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MANUFACTURING TECHNOLOGIES AND ADVANCED MATERIALS
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MACHINE TOOLS AND INDUSTRY 4.0 - TRENDS OF DEVELOPMENT

Saša Živanović[1], Slobodan Tabaković[2], Milan Zeljković[3]

Abstract:Primary goals of trends of digitalization in the Industry are increasing of efficiency, productivity and quality of product. As a basic unit of modern manufacturing industry, numerical controlled machine tools have important role in industrial digitalization. Their improvement trough implementation of digitally connected components and subsystems enables a creation of an adaptive mechatronic system which can be a part of connected production system. This paper describes some of the key and desired characteristics of Machine Tool 4.0 such as Cyber-physical Machine Tools, vertically and horizontally integrated machine tools and more intelligent, autonomous and safer machine tools.

Key words: Cyber-physical systems (CPS), Cyber-physical machine tools (CPMT), Industry 4.0, Machine tools

1 INTRODUCTION

The continuous development of technologies and society is enabled by intensive developments improvement of production technologies. This applies in particular to the development of machine tools as a basis of industrial technological systems of today [1].

Intensive development of technology with integration of information systems into all elements of society at the beginning of the twenty-first century has significantly influence in development of the society, globalization and market demands.It could be seen basis on changing the product life cycle of on market, intensive using the new materials and with an increasing trend towards the personalization of products. That caused intensive structural and functional changes in whole industry. As a good example for mentioned above could be taken a time reducing trends between significant conceptual changes in industrial production, popularly called industrial revolutions (Fig. 1). As well evolution of machine tools follows this trend, but it does not match completely with time period and time intervals until the occurrence of significant changes in development of machine tools, are shorter.

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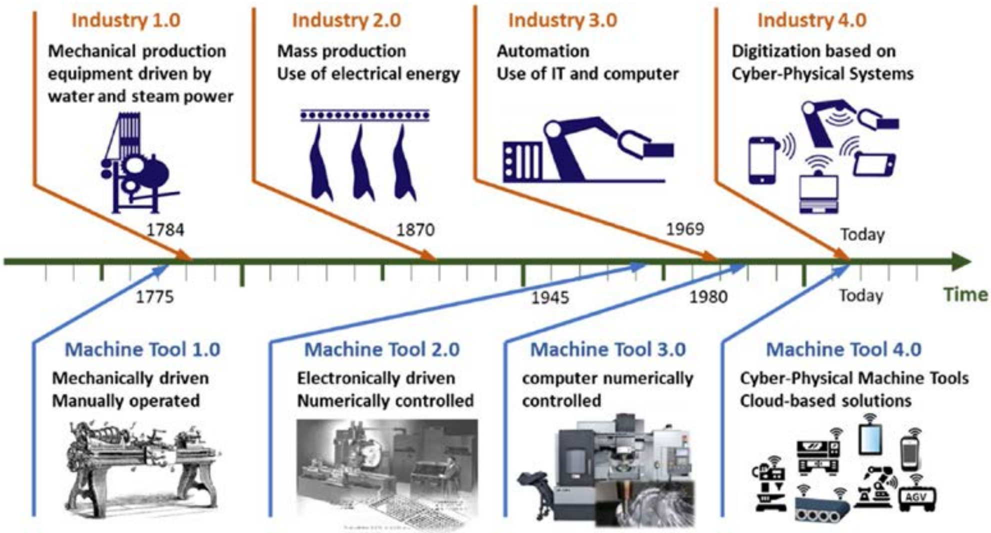

Figure 1. *Evolutionary history of industrialization and machine tools [3]*

In the past five years, several industrial initiatives such as “Industry 4.0”, “Industrial Internet of Things”, “Factories of the Future” and “Made in China 2025”, have been announced by different governments and industrial leaders [2]. This initiative is stimulus for improvement of production systems and machine tools with high degree of intelligence and autonomy. The evolutionary history of machine tools has significantly affected the history of industrialization. As shown in Fig. 1, while industrialization can be briefly divided into four industrial revolutions, i.e. Industry 1.0 (mechanization, end of 18th century), Industry 2.0 (mass production, start of 20th century), Industry 3.0 (automation and IT, start of 1970s) and Industry 4.0 (Cyber-Physical Systems-based digitization, present time) [3].

History of evolution of machine tools is presented in Fig. 1. They can be presented trough four phases: (i) Machine Tool 1.0 (mechanically driven but manually operated, end of 18th century), (ii) Machine Tool 2.0 (electronically driven and numerically controlled, middle of 20th century), (iii) Machine Tool 3.0 (computer numerically controlled, late 20th century) and (iv) Machine Tool 4.0 (Cyber-Physical Machine Tools and cloud-based solutions, present time) [3].

As is stated in [2] it is predicted that current CNC machine tools are not intelligent and autonomous enough to support the smart manufacturing systems envisioned by the aforementioned initiatives. Inspired by recent advances in Information and Communication Technology (ICT) such as Cyber-Physical Systems (CPS) and Internet of Things (IoT), a new generation of machine tools, i.e. Machine Tool 4.0, represents a future development trend of machine tools for Industry 4.0. The Industry 4.0 as the new industrial revolution we are experiencing is predicted to be based on the advances of ICT such as CPS, IoT and cloud computing [2, 4].

