency part of spectrum of the recorded vibration signal. The resulting filtered spectrograms are shown in Fig. 4. This figure shows the variation of signal spectrogram at particular scales, after the application of LM filters for feature extraction.

3.2. Defining the input feature vector

Based on the analyzed feature extraction methods reviewed in literature, following statistical parameters were selected for input feature vector: mean, variance, skewness and kurtosis, also known as the measures of central tendency. In probability theory and statistics, the k-th moment of mean (or the k-th central moment) of the real random variable X is μk = E[(X – E(X))k], where E is the expectancy operator. For a continuous, univariant probability distribution with the probability density function of f(x), the mean moment μ, is given by (2).

$$\mu(X)_k = E\{[(X-E(X))^k]\} = \int_{-\infty}^{+\infty} (x-\mu)^k f(x)dx \qquad (2)$$

Since the distribution function is not known. The moment of the generated function of random variable X can be written as (3):

$$M(t)=M_X(t)=E[e^{tX}] \qquad (3)$$

where t is a real number, and $M_X(t)=1 + tX + t^2X^2/2! + t^3X^3/3! + ...$ if $\mu n = E(Xn)$ *n*-th moment of X, then the expected value is (4):

$$M(t) = 1 + \mu_1 t + \frac{\mu_2 t^2}{2!} + \ldots + \frac{\mu_n t^n}{n!} + \ldots + \qquad (4)$$

Since the coefficient *tn* in the Taylor order M *n(0)/n*!, where M*n* is the *n*-th derivative of *M*, then μn = M *n*(0). The characteristic function is approximated using the moments, which are represented by input feature vectors for the fuzzy classifier. The exception is the deviation of directedness in the case of tool insert with the highest degradation of cutting geometry. This can be explained by the fact that this insert was fully degraded which resulted in the complete change of the type of chip segmentation, leading to the change of the vibration signal spectrum.

3.3. Module for tool wear classification

Feature recognition using analytical functions consists of two well defined stages: the stage of transduction and stage of classification. Let Ω be a set of physical objects, i.e., objects and processes. These objects can be characterized using a finite set of parameters, relevant for the classification task. Each of the parameters, or a pair of them, represent the specific features of the object q ∊ Ω. Each object parameter can be measured using some measuring procedure. It is also possible to measure certain features, after applying an arbitrarily complex measuring procedures m, which are related to those features.

The second stage of feature recognition is the classification of sample vectors. Classification means that a given mathematical object x can be assigned to a class of similar or partially similar objects. Thus, within a rigid system of feature recognition, the value of membership equals zero or one, μ(x), while the fuzzy feature recognition assigns membership values between zero and one to each sample within the membership function μF(x). The best-know standard algorithm to apply to this problem is Fuzzy c-mean (FCM) algorithm, which is why it was also used in the case of tool wear identification.

4. VERIFICATION OF MODEL

To verify the proposed model, experimental data were divided into two sets, the training set containing about 4/5 of experimental data, and a test set containing the remaining 1/5 of data. All data were collected during the same series of experimental investigations. Data sets were carefully organized so that each contained the data from all combinations of cutting parameters. The selected FCM classification method was used to classify the extracted features into clusters, based on their classification matrix. Classification model was verified using a training feature set by defining six cluster centroids, one for each wear group at three different scales. Shown in Fig. 3 are the results of classification using FCM algorithm at the second scale with the mutual relationship for the three features. Defined for each scale are the mutual relationships between the features, which are defined by input feature vectors.

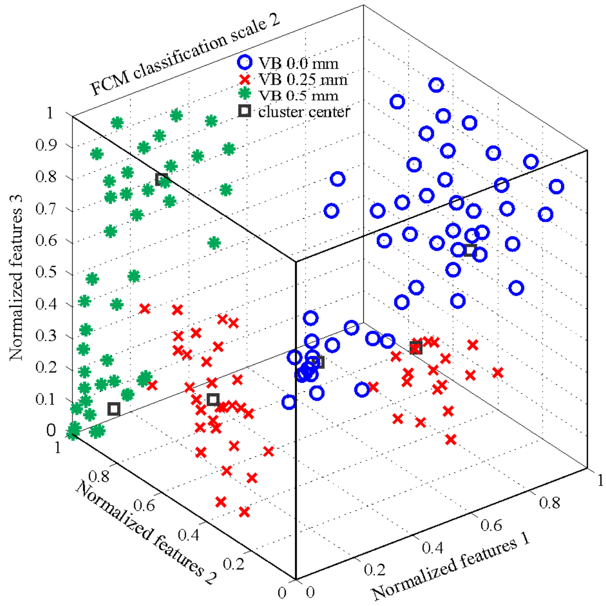

Fig. 3. Classification of the training set using FCM algorithm at the second scale

