Machining Simulation and Verification of Tool Path for CNC Machine Tools with Serial and Hybrid Kinematics

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Development of modern machine tools basically is directed on improvement of kinematic structures and exploitation characteristics. As a result of this in last two decades industry more and more uses machine tools based on parallel and hybrid kinematics with significant increasing of speed of main and movement and feederate. In order to provide more efficient exploitations of these machines, reduce of the preparation time of production, increase of the safety of users and machines is necessary application of software for simulation and verification programs.

This paper presents the concept of modern technological preparing of manufacturing in the case of the definition of virtual machine tools based on conventional - serial and hybrid kinematics, simulation of machining and verification of programs for machining of characteristic workpiece.

Keywords*: *Virtual machine tool, machining simulation, verification of tool path, CAD/CAM, CLF, NC program

1. INTRODUCTION

Development of industrial production with a view to further development of the society in the twenty-first century is largely based on the development of production capacities and resources that enable their effective exploitation. In the area of discrete mechanical production this primarily involves significant innovation in the field of machine tools. Their development in a contemporary environment entails further development of: exploitation characteristics (that is primarily to increase processing regime up to several times) and kinematic structure.

These trends in production engineering have necessitated the use of an appropriate software the objectives of which include reducing the time for production preparation, increasing processed surface quality and the elimination of waste.

The machining simulations and verification programs before executing which includes of virtual machine prototype when it works according to the running program is broad topic and includes the complete models of machining process, structure of machine, actuators, kinematic subsystem, etc [1]. All of these models can be be integrated into a some software systems, which allows a part of the virtual production [2-4].

For the purpose of the simulation and verification tool path, i.e., the NC program, different tools such as CNC editors, CNC simulators, CAD / CAM systems and CAM systems can be used, Fig.1. Common to most of these software, except CNC editor, is the possibility of verify the NC program by simulation of the processing that includes a complete virtual model of the machine tools.

CNC editors are used when instructions for machines are generated in manual programming. Their main advantages are: the visualization of the programmed tool path and the possibility of simulating the movement of the tool during removal of the material [5], Fig. 2, for both new and previously made CNC programs. Drawback of such a program is impossibility of simulation cutting processing which includes model of machines tools.

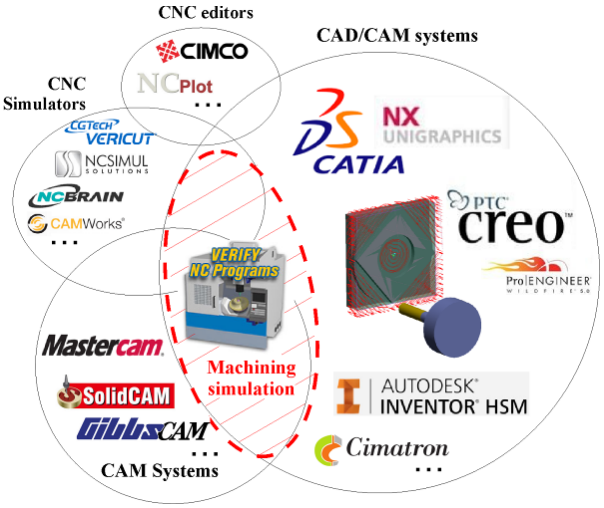

Figure 1: Machining simulation for verify NC programs

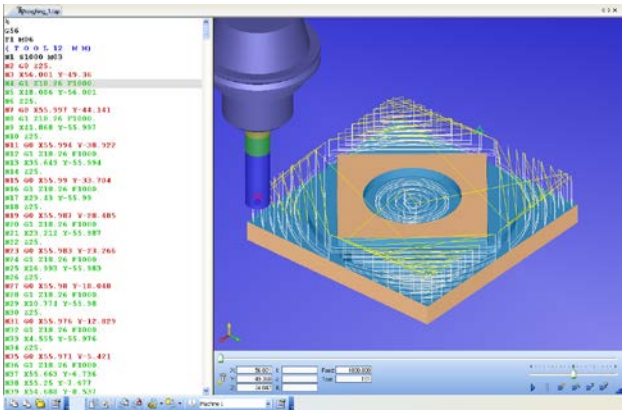

Figure 2: Cimco CNC editor

CNC simulators allow loading and verification programs as well as training in using different types of control units.

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There are also a lot of CNC Simulation Software for programming training, such as CNC Swansoft simulator [6] - Fig. 3, CNC simulator Pro [7], and others.

