MMA 2021 FLEXIBLE TECHNOLOGIES
14th INTERNATIONAL SCIENTIFIC CONFERENCE
NOVI SAD, SERBIA, SEPTEMBER 23-25, 2021

Tabaković, S., Živanović, S., Dimić, Z., Zeljković, M.

# PROGRAMMING AND PROGRAM VERIFICATION OF 3-AXIS HYBRID KINEMATICS CNC MACHINE FOR RAPID PROTOTYPING

***Abstract:*** *The paper presents the programming and program verification on 3-axis hybrid kinematics CNC machine for rapid prototyping. The original hybrid (parallel-serial) 3-axis O-X glide mechanism developed for the purpose of building rapid prototyping machine and multifunctional machine tools is presented. The paper analyzes the available programming software, which can be one of the standard CAD/CAM systems or a specialized CAM system. In addition to the analysis and presentation of the programming method procedure, the program verification by material removal simulation and virtual machine simulation according to a given program was also considered. Verification of programming methods was realized by machining several characteristic parts. The paper presents the first prototype of a machine, developed for the purpose of testing characteristics with an open control system based on the LinuxCNC.*

***Key words:*** *programming, CAD/CAM, program verification, virtual machine, O-X glide mechanism*

## 1. INTRODUCTION

The improvement of modern society at the beginning of the XXI century is directly conditioned by the development and improvement of production capacities and means that enable their efficient application. An example of this is the constant growth of industrial production encouraged by the improvement of machine tools. Their development in modern conditions implies the improvement of exploitation characteristics (this primarily means increasing the processing mode up to several times) and kinematic structure [1].

As a result, in addition to conventional serial, there is also a parallel as well as a hybrid kinematic structure that provides significant opportunities to improve the characteristics of machine tools in certain areas. The problem of programming such machine tools due to the need to transform the machining path into the movements achieved by the so-called virtual axes of the machine tool can be a significant engineering challenge. Depending on the structure and characteristics of the control system, this problem can be solved within the software that transforms the coordinates of the virtual axis, which is an original technical solution for each individual problem.

The paper presents the programming and program verification on a 3-axis hybrid kinematics CNC machine for rapid prototyping. The presented machine has a kinematic structure based on the original hybrid (parallel-serial) 3-axis O-X glide mechanism [2-5] which was developed to build a rapid prototyping machine and multifunctional machine tools are presented. The paper analyzes the available programming software, programming method procedure, the program verification by material removal simulation and virtual machine simulation. Verification of programming methods was realized by machining several characteristic parts.

## 2. BASIC CONCEPT OF 3-AXIS HYBRID KINEMATICS CNC MACHINE FOR RAPID PROTOTYPING

The O-X glide mechanism with hybrid kinematics was taken as the basis of the mechanical structure of the presented machine tool. This type of machine tool was created by combining a plane parallel mechanism and a supporting structure that enables its translational movement. The planar parallel mechanism is designed so that the executive body of the machine can reach the largest part of the working space in two configurations of the mechanism, which behaves dual as two parallel mechanisms with different characteristics in terms of: working space dimensions, stiffness, speed, etc. Figure 1 shows the initial concepts of a machine with hybrid kinematics in positions with a stretched (O) and crossed (X) O-X structure [1].

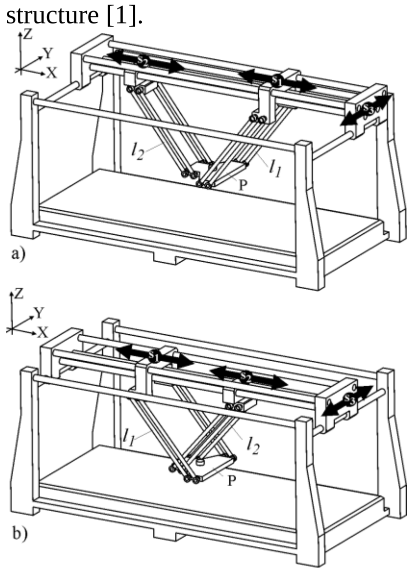



Fig. 1. Initial hybrid O-X glide mechanism

The parallel mechanism consists of a planar structure containing a movable platform, which is connected to rods of constant length via spherical joints. At the other end, the rods are connected to the corresponding sliders by rotating joints (with one degree of freedom), each of which moves according to its own guide. In order to increase the autonomy of the slider movement, they are positioned at different distances, in the direction of the vertical axis, which enables their passing in the plane, as well as the movement of the mechanism, in the extended (O) and crossed (X) position.