Shown in Fig. 4 are statistical results of classification, obtained with the test set. Judging by the presented results, it is possible to conclude that the third scale yields best classification results. This can be explained by the fact that the third scale pertains to the widest frequency range of the recorded signal, since it is least burdened with signal noise. At lower frequencies, the signal suffers from external noises, ,such as the vibrations of the machining system.

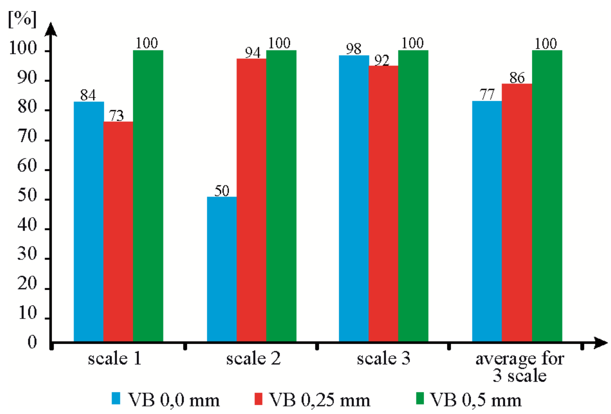

Fig. 4. Statistical results of feature classification system in longitudinal machining

5. CONCLUSION

The results presented in this paper confirm the assumption that the proposed model of feature classifier can obtain the required accuracy during wear monitoring of the longitudinal cutting tool. Moreover, the results reveal that the proposed method of classification requires a training set which consists of a larger number of quality input vectors. Also, an important prerequisite for accurate classification is to apply a larger number of combinations between cutting parameters during initialization, i.e., during training of the feature recognition system.

Acknowledgments: This paper presents a segment of the research on the project "Contemporary approaches in the development of special solutions bearing in mechanical engineering and medical prosthetics", project number TR 35025, financed by the Ministry of Education and Science of the Republic of Serbia.

REFERENCES

[1] Dutta, A.K.; Paul, S.; Chattopadhyay, A.B. Fuzzy controlled backpropagation neural network for tool condition monitoring in face milling, International Journal of Production Research, 38, 13(2000), pp. 2989–3010.

[2] Balazinski, M.; Czogala, C.; Jemielniak, K.; Leski, J. Tool condition monitoring using artificial intelligence methods, Engineering Applications of Artificial Intelligence, 15, 1(2002), pp. 73–80.

[3] Barreiro, J.; Castejon, M.; Alegre, E.; Hernandez, L.K. Use of descriptors based on moments from digital images for tool wear monitoring, International Journal of Machine Tools & Manufacture, 48, 9(2008), pp. 1005–1013.

[4] Salgado, D.R.; Alonso, F.J. Tool wear detection in turning operations using singular spectrum analysis, Journal of Materials Processing Technology, 171, 1(2006), pp. 451–458.

[5] Antić, A.; Petrović, B.P.; Zeljković, M.; Kosec, B.; Hodolič, J. The influence of tool wear on the chip-forming mechanism and tool vibrations, Materiali in tehnologije/Materials and technology, 46, 3(2012), pp. 279–285.

[6] Tamizharasan, T.; Senthil Kumar, N. Optimization of cutting insert geometry using deform-3D numerical simulation and experimental validation, International Journal of Simulation Modelling, 11, 2(2012), pp. 65-76.

[7] Antić, A.; Šimunović, G.; Šarić, T.; Milošević, M.; Ficko, M A Model of Tool Wear Monitoring System for Turning, Tehnički vjesnik/Technical Gazette 20, 2(2013), 247-254.