2 EVOLUTION OF MACHINE TOOLS FROM MT1.0 TO MT4.0

Much like the different stages of industrialization, machine tools have also gone through different stages of technological advancements, from Machine Tool 1.0 (MT1.0) to Machine 4.0 (MT4.0). Industrie 4.0 pleads for a new generation of machines—Machine Tool 4.0. Figure 2 shows the evolution of machine tools from MT 1.0 to MT 4.0.

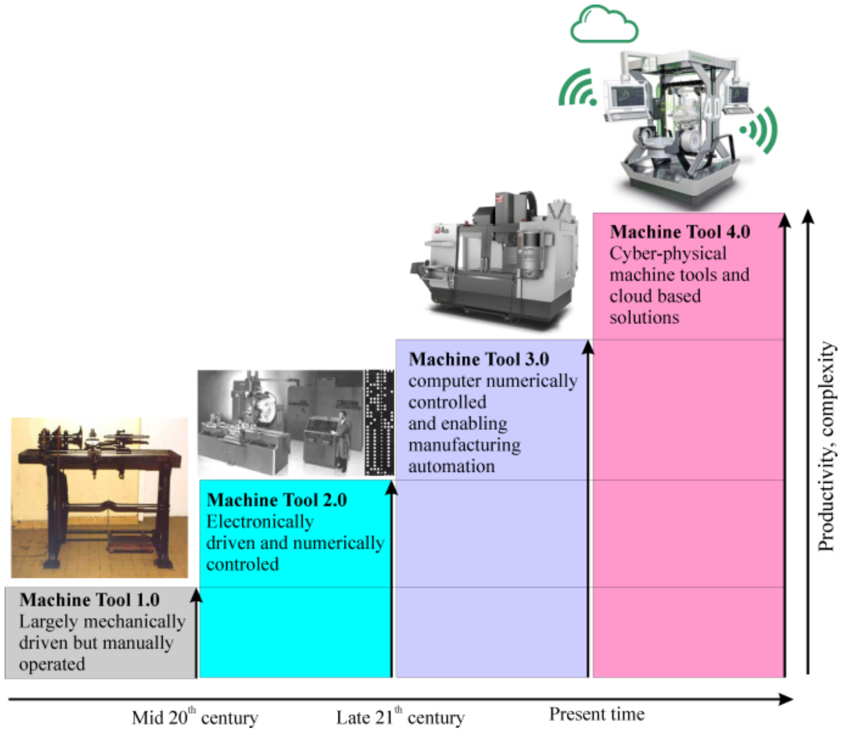

Figure 2. *From MT1.0 to MT 4.0*

2.1 Machine Tool 1.0 (1775-1945)

Machine tools besides the steam engine are the driving force of the industrial revolution. They had been existed before industrial revolution, but development of steam energy made possible to building the machine tool in today's form. Therefore, 1800 years is considered as the year of development modern machine tools.

The first machine tools offered for sale (i.e. commercially available) were constructed in England around 1800. During this time, both Henry Maudslay and Joseph Whitworth were responsible for dramatically advancing the accuracy of the machine tools [5].

In the early twentieth century, automobile industry dominantly influenced in further machine tool development in terms of rapid progress of standardization and the advances of machine tool design and construction. The machine tools up till this time were mostly manually operated with some form of mechanical assistance for high precision machining. These machine tools still required a great deal of skills and experiences to operate [2, 6].

2.2 Machine Tool 2.0 (1945-1980)

Since the late 1940s, machine tools had experienced a significant advancement in motion actuation and control, i.e. the development and deployment of numerical control (NC), and the gradual shift from mechanical to electronic actuations in general [2,6].

The first NC machines were designed for manual or fixed cycle operations at the Massachusetts Institute of Technology in the late 1940s [7]. These machines had electronically driven and numerically controlled, though only for positioning the workpiece relative to the tool. Considerable time was saved, but yet the operator had to select the tools, speeds and feeds. Later, the enhanced NC machines enabled material removal to occur at the same time as the control of the workpiece/tool movements [2, 6].

These NC machines were also termed tape-controlled machines, because the information was stored on either punched card/tape or magnetic tape [2, 6, 8]. It was difficulty to edit and change the programs at the machine, the machines had only very limited memory capacity. In any case, in comparison with the conventional manually-operated machine tools (MT1.0), the advantages of NC machine tools (MT2.0) are multiple.

2.3 Machine Tool 3.0 (1980-)

The accelerated advancement of computers, around the 1970s, has resulted them being used in assisting NC machines, which led to the birth of Computer Numerical Control (CNC) machine tools. Around 1980th for controlling the machine tools computers was successfully used, thereby forming a CNC machine tool. CNC machine tool is part of machining system which is guided with alphanumeric geometrical and technological data's of part which should be produced on the machine [9].

Controller is configured for every machine itself, by adjusting the specific operating system parameters of the computer which running the machine. Contour machining was begun to be common and servosystem were used. In programming were used programming languages, and then the first CAD/CAM version of systems.