## 3. PROGRAMMING AND PROGRAM VERIFICATION

This chapter provides basic information about an established programming environment, which includes a virtual machine for tool path verification in CAD/CAM system PTC Creo, as well as information about programming based on STL files [6].

Generating of model, i.e. STL file, and appropriate toolpath prior to fabrication of the physical models using subtracting technology can be done using any CAD/CAM systems (Creo, Catia,…) or specialized software for the rapid manufacturing (based on STL), which allows pre-machining layer by layer and finally finishing.

### 3.1 Programming in CAD/CAM system PTC Creo

As a basic programming software for 3-axis hybrid kinematics CNC machine based on O-X glide mechanism can be used available CAD/CAM solutions. For this research is chosen CAD/CAM system PTC Creo or Catia. Figure 2 shows basic structure of programming systems. Verification of program can be realized by: simulation of tool paths, material removal simulation and machine simulation when virtual machine working using program CLF (Cutter Location File). Process of postprocessing of tool path is same as for conventional three axis machine tools, by ISO 6983 standard.

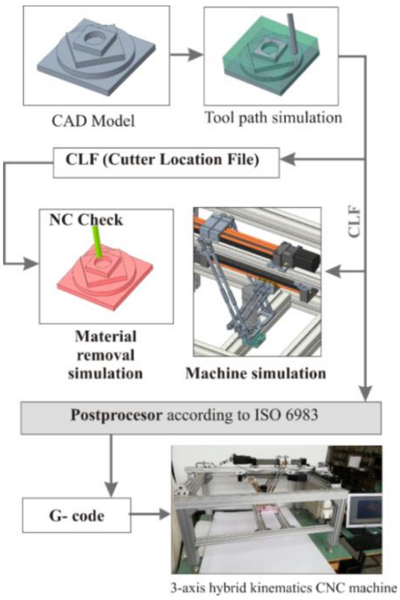



Fig. 2. Basic structure of programming system

### 3.2 Machine simulation in the CAD/CAM system

PTC Creo software system supports all stages of the programming CNC machine tools, modeling and simulation of virtual machine model. The stages are [6]: (i) modeling the mechanism with defined kinematic connections, (ii) definition of ranges in kinematic connections, (iii) manual interactive inspection of defined virtual kinematic connections, (iv) creating a video file of tool path simulation on a virtual machine.

The configured virtual machine can be used for simulation of tool path which include the possibility of virtual prototype elements movements as a rigid body system [5]. For this possibility need define all kinematic connections between components. The required kinematic connections for the considered 3-axis hybrid kinematic machine are three translations (s1, s2, and s3) with slider type of connection, and 16 rotary joints with pin type connection, at the points of connection the parallel mechanism rods with the moving platform and sliders, Fig.3.

After defining the kinematic connections of the moving parts of the machine, it is necessary to make a connection between the coordinate systems on the workpiece and the tool and the virtual machine within the used CAD/CAM system (PTC Creo). Virtual machine tool need defining coordinate system MACH_ZERO, on machine table and TOOL_POINT on front of main spindle (Fig. 3). Also, workpiece and tool have the same coordinate systems. By matching of the appropriate coordinate systems of tools and workpieces is possible to prepare set-up for simulation. After that it is possible to run a simulation of the virtual machine tool according to a program by using Machine Play option, Fig.4.