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25 - 28 September 2013
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DESIGNING AND MODELING PROGRAM SYSTEM TAPS USING PRO / ENGINEER WILDFIRE 5.0

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Abstract: *In this day and age is present intensive introduction of automation in the design, modeling and manufacturing of products from different materials. According to contemporary records, 50% of the total relates to the process by removing material where the application of different techniques from artificial intelligence expert systems, artificial neural networks, fuzzy logic, genetic algorithms and genetic programming, advanced modeling techniques found a suitable area for the concrete implementation and its evaluation in compared to existing conventional design techniques, modeling, process control and optimization of processing parameters. Tools for threading tools are complex, it is a theory construction is very complicated and extensive. This paper presents a theory of design and modeling software system taps using Pro / ENGINEER Wildfire 5.0*

Key words: *designing, modeling, taps*

1. INTRODUCTION

Mastering the information and technology of their transfer is one of the most important keys in the development of future human society. Information now occupies a high place in the production, and in addition to capital and labor, information becomes the third factor of production [1]. Science is a constant striving for inventions, understanding of the world we live in and search for new knowledge. A systematic practical application of scientific knowledge is possible in the design engineering and manufacturing. Modern technological methods are increasingly being applied in the production. We have consciousness that the boundaries of science is constantly moving, and the designers and technologists that scientific knowledge have successfully introduced into practical use.
Two-thirds of world production in mechanical engineering makes small-scale production. In this production a wide range of cutting tools is used. They should satisfy the required technical, aesthetic and economic requirements [2]. It is clear that the application of advanced CNC machines is necessary. The above requirements and further development of new technologies inevitably point out to the use of computers in the process of designing, constructing and modeling of cutting tools. At the Faculty of Technical Sciences, University of Novi Sad a lot of attention is paid to the automation of designing, constructing and modeling tools of cutting tools. This paper presents a part of the automation of design and modeling of taps as one of the most complex cutting tools

2. DESIGN, CONSTRUCTION AND MODELING OF CUTTING TOOLS

Cutting tools are the products of human labor that arose out of necessity. Design, construction and modeling of cutting tools can be defined as a kind of processing and transforming of information. At the beginning first step is collecting of information, and then it continues with processing of information. The process ends with the formation, presentation and transmission of information.
When designing , constructing and modeling of cutting tools there is a need to know information about the shape and dimensions of the machined surface, the required accuracy and tolerances for surface machining, the material of the workpiece and its technological properties, and also technical specifications of the machine on which machining will be performed [2, 3, 4, 5]. Based on the previously mentioned data the type of cutting tool, its possible construction, cutting tool material and the basic parameters of cutting tool are adopted.
In order to reduce the time required for the design, construction and modeling of cutting tool the automation of the above mentioned activities supported with its automated calculation are introduced.
The process of designing, constructing and modeling of cutting tools by a computer is possible only under the condition that the task is correctly set, i.e. the appropriate formalization and algorithm setting are needed. This paper presents the development of the workpiece model and special tap using the programming system Pro / ENGINEER Wildfire 5.0.

3. MODELING OF WORKPIECE AND A SPECIAL TAP USING PROGRAM SYSTEM PRO / ENGINEER WILDFIRE 5.0.

Taps are cutting tools for machining of screw thread in holes, apertures and nuts [6]. They are used for hand or machine tapping. Taps are the tools of complex design and manufacture. They are manufactured with straight and helical grooves. (Figure 1)

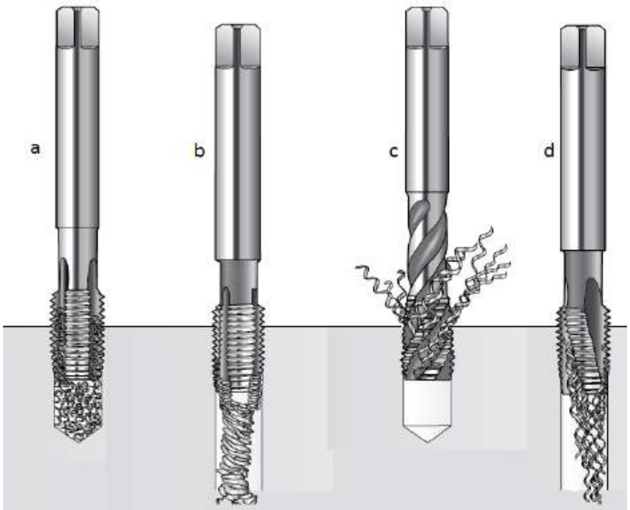

Fig. 1. Taps with straight and helical grooves

Also chip evacuation in the direction of displacement at the holes is obtained by setting the angle λ on the grooves in the cutting part of the tap. Taps with openings for the supply of coolant and lubricants have better cutting and better production characteristics than those using external cooling. (Figure 2)