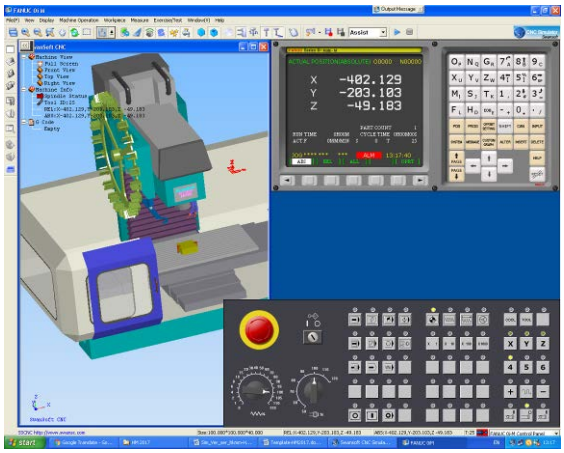

Figure 3: Swansoft CNC simulator

These simulators in addition to the emulation of different control units, offering the possibility to work with virtual machine tools in the software environment which includes both handling and simulation cutting process. These software are developed for the milling and turning processes.

For verification and optimization of CNC programs, including cutting process on virtual machine tool, there are commercial software such as VeriCUT [8], NC Simul [9], NC Brain [10], CAMWorks [11] etc.

Figure 4 shows verification of NC program by simulation of material removing that includes a complete virtual model of a 5-axis machine tool [12] in the software VeriCUT.

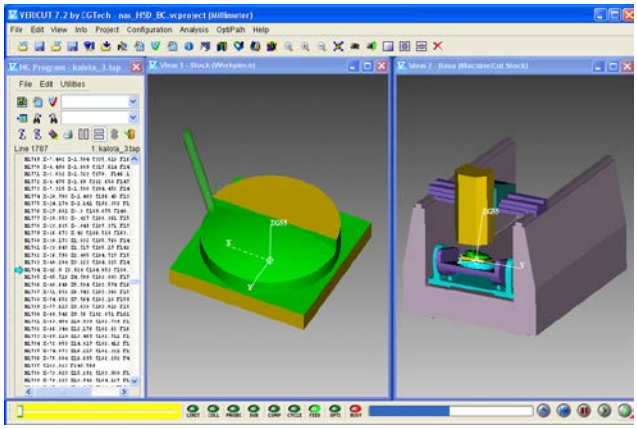

Figure 4: VeriCUT machining simulation [12]

Modern CAD/CAM systems such as the PTC Creo [13], Catia [14], NX, [15] SolidCAM [16], MasterCAM [17], GibbsCAM [18] Inventor-HSM [19], CIMATRON [20], and others, have modules for cutting process simulation using virtual machine tools.

Configure of the virtual machines with serial kinematics is a relatively simple task, which cannot be said for machines with parallel and / or hybrid kinematics.

The paper shows the simulation cutting process that includes configuring the machines in CAD/CAM system PTC Creo 2.0 in case of an existing machine with a serial and a machine with hybrid kinematics.

2. CONCEPTIONS OF CNC MACHINE TOOLS WITH SERIAL AND HYBRID KINEMATICS

Demands for improvement of exploitation characteristics of machine tools in the last twenty years, apart significantly improved characteristics of existing components and subsystems, require also the use of different kinematic structure concepts. Thus, apart to conventional serial kinematic, increasingly in the application are parallel and hybrid kinematics which, in certain conditions, significantly improve characteristics of machine tools.

The main difference in the process of analysis of the paths, simulation and verification CNC programs in numerically controlled machine tools with different kinematic structure is a problem of defining the position of the elements of the machine in relation to the tool, i.e. its trajectory. In machine tools whose kinematic structure is based on parallel or hybrid mechanisms, procedures for solving of this kinematic problem is significantly different compared to solving of serial kinematics mechanisms problems.

The paper uses two different machine tools for the analysis of this problem: horizontal machining center Heidenraich & Harback FM38 (H&H FM38) with serial kinematic structure and the experimental machine tool based on a hybrid O-X mechanism.

2.1. Horizontal machining center

Horizontal Machining Center H&H FM38 belongs to a group of numerically controlled machine tools conventional kinematic structure, with 3 numerically controlled linear axis and the index programming CNC rotary table i.e. rotational axis (B axis), Fig. 5.

Figure 5: CNC Horizontal Center H&H FM38

The machine is equipped with automatic tool changer with drum style magazine containing 15 tools for milling and drilling and a mechanism for automatic tool

change and handling. Control unit is Siemens Sinumerik 840D.