Using of CNC machines has radically improved industrial production. Curves are as easy to cut as straight lines; complex 3-D structures are relatively easy to produce; and the number of machining steps that require human action is dramatically reduced. CNC automation also allows for more flexibility in the way that part programs for different components are quickly produced and executed on a single machine tool [2, 6]. The significance of CNC machines in fact goes much further beyond machines themselves. Several CNC machines can be tied together and/or controlled via a central computer to perform coordinated machining processes. This gives rise to Direct Numerical Control (DNC) and Flexible Manufacturing System (FMS) [10].

2.4 Machine Tool 4.0

Machine Tool 4.0 (MT4.0) defines a new generation of machine tools that are smarter, well connected, widely accessible, more adaptive and more autonomous [2,6]. MT 4.0 can be better used for predictive maintenance, increasing efficiency and process optimization.

Machine Tool 4.0, otherwise known as Cyber-Physical Machine Tool (CPMT), is the integration of machine tool, machining processes, computation and networking, where embedded computers and networks can monitor and control the machining processes, with feedback loops in which machining processes can affect computations and vice versa [2].

3 MACHINE TOOLS AND INDUSTRY 4.0

Industry 4.0 is the term given to the factory of the future and the shift toward using advanced technologies that are heavy on automation, data collection and connectivity. In this new industrial world, everything will be connected through the internet and the cloud, enabling factories to function as a system rather than individual parts [11]. Machine tools will become a part of Industry 4.0 which will affect changes in them. These changes primarily relate to: (i) preventative maintenance, (ii) improved utilization, (iii) energy savings, (iv) avoiding improper use, (v) improved quality assurance and (vi) change in the role of humans.

One of the main characteristic of Industry 4.0 is data collection. Machine tools will have sensors that will collect many different kinds of data, including data on how much the machine has operated the conditions it has operated in and the condition of the components of the machine tool. By collecting and analyzing these data, machines could estimate when a component needs replacement. Predictive maintenance could keep machines running more efficiently and prevent downtime [11].

Research carried out over in the last few years has shown the fact that in industrial plants machine tools are used inefficiently. In the total time of machine tools using, machining takes less than 40% (in some cases less than 25%) of the time [11]. Improved utilization of machine tools is possible by collecting and analyzing data about things like tool changes, program stops and feed holds. Energy savings is important characteristic for smart new machine tools, which can also collect data on energy use to help save companies money.

Industry 4.0 will also help identify when machines are being used improperly. Machine can send out an alert if it detects conditions outside of norm of normal work. This could help prevent serious mistakes caused by human error or malfunction, which could avoid downtime as well as worker injury. One of the most important goals of Industry 4.0 in the area of machine tools is improvement of quality. In new machine tool is very important use of automation which also improves quality by reducing the natural variation that comes with human action.

Concept of Industry 4.0 will change basic role of human operators in Shopfloor. Many jobs will shift from physically operating to operating them via computers, monitoring data and providing oversight to automated operations. This will require some substantial retraining of human workers [11]. One of advantages of Industry 4.0 for workers is improved safety. Automatization allows to workers a surveillance job thereby decreasing a risk of human error.

Getting started with IoT, automatization and other benefits Industry 4.0, on the beginning looks frightening, but it should be started where is possible, so as not to be left behind for competition. Basic aims which should be achieved using Industry 4.0 principles are better information – better making decision and better achieved results.

4 CYBER-PHYSICAL MACHINE TOOL

In the era of Industry 4.0, inspired by advances in Information and Communication Technology (ICT), such as CPS (Cyber-Physical Systems), Internet of Things (IoT) and cloud computing, in [2] propose a new generation of machine tools – Cyber-Physical Machine Tools (CPMT) – as a promising development trend of machine tools. The definition of CPMT is given in section 2.4, while the four main components shown in Fig.3, from [1].

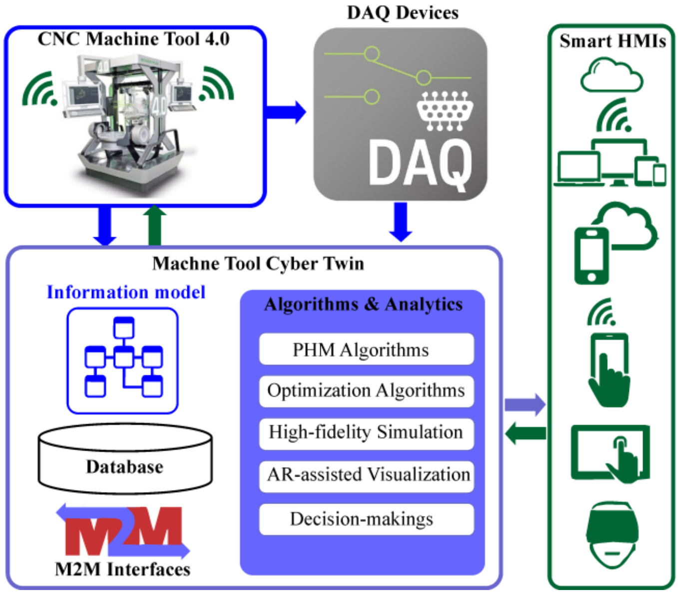

Figure 3. *Components and functions of Cyber-Physical Machine Tool*

Proposed CPMT [2] consists of four main components: (1) CNC Machine Tool, (2) Data Acquisition Devices, (3) Machine Tool Cyber Twin (MTCT), and (4) Smart Human- Machine Interfaces (HMIs).