Fig. 2. Tap with openings for the supply of coolant and lubricants

When modeling the workpiece is necessary to define the work area, and then set the working directory, and then create a new document and determine the type and name of the document. Selecting the type of document and measurement units are the next step, and then defining the desktop and areas for sketching the profile and at the end sketch the profile and define the length of the extrusion [7, 8]. Next step is to define the parameters of the opening (Figure 3) and adding the thread (Figure 4), and then define the parameters of the thread (Figure 5) and thread surface of initial surface, the direction of the thread, the thread depth, the end surface, the diameter of the thread and chamfering holes. As a result of previous activities workpiece model is obtained (Figure 6) .

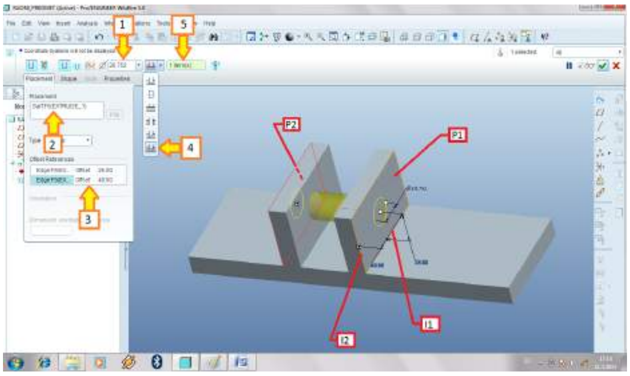

Fig. 3. Defining parameters of opening

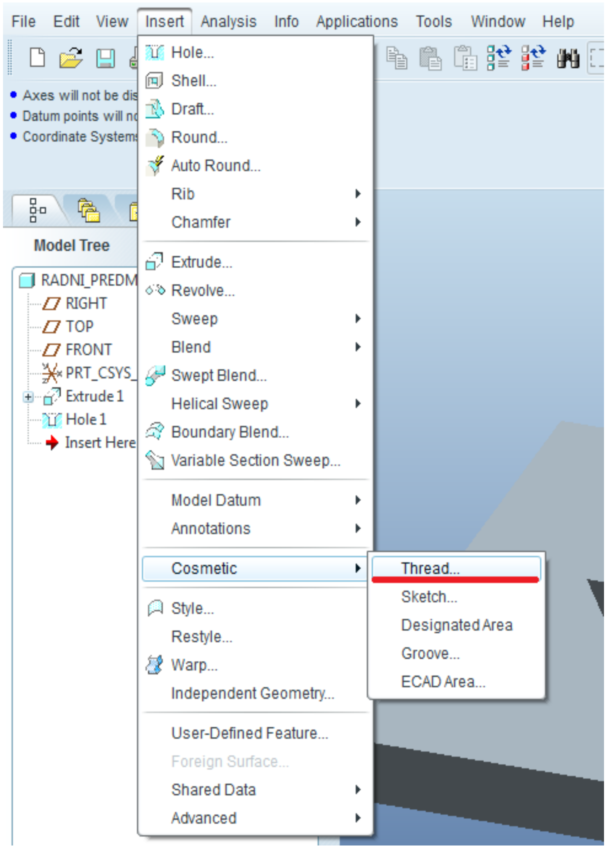

Fig. 4. Adding the thread

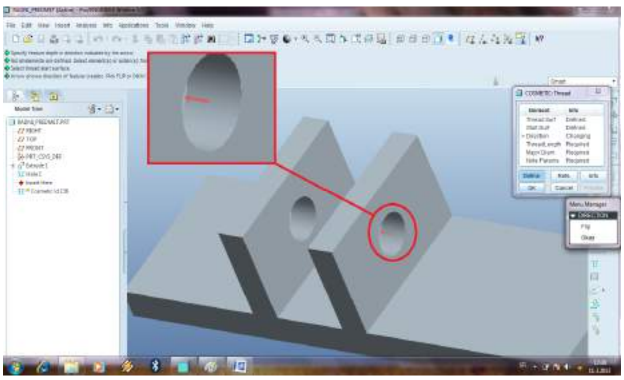

Fig. 5. Defining the parameters of thread – direction of thread

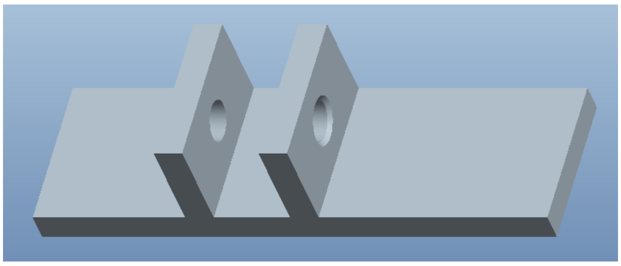

Fig. 6. Model of the workpiece

Modeling of the special tap begins with similar activities as well as modeling of the workpiece . The first step is the creation of a new document, the selection of units, the modeling of the cutting part of the tool and the creation of new sketch of cutting part and calibrating part. Next step is to define the area of drafting and defining a circle, then defining the extent to which a circle is drawn in order to form the handle. After previously