In the context of conducted research, H&H FM38 horizontal milling center, due to its structure and accessibility on the Faculty of Technical Science Novi Sad was used for analysis the possibility of forming the virtual machine tool and accuracy in the simulation tool path processing.

2.2. O-X glide hybrid kinematics milling machine

The second part of the research is analyzing possibilities for application of advanced software for simulating operation of machine tools with hybrid kinematic structures, which include a combination of parallel and serial mechanisms.

Machine tool based on the original O-X glide mechanism with hybrid kinematics was taken as a basis for this analysis. This type of machine tool is created by combining planar parallel mechanism and the machine structure which allows its translational movement. Plane parallel mechanism is designed so that the tool can reach the biggest part of work space in two configuration of mechanism which behaves as dual two parallel mechanisms with different characteristics in terms of: the dimension of the working space, stiffness, speed etc. Figure 6 shows the initial concept machine with hybrid kinematics in two positions: extended (O) and cross (X) O-X structure [21, 22].

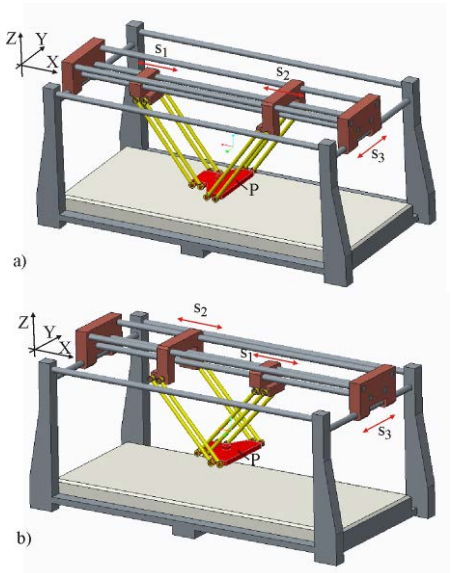

Figure 6: CAD model of the O-X glide mechanism

Plane parallel mechanism consists of the mobile platform, connected via spherical joints to the rods of constant length. On the second end rods are conected to sliders via revolute pair (with one degree of freedom), each of them moves on its own guide rails. In order to increase the autonomy of sliders, they are positioned at different distances in the vertical direction, which enables their passing in the plane, and the movement mechanism in an extended position (O) and cross (X) position.

In the first phase of O-X glide mechanism prototype development based on previously acquired dimension of parallel mechanism, first physical prototype is made using the rapid prototyping technology, Figure 7a.

On the example of this prototype, verification of working space O-X glide mechanism is performed by moving the slider and following the center of gravity of the mobile platform. Thus it is confirmed that workspace of prototype mechanism corresponds to mathematically obtained workspace. Characteristic positions of prototype O-X glide mechanism, in which center of gravity of mobile platform is observed, are shown on Fig. 7b for extended shape and on Fig. 7c for cross shape of mechanism [24].

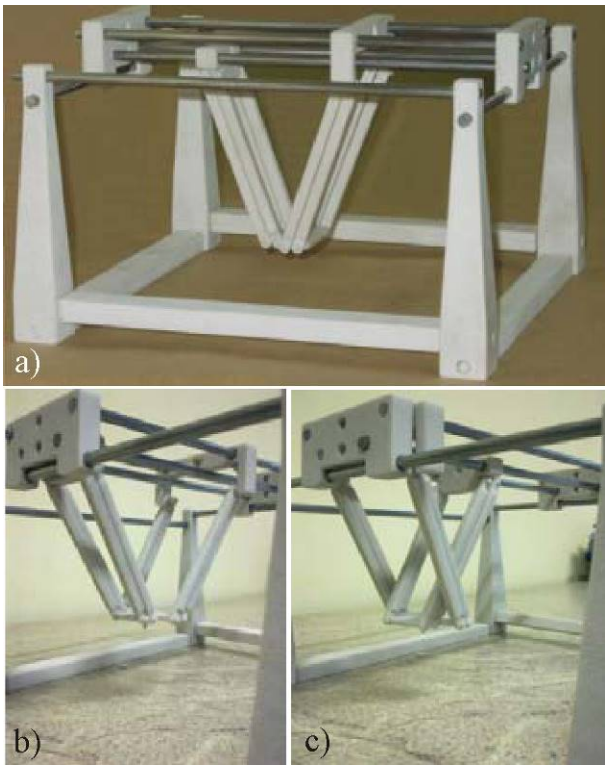

Figure 7: 3D printed real model of the O-X glide mechanism [24]

This paper shows the simulation kinematics machine based on the O-X glide mechanism on the virtual prototype.