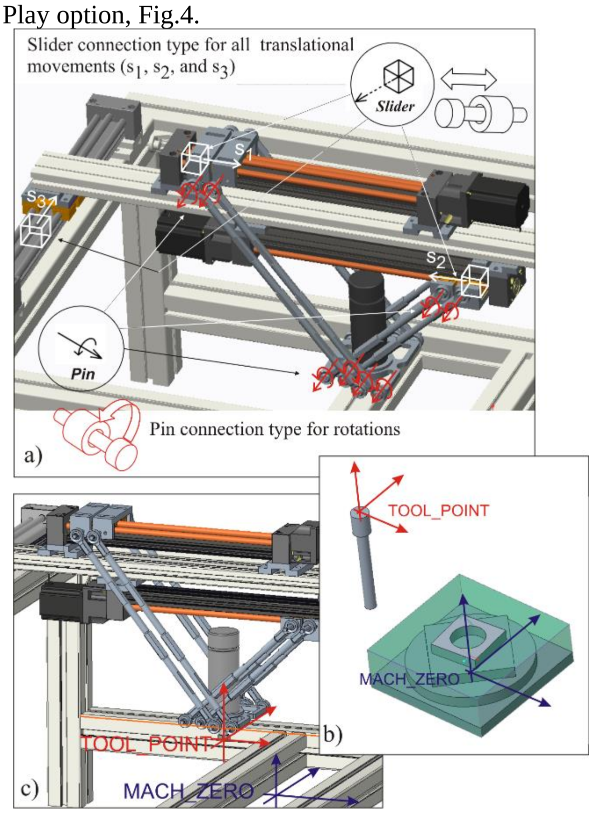



Fig. 3. Virtual machine tool of 3-axis hybrid kinematics CNC machine with defined kinematic links and

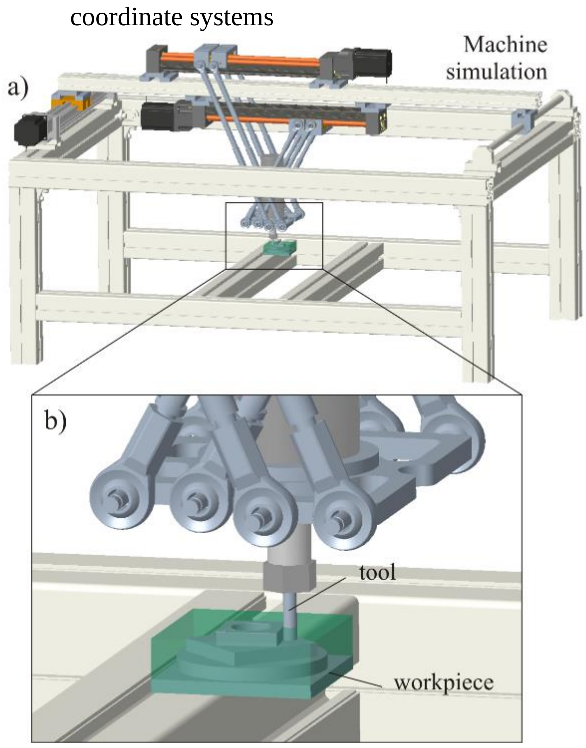



Fig. 4. Virtual machine simulation in CAD/CAM environment

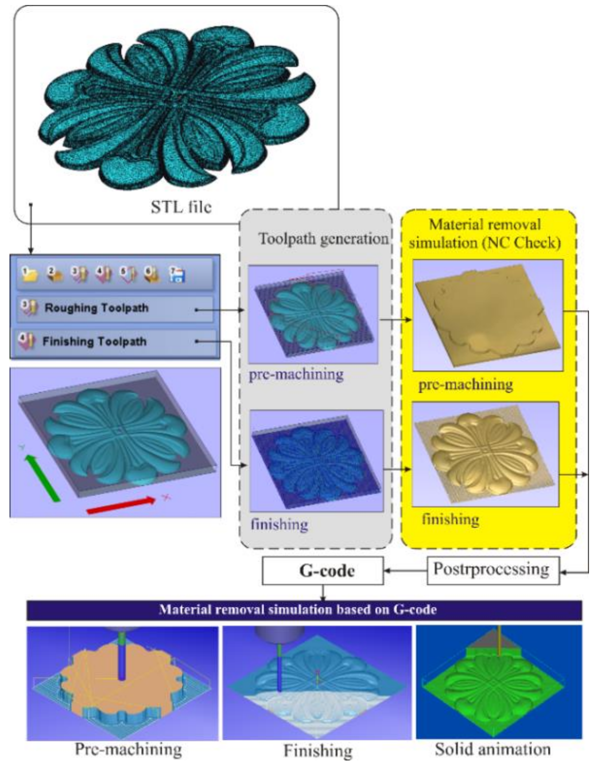



Fig. 5. Rapid prototyping using subtractive technology based on STL files in CUT3D

### 3.3 Programming in CAM based on STL files

Typical process for subtractive technology in rapid prototyping also known as desktop milling. This procedure involves the following steps: (1) CAD modeling of prototype; (2) STL conversion; (3) Loading of STL file in CAM system; (4) planning roughing and finishing strategy for milling; (4) generating adequate G-code; (5) G-code verification with material removal simulation; (7) Fabrication of prototype using desktop milling [6].