(1) The CNC machine tool here it represents physical CNC machine tool including all components and subsystems, as well as the machining processes, with possibility of the integration of machine tool, machining processes, computation, networking, monitoring and control the machining processes, with feedback loops. Aiming to advance current CNC machine tools into a higher level of intelligence and autonomy, in researches [2, 3, 6, 12] proposes a new generation of machine tools, i.e. Cyber-Physical Machine Tools (CPMT).

(2) Data acquisition devices include various types of sensors, and are responsible for collecting real-time field-level manufacturing data from the critical components and machining processes such that important real-time manufacturing data generated during machining processes can be recorded and analyzed in the next stages [4].

(3) The Machine Tool Cyber Twin (MTCT), is the most significant difference between a CPMT and a traditional CNC machine tool. The MTCT, as a digital abstraction of the machine tool, has built-in computations that monitor and control the physical processes on the one hand, and provide the data to the cloud for further analysis on the other [12].

(4) Smart Human-Machine Interfaces should provide information's from machines with Internet based storage in form of a cloud. Commercial solutions of IIoT applications use two type of Cloud storage: private (with acquisitions software installed on premise) and public (where the software manufacturer is owner of the cloud).Smart HMIs allow users to intuitively interact with the system and make efficient decisions with the implementations of various network and interaction technologies [2].

5 TRENDS OF DEVELOPMENT

For the further development of machine tools in era of Industry 4.0 is crucially to using open platforms, standards and interfaces. Trends or fields of action for machine tool manufacturers are [13-19]:

- digitalization of CNC machines,
- MT integration-vertical and horizontal,
- Real-time manufacturing data acquisition,
- Data integration and communication,
- Intelligent algorithms and analytics,
- M2M communication,
- Advanced Human-Machine Interactions.

The digitalization of CNC machines, mills, and other factory production equipment is the future that the Internet of Things has been promising us [15]. Digitalization is a growing trend in the industrial space, and the process finding its way into every corner of the factory floor. The digitalization of machines can help engineers predict real world results and failures [15]. An example of real and digital machine tools (milling and turning) is shown in Fig.4.

a) real and digital milling Machine Tool [14]b) real and digital turning machine tool [15]

Figure 4. *The digitalization of machines can help engineers predict real world results and failures*

5.1 MT integration-vertical and horizontal

CPMT presents the class of machines with new level of integration, which can be horizontal or vertical.

Vertically integrated machine tools support the end-to-end digital integration throughout the engineering process which encompassing design, process planning, manufacturing, assembly etc. [6].

Typical model of the preparation machining process starts with CAD model of workpiece with an information about geometry, tolerance, material. Based on this model in CAM is chosen machine tool, tool, fixture and toolpath is generated, simulation of toolpath and/or removing material and postprocessing for translating into G code all information except axis movement is lost.

Today a new standard, known as STEP-NC (Standard for Product Model Data Exchange for Numerical Control), is being used as the basis for development of the next generation of CNC controller. These standards are ISO 14649 [20] and ISO 10303 AP 238 [21].

The STEP-NC AP238 standard is the result of a more than decade international effort to replace G code (ISO 6983 standard) with a modern associative language that connects the CAD design data used to determine the machining requirements for an operation with the CAM process data [22,23]. Classical programming is still the most commonly used way of programming and object oriented programming has not been introduced to the full extent. However, these two methods are simultaneously used as illustrated in Fig.5 [38].

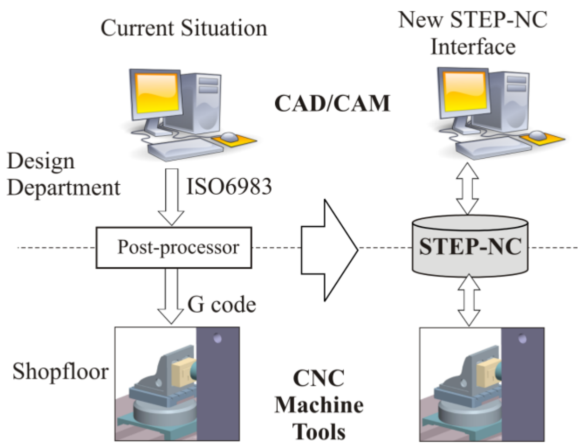

Figure 5. *Current G code and new STEP-NC interface for programming CNC machine tools [38]*

Unlike G-code, STEP-NC describes tasks which to be carried out (what-to-do information) instead of methods to do the job (how-to-do information) for a machine tool [6]. The STEP-NC provides new opportunities to support high level information from design to CNC controller. It allows bi-directional data flow between CAD/CAM and CNC without any information loose [23]. Therefore, STEP-NC is not machine-dependent. STEP-NC is fully compliant with STEP [24], which makes it possible to bring complete design data to the machine tool, hence enabling machine tools to be vertically integrated.