3. MACHINING SIMULATION IN THE CAD/CAM ENVIRONMENT

The configured virtual CAD models of CNC machine tools with serial and hybrid kinematics is used for the verification of tool path using machining simulation in CAD/CAM environment. This machining simulation based on generated tool path, which also includes machine simulation. This machining simulation is very important in order to: (i) configure the off-line programming environment, (ii) verify program before machining, (iii) detect collision during program execution.

3.1. Machine virtual models for simulation

Machining simulation by running the program is possible thanks to the applied modelling of machine virtual model for simulation with all kinematic connections between the components, which allows the motion of a virtual model as a system of rigid bodies.

Figures 8 and 10 shows a detailed virtual model of machine tool for machining simulation. Those machine models, configured in CAD/CAM system PTC Creo 2, with all kinematic relationships. Examples of such simulations can also be found in the previus papers [12, 21-23]. Virtual machine models discussed in this paper, are configured including appropriate kinematic connections. For CNC H&H FM38, Fig.8, which has all three translational axes are used only kinematic connection type *Slider*.

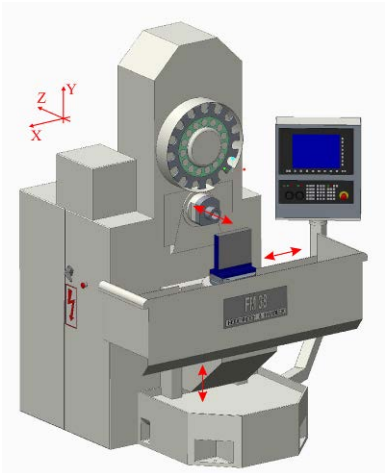

Figure 8:CAD model of the CNC Horizontal Machining Center H&H FM38

An example of defining translational axis (Y) for the horizontal machining center H&H FM38 is presented on Fig. 9.

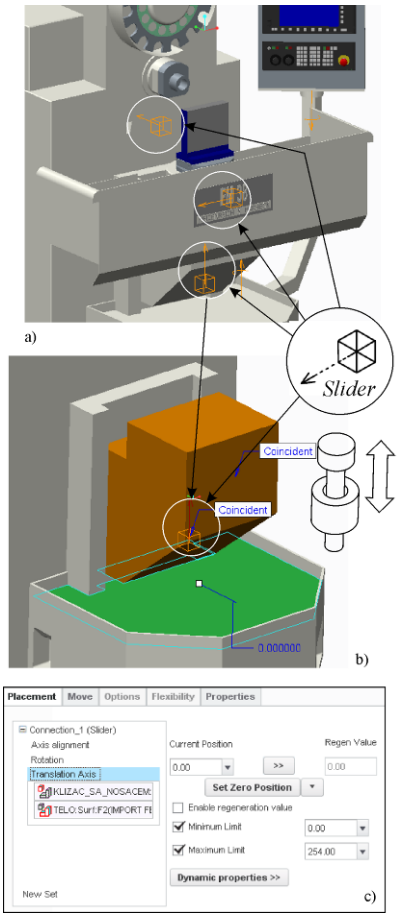

Figure 9: An example of defining the kinematic connection type Slider

During designing of the machine model in PTC Creo, movable elements are connected by kinematic relationship. According to Fig. 9 all movement are translations. It's necessary: (i) match all translation axis, (ii) match surfaces or planes of translation, (iii) define referent point of translation axis and travel length. Virtual machine model designed in such way can be included in the cutting process simulation.

In case of machines with a hybrid kinematics, for both variants shown on Fig. 10, except translational axis, rotary joint were used to link the support plate on the slider to platform using 4 pair of coupling, corresponding to joints type *Pin*.

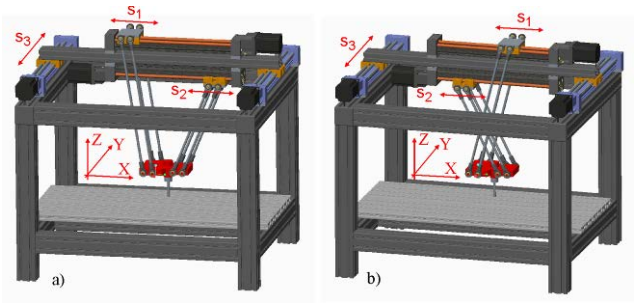

Figure 10: Virtual prototype of a) extended and b)crossed form of the O-X glide hybrid kinematic milling machine

Figure 11 shows the detail of machines used kinematic joints type Slider and *Pin*.