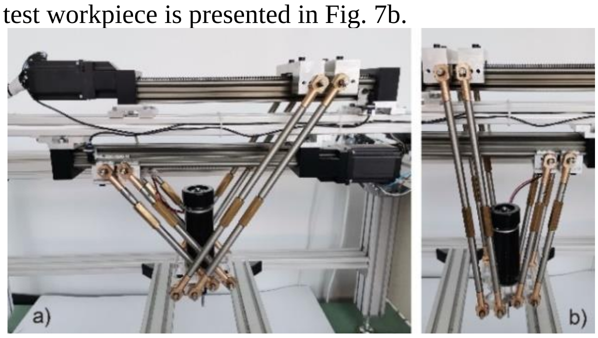
Specialized software packages for machining based on STL file have many and some of them are CUT3D, Deskproto, MeshCAM, etc. These software packages is characterized by easy use and fast generation of roughnig and finishing tool paths. These software packages enable the loading of the model in the STL format, orientating of model for machining, tool selection, choosing machining strategies for roughing and finishing, material removal simulation for different materials, and finally postprocessing the toolpath into G-code.

One example of the application of specialized CAM software that works on the basis of the STL file is shown in Figure 5. The Fig. 5 shows an example of the generated paths for roughing and finishing, as well as the corresponding verification of material removal in the software itself. Postprocessing was then performed to obtain the G code. The postprocessed G code was additionally verified by a material removal simulation in another program such as the CIMCO editor. Based on this example, machining was performed, and results of which are shown in section 4.

## 4. MACHINING TEST

First prototype of the machine tool with hybrid kinematics based on O-X glide mechanism has been built in the Laboratory on the base of a customized concept and mechanical characteristics analysis. Linear axes are composed of step motors NEMA 23 and Igus linear axes. Figure 6 shows the realization of both machine variants i.e. with the extended (O) and crossed (X) glide mechanism.

The first tests were performed on a crossed form X configuration the machine by machining the test part. Verification of the machine prototype is realized through machining of several workpieces, where as a material Styrofoam was used. A custom test workpiece which is used for test of the CNC machines work accuracy was used in process of verification of the machine's performance during test work of machine, Fig 7a. This test was performed by machining of the part which is similar to ISO test workpiece. In this case, a flat endmill (diameter 5 mm) was used. The finished test workpiece is presented in Fig. 7b.




a) crossed (X) glide mechanism b) extended (O) glide mechanism

Fig. 6. Configured prototype of machine with O-X glide hybrid mechanism

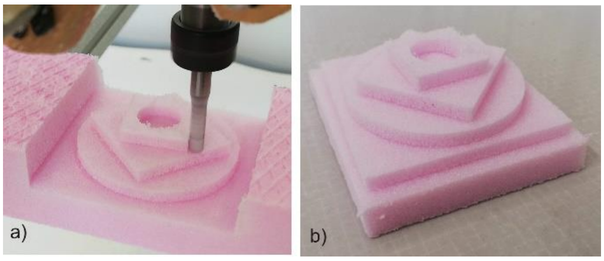



Fig. 7. Machining a custom test workpiece

The second test was performed by machining model of the rosette sculpture, based on STL file, Fig.8. Procedure of programming and program verification, for this example, is shown in Fig.5. This is an illustration of machining using subtractive rapid prototyping technique. In this case, a flat-endmill (diameter 5mm) and ball-endmill (diameter 3mm) was used. Figure 8 displays 3-axis machining where is first executed pre-machining (Fig.8a), and after that finishing (Fig.8b).