performed activities modeling of grooves for chips drain is carried out. A profile drawn through the defined trajectory is created. It is necessary to define trajectory attributes and then sketch the profiles and define material removal. After copying of grooves, there is need to rounding the edges according to Figure 7.

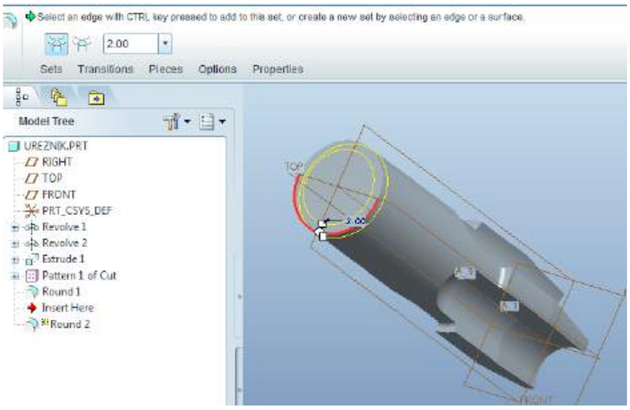

Fig. 7. Rounding of edge of tap handle

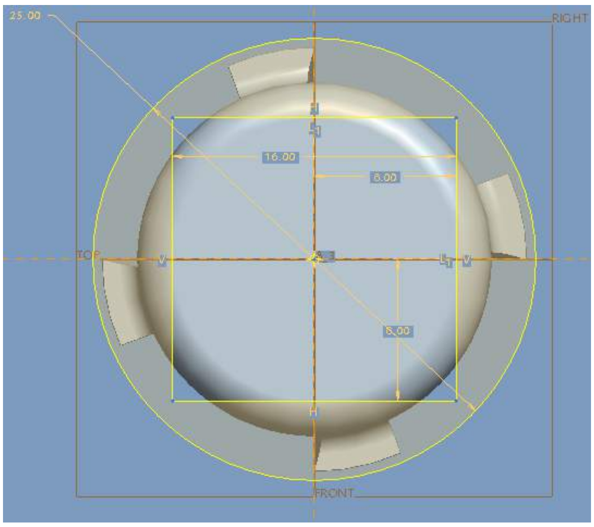

Fig. 8. Sketch the profile of the handle part for the acceptance on the machine

After this operation, the modeling of handle part for the acceptance on the machine is performed. Figure 8 shows the profile of the handle part for the acceptance on the machine. Then the definition of drawing of profile length and removing of the material are following as shown in Figure 9.

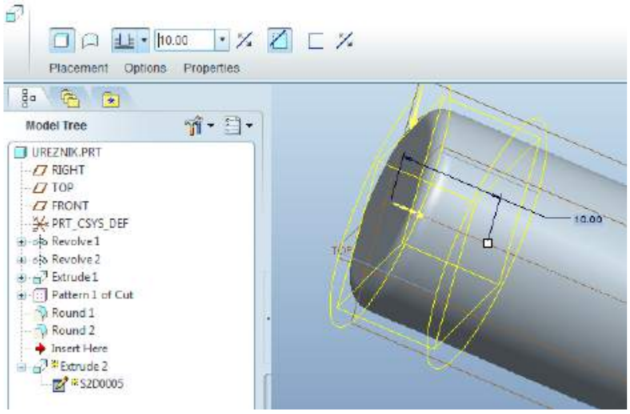

Fig. 9. Definition of parameters Extrude operation

Next activity is defining of the λ angle on the grooves. Creating a plane is done by the command datum plane, and creating of DTM1 plane is performed according to Figure 10. Then points PNT0, PNT1, PNT2 and PNT3 are defined. The next plane defined is the DTM2. After previously performed operations curves are sketched. From these curves a real curve surface is made. This curved surface, which is at an angle λ with respect to the axis of rotation of taps, is cut from the tap material. After this creating of surface, drawing of surface and then copying of surface and elongation are carried out. Removal of material is carried out as shown in Figure 11 and this operation is repeated for each groove separately.