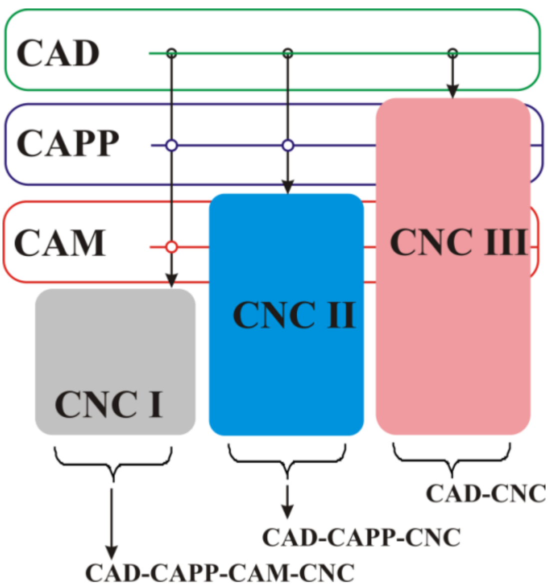

Figure 6. *Evolution of CNCs for vertical integration*

The illustration of the evolution of the CNC system is shown in Fig. 6, where CNC III represents the ultimate scenario for CNCs that are vertically integrated in such a way that they will act using STEP-NC standards as an interface between CAD and CNC.Such a move, or any other similar approach, effectively calls upon CNC controllers to embrace a brand new control language, and controller manufacturers to develop more robust, interoperable and intelligent CNC controllers [6].

Horizontally integrated machine tools are those interconnected among themselves as well as with other manufacturing facilities and resources (e.g. robots, conveyors, in situ measurement equipment and even MES (Manufacturing Execution System) and ERP (Enterprise Resource Planning) systems) to establish a cooperative production system [6].

There are some preliminary attempts by some controller manufacturers. CNC developer Siemens and robotic supplier KUKA teamed up to integrate KUKA's mxAutomation with the Sinumerik CNC platform [27], Fig 7. With such integration, the operator of the machine can run both the machine tool and robot from a single control panel [6].

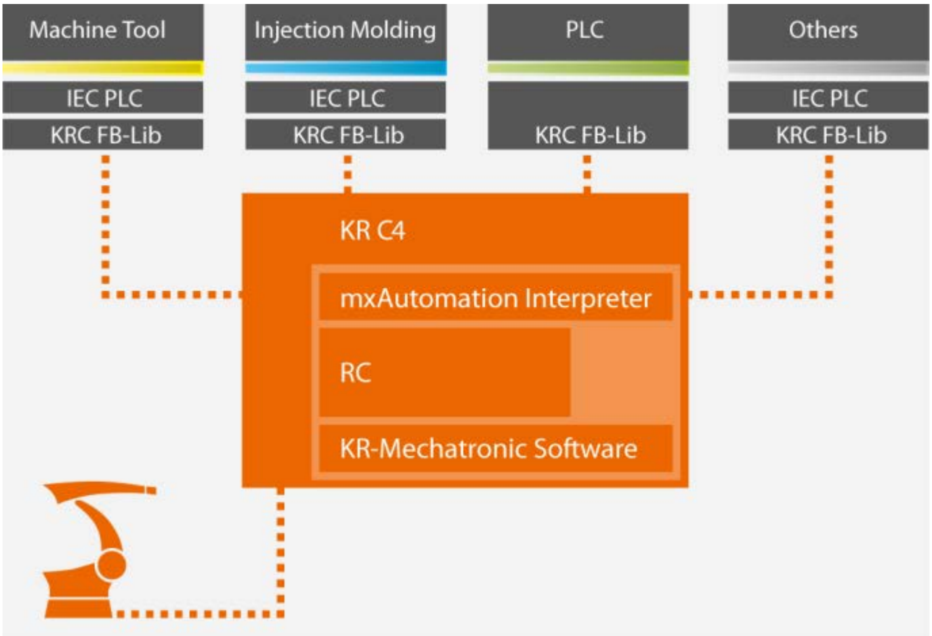

Figure 7. *Integration of Kuka robots in machine environment [25]*

The mxAutomation function package, KUKA.PLC mxA, makes it possible for external controllers with an embedded PLC to command KUKA robots on the basis of elementary motion instructions. This provides an easy route to implementing a central operator control concept for robot-automated production machines that is highly convenient for end customers [25].

A key requirement of CPMT is the ability to acquire accurate and reliable data from the machines and/or their components. The data might be directly measured by sensors or obtained from the controller. Considering various types of data, a seamless and tether free method to manage data acquisition procedure and transferring data to the central server is required where specific protocols such as MTConnect [6, 26].

Integration of machine tools with other industrial equipment is also a focus of the Industrial Internet Consortium (IIC) [27], which is formed in 2014 with an aim to accelerate the development, adoption and widespread use of interconnected machines and devices, and intelligent analytics [6].

5.2 Real-time manufacturing data acquisition

During the machining process every component or/and subsystem of machine tool generates huge amount data's in real time. Collecting this data's is precondition for achieving advanced functionality of new machine tools (CPMT) because thesedata's could have big influence on product quality, productivity and costs [2].

Although modern CNC controllers could directly provide some useful feedback data (e.g. spindle speed, axes position, etc.), some critical data that severely affect the manufacturing processes such as tool/workpiece/machine vibration, temperature, cutting force, etc. can only be acquired by deploying additional sensors [2,28].