An example of defining the kinematic connection type Pin, which represents the rotary joint on the machine is shown on Fig. 11b.

The procedure defining pin joint connection includes: (i) align axis of rotation, (ii) match surfaces or planes to align the rotating components along the rotation axis (iii) define current position of rotary axis and minimum and maximum of rotation limits.

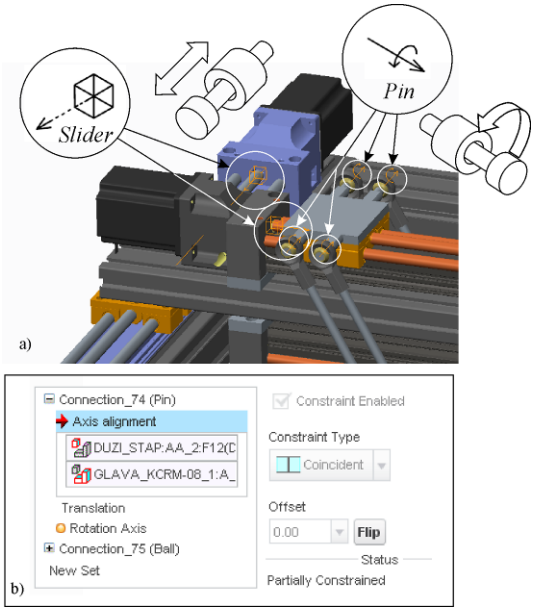

Figure 11: An example of defining the kinematic connection type slider and pin for the machine with hybrid kinematics

On the base of defined kinematic joints on designed virtual machine model, it is possible to include a complete

virtual model of the machine during simulation of the tool path.

3.2. Machining simulation

Simulation of the machining using a virtual prototype is the safest and most economical way of program verification.
This type of simulation is particularly important in the development phase of new machines because it allows the identification of possible deficiency, which is especially interesting in the case of second discussed machines with hybrid kinematics whose development is in progress. System for programming using CAD/CAM system PTC Creo 2.0 [13] is designed so that include a simulation of discussed virtual machine model, thus performing a verification of the obtained programs. Fig.12 shows the programming environment applicable to both considered machines.

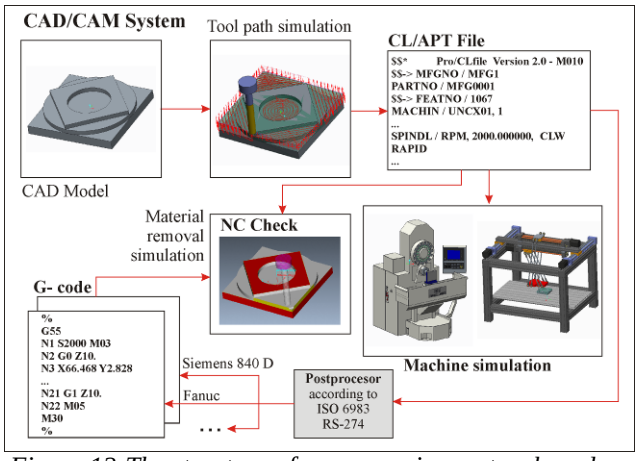

Figure 12:The structure of programming system based on CAD/CAM system

As an example, variant of modified workpiece for testing the accuracy of machine tools was used for the simulation. After generating the tool path (CLF - Cutter Location File), it is possible to verify these paths by simulation of material removal and machining of the entire virtual machine model. For configured virtual machine models, simulation of the machining processing using the entire virtual machine is starting by Machine play. This simulation is realized in the running mod using defined program.

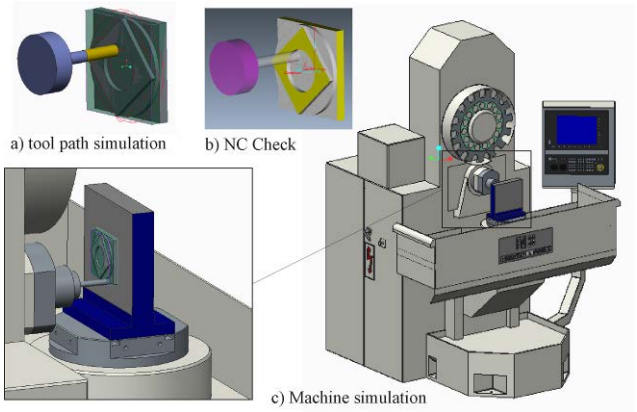

Figure 13:Simulation and verification of tool path for CNC Horizontal Center H&H FM38

Examples of simulation for both machines in the system for programming PTC Creo 2 environment, are shown in Figs. 13 and 14.