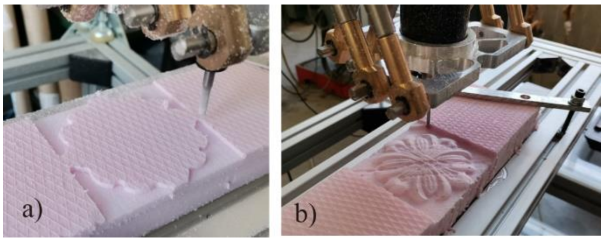



Fig. 8. Machining the rosette sculpture

## 5. CONCLUSION

In this paper presented prototype of of 3-axis hybrid kinematics CNC machine for rapid prototyping, based on O-X glide hybrid mechanism. Developed 3-axis hybrid kinematics CNC machine for rapid prototyping is an educational and research resource that is open to further improvements. This machine is reconfigurable and capable for building of multifunctional machine tool. The paper describes methods for programming and program verification, and experimental verification trough machining test.

During the realization of the first prototype of 3-axis hybrid kinematics CNC machine for rapid prototyping following activities were realized: (i) testing X variant of the mechanism, (ii) configuration of the machine tool control, (iii) configuring of the virtual prototype, (iv) simulation of the virtual prototype, (v) preparing and testing programming enviroment, (vi) verification of generated toolpath and (vii) testing and trial runs of the machine tool.

The first next steps are further testing and other variants of the O mechanism while providing easy reconfiguration from the X to the O variant and vice versa.

Future research in the field of improvements of the presented concept includes analyzes the applicability of the concept to laser processing machines and additive technology.

## 6. REFERENCES

[1] Živanovic, S., Tabaković, S., Zeljković, M., Mladjenovic C.: *Machining simulation and verification of tool path for CNC machine tools with serial and hybrid kinematics*, VIII International Conference "Heavy Machinery-HM 2014", Zlatibor, 25-28 June 2014

[2] Tabakovic S., Zeljkovic M., Gatalo R., Mladjenovic C.:*Device for manipulating workpieces or tools in machine tools and industrial manipulators*, in: S. Intellectual Property Office (Ed.), Republic of Serbia

[3] Tabakovic, S, Zivanovic, S, Zeljkovic, M.: *The application of virtual prototype in design of a hybrid mechanism based machine tools*, Journal of Production Engineering Vol.18, pp.77-80, 2015.

[4] Zivanovic, S., Tabakovic, S., Zeljkovic, M., Milojevic, Z.:*Configuring a machine tool based on hybrid O-X glide mechanism*, Machine Design, Vol.8, pp.141-148, 2016.

[5] Tabaković, S., Živanović S.: *Simulation of kinematic of virtual prototype of a machine tool based on hybrid O-X mechanism*, Proceedings of 3rd International Scientific Conference Conference on Mechanical Engineering Technologies and Applications COMETa 2016, pp.199-206, University of East Sarajevo, Faculty of Mechanical Engineering, Jahorina, B&H, Republic of Srpska, 2016.

[6] Zivanovic S., Popovic, M., Vorkapic, N., Pjevic, M., Slavkovic N.: *An Overview of Rapid Prototyping Technologies using Subtractive, Additive and Formative Processes*, FME Transactions Vol.48, No. 1, pp. 246-253, 2020.

***Authors:*** **Full Prof. Slobodan Tabaković, Full. Prof. Milan Zeljković,**
University of Novi Sad, Faculty of Technical Sciences, Department of Production Engineering, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, Phone.: +381 21 485-23-24, Fax: +381 21 454-495.
E-mail: tabak@uns.ac.rs; milanz@uns.ac.rs
**Full Prof. Saša Živanović, PhD Zoran Dimić,**
University of Belgrade, Faculty of Mechanical Engineering, Production Engineering Department, Kraljice Marije 16, 11120 Belgrade, Serbia, Phone.: +381 11 3302-423, Fax: +381 11 3370-364.
Lola Institute, Kneza Viseslava 70a, Serbia
E-mail: szivanovic@mas.bg.ac.rs; zoran.dimic@li.rs;

**ACKNOWLEDGMENTS:**
This paper has been supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia through the project no. 451-03-68/2020-14/200156: "Innovative scientific and artistic research from the Faculty of Technical Sciences, Novi Sad, Serbia, activity domain"
The presented research was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia by contract No. 451-03-9/2021-14/200105 of 05.02.2021.