With the rapid development of sensing technology, various sensors (e.g. force/torque, accelerometers, acoustic emission, motor power and current sensors, etc.) are available for extracting different data from the machine tool. A summary of real-time data acquisition technologies regarding process monitoring can be found in [28, 29].

5.3 Data integration and communication

Complexity of data's which are collected from different sources make integration this data's for the purpose of managing a serious challenge. There is an urgent need for a unified data exchange standard for the field-level manufacturing devices.

Currently, MTConnect and OPC-UA are both striving to solve this problem. MTConnect is a lightweight, open, and extensible protocol designed for the exchange of data between shop floor equipment and software applications [30]. OPC-UA is an open and royalty free set of standards designed as a universal factory floor communication protocol developed by the OPC Foundation [31]. MTConnect provides a bottom-up strategy which makes it easy to be implemented, but it is currently a read-only standard, which means it is only able to be used in reading data from the devices, but not writing to them. On the other hand, OPC-UA is a bidirectional standard which is able to be used for both monitoring and controlling [2].

5.4 Intelligent algorithms and analytics

To be apossible to use extensive data collected from the machine and machining process, it is necessary to have developed intelligent algorithms and methods for data analysis, which should be implemented in MTCT, whit what CPMT can get advanced autonomous functionality and possibility for making decision. Research in this area has always been current and active. To shorten machining time and increase product quality developed a Fuzzy logic algorithm that allows in-process feed-rate optimization [32]. Developed a System Manager algorithm to achieve high-fidelity machining simulation was realized by the utilization of STEP, STEP-NC and real-time monitoring data [33].

Although the research is very intensive in this field of study, much effort is still needed in developing efficient, accurate and reliable algorithms and data analysis methods in order to provide to a new machine a real intelligence.

5.5 M2M communication

Generally, M2M refers to the communications among computers, embedded processors, sensors, actuators, and mobile terminal devices without or with limited human intervention [34]. In the proposed CPMT, M2M communications include the communications between the machine tool and other field-level devices, for example robots, AGVs, workpieces, and so forth. M2M interfaces should allow the machine tool to exchange information with other devices so that they can actively monitor and control each other.

Research on M2M communication is still at the preliminary stage. Developing M2M interfaces for the proposed CPMT is a crucial and challenging task [6].

5.6 Advanced Human-Machine Interactions (HMI)

CPMT allows advanced human-machine interactions. Smart, mobile, networked and context-sensitive HMIs need to be developed to provide users with: (i) comprehensive and intuitive perception of the CPMT, (ii) ubiquitous access to the real-time information and applications, as well as (iii) instant and distributed decision making support [2].

6 CHALLENGES FOR MACHINE TOOL

Machine tools producers follow the machine tools development trends according to Industry 4.0,and in this chapter some of actual example will be shown. Mazak is presented challenges in development of large machine tools [19], which can be listed: (i) thermal compensation, (ii) volumetric compensation, (iii) additive manufacturing AM, (iv) hybrid manufacturing, (v) multi-tasking machine, etc.

In the **thermal compensation** of the errors in machine tools include sensors are positioned on the machine structure and the spindle and feedback data to the CNC, which then compensates for axis positions accordingly (Intelligent Thermal Shield), Fig.8.

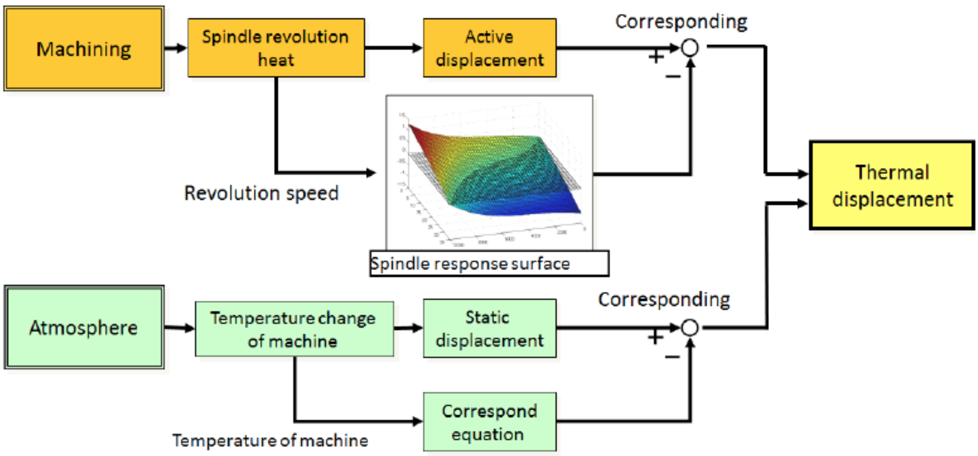

Figure 8. *Thermal compensation [19]*

Volumetric error compensation is a method of compensating the axes of a machine tool to remove geometric errors in positioning. This type of compensation produces a machine geometric performance, which is consistent throughout the whole volume of the machine tool. Major manufacturers of CNC control units as are: Siemens, Fanuc, Heidenhain and Mazak have optional function for volumetric error compensation. Calibration is carried out with an Etalon laser tracker system but it is a time consuming & costly activity, Fig.9. Technique & customer understanding is still in the early stages of acceptance [19].