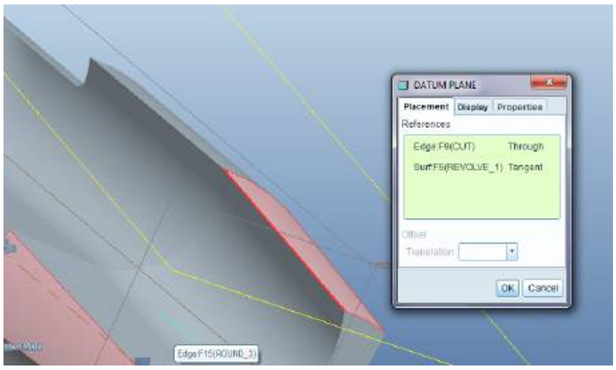

Fig. 10. DMT1 plane

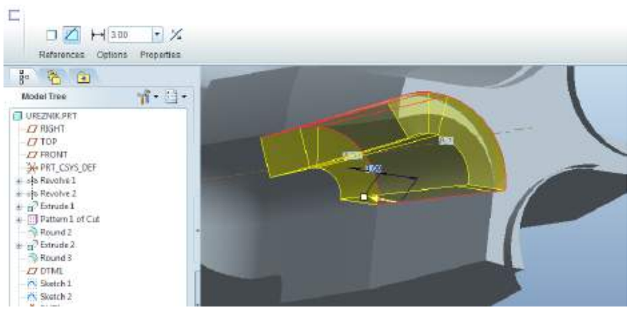

Fig. 11. Removing of material

At the end of modeling of special tap screw thread is manufactured. There is also need to define the shape, the length of the screw thread, the pitch and the profile of screw thread. Also it is necessary to define from which side of the profile material is removed. Model tap is shown in Figure 12.

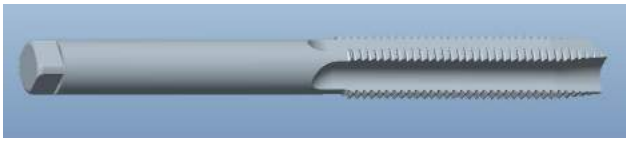

Fig. 12. Model tap

4. CONCLUSION

The modern approach to the design, construction and modeling of cutting tools requires a wide range of knowledge of implementer. In addition to knowledge of geometry and material for the manufacture of cutting tools it is necessary to possess knowledge of the kinematics and geometry of the machine on which the tool designed will be used.

Application of modern software systems in addition to faster and better modeling of tools also enables the automation of design and construction of cutting tools by applying software systems. Having in mind the rapid development of software systems in all aspects of human life and work we can safely claim that in the future the software systems will enable more efficient automation of designing, constructing and modeling of cutting tools.

ACKNOWLEDGMENT

This paper is part of the technological project TR 35015 at the University of Novi Sad, Faculty of Technical Sciences, and was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia

REFERENCES

[1] TANASIJEVIĆ, S. (2004) *Tribološki ispravno konstruisanje*, Mašinski fakultet, Kragujevac
[2] SOVILJ, B., (1988) *Identifikacija triboloških procesa pri odvalnom glodanju*, FTN Novi Sad
[3] KOLEV, I. (2009) *Rjazane na materialite*, Preč baza na RU “A. Kičev”, Ruse
[4] Nikolčeva G (2008) *Režešci instrumenti*, Interpres, Sofija
[5] KLIMOV, V. I., LERNER, A. S., PEKARSKI, M. D., SMIRNOV, L. N., ŠLEIMOVIČ, M. A. (1964) *Priručnik za konstruktore reznog alata*, Beograd
[6] DECKER, K.-H., (2006) *Elementi strojeva*, Tehnička knjiga Zagreb, Zagreb
[7] LAMIT, L. G. (2010), *Pro/ENGINEER Wildfire 5.0* , Cengage Learning, Independence,
[8] HANH & KOLB GRUPA (2011) *Katalog_SRB_2011*, www.hanh-kolb.de

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