For machines with hybrid kinematics particularly important possibility is checking the positioning of the workpiece in the machine workspace, since machine does not have the regular shape of workspace geometry [21]. Corresponding post-processor for NC program generating according to ISO 6983 is configured in the CAD/CAM system, for both machines and for Siemens Fanuc CNC systems, Fig.12.

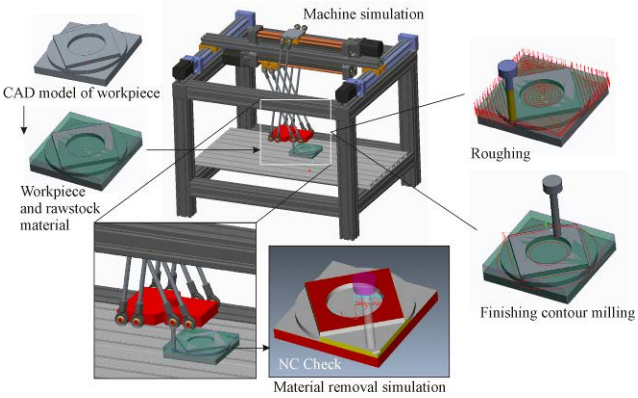

Figure 14:Simulation and verification of tool path for O-X glide hybrid kinematic milling machine

4. MACHINING TEST

Cutting process testing for modified workpiece used for testing the accuracy of machine tools is implemented on machining centre H&H FM38.

Dimensions of workpiece used for testing are the same like dimensions of model used in simulation. Also, identical CNC program was used for both, testing and simulation. Figure 15 shows the workpiece obtained during testing.

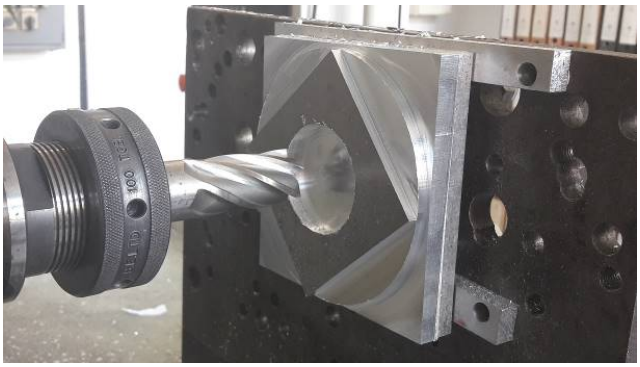

Figure 15:Test workpiece after machining test

Control of geometric shapes and dimensions of the workpiece after testing shows that result obtained by simulation based on generated CNC program fully meet workpiece dimensions.

5. CONCLUSION

Machining simulation plays an important role in modern manufacturing. There are many benefits to machining simulation, and one of the most important is testing program for machine, without pressure. Crashing machine on the computer screen is not a big problem. The process of setting up machine simulations is very similar

to setting up a real machine. The part must be placed in the machine in the correct position and orientation.

Analysing generally accepted simulation processes and verification of CNC program for CNC machine tools on the example of machine tools with different kinematic structures, advantage of their use can be seen: (i) Significantly shorter period of time for the preparation and verification of the program for the CNC machine tools; (ii) the machining simulation enabled prior identification of possible collisions between the machine elements during program execution and verification; (iii) ability to simulate removal of material and analyses of virtually produced workpiece; (iv) significant reduction in the percentage of waste on the produced parts.

However in order to simulate the cutting process on the virtual machine, it is necessary to configure it according to the procedure that is different in particular software environments. This paper shows how this can be done using CAD / CAM system: PTC Creo 2.0 in the case of one machine with the serial and one with hybrid kinematics.

On the first machine, horizontal machining center H&H FM38 process verification was done by producing modified workpieces for testing the accuracy of machine tools.

Based on the above it can be concluded that in modern production application of appropriate software systems for simulation and verification of CNC program is necessary. This becomes more important when preparing complex workpieces in individual production where waste occurrence are extremely expensive and obtaining optimal tool path during production by adjusting existing programs is not possible.

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