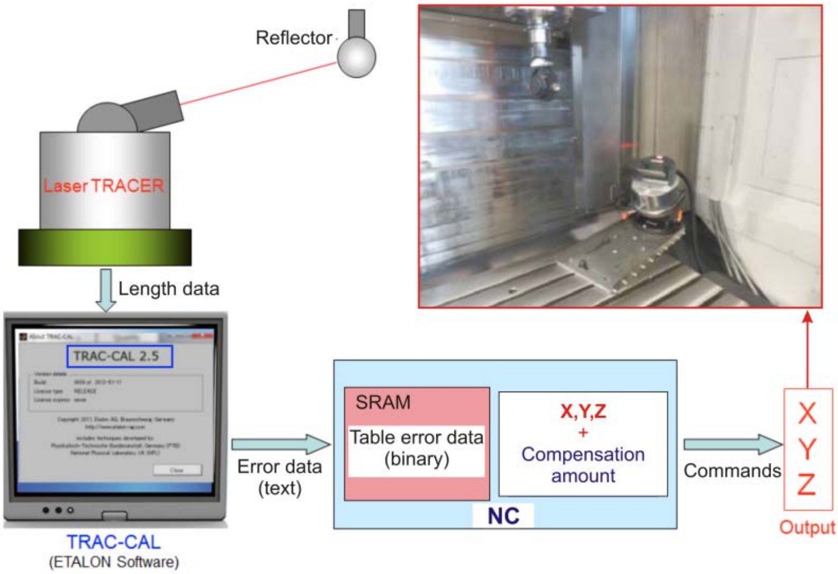

Figure 9. *Volumetric compensation [19]*

Additive manufacturing and Machine tool 4.0 have the goal is to develop laser metal deposition welding so that it can be used for the flexible manufacture of components for prototypes and for small batch sizes. Two main types of AM technology being developed: Selective Laser Melting and Laser Metal Deposition. In laser metal deposition welding, a material is simultaneously melted and applied to a surface. In this case, the material is metal powder. The heat source is a high-performance laser. This additive manufacturing process is combined with conventional machining in the hybrid machine tools.

As a samples of development this hybrid type of machine tools can be mentioned manufactures MAZAK [19], and DMG MORI in cooperation with Schaeffler Technologies AG & Co [35], whose concept will be described below.

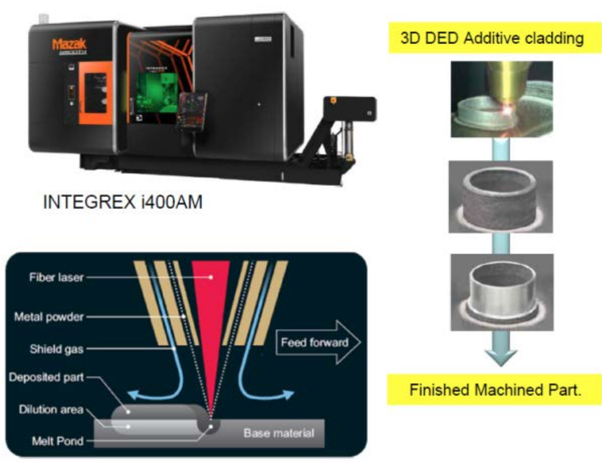

Figure 10. *Integrex i400AM [19]*

Hybrid manufacturing is a synergistic combination of 3-D printing and advanced 3 or 5-axis machining that should allow the user to design and make parts that are uneconomic or simply impossible to produce any other way. Hybrid manufacturing technologies will deliver the benefits of both subtractive and additive technologies, such as: reduced material usage, high accuracy surface finish, mixed material properties, greater geometrical freedom, and enhanced productivity. Figure 10 shows machine of the company MAZAK Integrex i400 AM which can accomplish hybrid technology of manufacturing. As can be seen on the Fig.11, machine tools that combine both, subtractive and additive technologies, have AM head and milling spindle in the same machine.

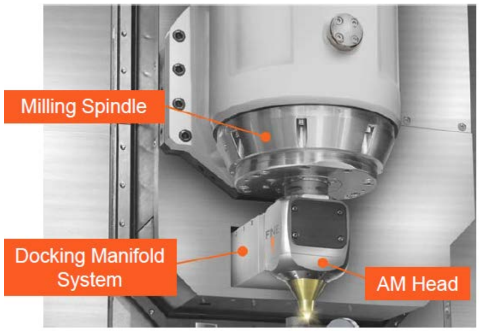

Figure 11. *AM head and milling spindle in same machine [19,37]*

Figure 12 shows another example of the DMG Mori machine tool, which can achieved 3D printing and 5-axis machining combined in one machine.

Reducing of the cost of production and time in the process of machining of complex parts is the very important for progress of industry in countries which is leader of industry. In order to meet these requirements by creating a new possibility for machine tools, a Hybrid Multi-tasking machine tool has been developed by equipping Laser Metal Deposition functionality in addition to existing integrated turning and milling capabilities [37].

Figure 12. *3D printing and 5-Axis machining combined in one machine [35]*

Another example of good cooperation between the two companies Schaeffler and DMG MORI's are developing a partnership, and as a result of this collaboration, the developed functional prototype of Machine tool 4.0.The "Machine tool 4.0" concept, one of four finalists nominated for the German Industry Innovation Award, is a joint development from Schaeffler and DMG MORI [16, 17, 36], one of the world's leading manufacturers of chip-forming machine tools, Fig.13.

Figure 13. *Schaeffler and DMG Mori's collaborative "Machine Tool 4.0", at EMO 2017 in Hanover [36]*

At EMO 2017 in Hanover, Schaeffler presented a functional prototype of a multi-channel CMS (Condition monitoring systems) for machine tools. In-house systems and sensors such as piezoelectric vibration sensors can be connected to the CMS. Piezoelectric vibration, force and pressure sensors from other manufacturers can also be integrated into the CMS via an IEPE (Integrated Electronics Piezo-Electric) interface. This offers a major advantage in those operators can use the sensors that are available and suitable for the individual measuring point and measurement task. The current prototype has six measurement channels. The system is designed so that, for example, the electronic monitoring of the lubrication conditions in linear recirculating roller bearing and guideway assemblies can also be integrated in the future [17].

The new multi-channel system for monitoring machine tool condition is specially designed for CNC machine tools. Schaeffler thus achieved two goals: (i) monitoring the condition of key components and predicting their behavior using a single CMS and (ii) the flexible integration of sensors, different manufacturers in one CMS. This prototype is tested in initial pilot projects on various CNC machine tools, Fig.14, as well as on the developed functional prototype Machine Tool 4.0 at Schaeffler's manufacturing location in Höchstadt. This machining center serves as a technology platform and development project for digitalized products in the machine tool sector. Machine Tool 4.0 is used to develop and test the algorithms for the multi-channel CMS for monitoring and diagnosing the condition of rolling bearings and components in machine tools under real conditions [17].

The software for the prototype is very sophisticated, as most functions, algorithms and the optional connection to the Schaeffler Cloud from other projects can be ported with only minimal outlay. Due to the connection to the Schaeffler Cloud, all digital services offered by Schaeffler for monitoring and detecting damage to rolling bearings are already available in the prototype CMS. As a local solution, the multi-channel CMS facilitates the monitoring of FAG rolling bearings based on the integrated bearing catalogue, as well as bearings from other manufacturers [17].

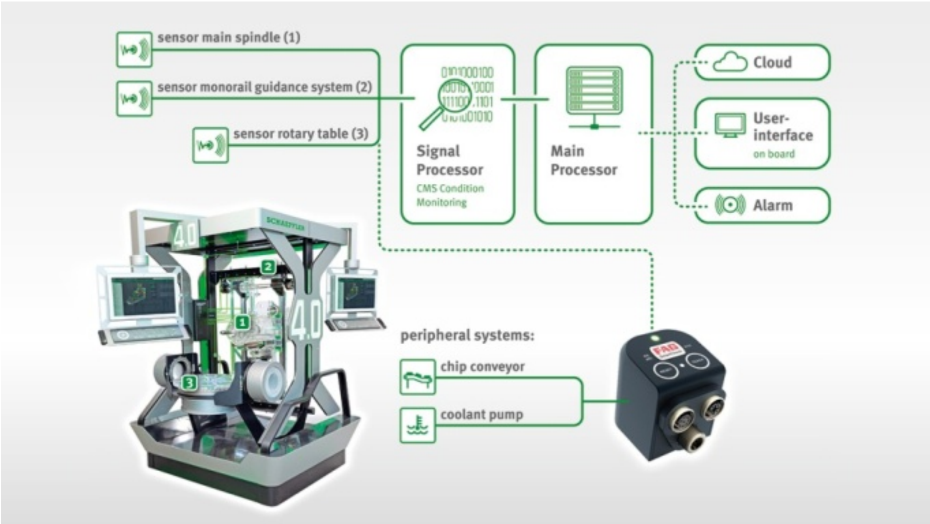

Figure 14. *Machine tool 4.0 and condition analyses [16, 17]*

Digital revolution with monitoring of all important subsystems of machine tools increases their reliability, quality and efficiency. Technical solutions like these have a goal to control of the processes, maximize availability, and optimize of the product quality.

7 CONCLUSION

At the dawn of the new industrial revolution, known as the Industry 4.0, some of industrial initiatives clearly indicate needs for improving production systems which will have high level of intelligence and autonomy.

As the key element of any production system, machine tools are expected to make step-changes to the new generation of machine tools, known as Machine tool 4.0, or Cyber-Physical Machine Tool (CPMT).

This paper examines the relation between Industry 4.0 and machine tools as well as development trends, which are a challenge for a new machine tools generation. From such new machine tools, they are expected to be smarter, well connected, widely available, adaptable and autonomous. Machine tool producers follow the trends in the development of machine tools according Industry 4.0 and some of the very current challenges are: (i) thermal compensation, (ii) volumetric compensation, (iii) additive manufacturing AM, (iv) hybrid manufacturing, etc.

Inspired by recent advances in ICT such as CPS, IoT and cloud computing, a new generation of machine tools, is proposed as a promising development trend of machine tools in the era of MT 4.0. In summary, the Industry 4.0 is paving the way for efficient and smart manufacturing systems.

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