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## PROGRAMMING AND VERIFICATION OF MILLING OPERATIONS FOR CNC MACHINES WITH HORIZONTAL ROTARY AXIS

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**Abstract:** The paper analyses the programming of CNC milling machines with horizontal rotary axis. These are usually machines for rapid prototyping of rotating symmetrical and/or asymmetrical parts. The paper analyses the available programming software, which can be one of the standard CAD/CAM systems or a specialized CAM system. In addition to the analysis of the programming method procedure, the verification of the program by simulating the removal of material and simulating the operation of a virtual machine according to a given program was also considered. Verification of programming methods was realized by machining several characteristic parts, on developed 3-axis desktop CNC milling machine - Multiprodesk, that has two translational and one horizontal rotary axis.

**Keywords:** programming, simulation, verification, rotary machining

### 1. INTRODUCTION

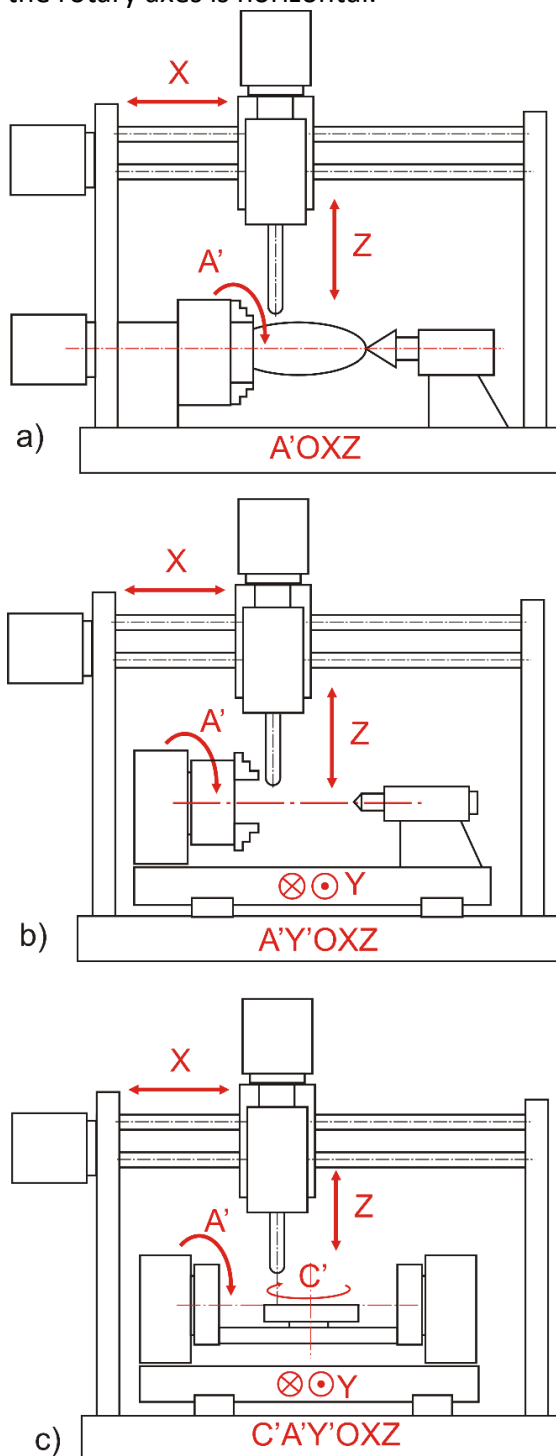
The complexity of the model of a part is directly related to the complexity of the milling machine that needs to be chosen for the machining process [1]. When it is necessary to implement machining of rotary primarily asymmetrical parts, machining with at least one rotating axis on the machine is necessary, so that machining is possible in one clamping.

The paper discusses the programming and verification of programs for CNC machine tools that have a horizontal rotary axis [2], Fig.1. These CNC machine tools can be:

- 3-axis with two translational axes and one horizontal rotary axis,
- 4-axis with three translational axes and an integrated or additional horizontal rotary axis and,
- 5-axis with three translational axes and an integrated or additional two-axis rotary table.

The type of machine whose programming is considered in this paper belongs to the class of CNC machines for rapid prototyping by milling, where one horizontal rotary axis is used for machining. These machines can be 3-axis, with two translational and one rotary axis (Fig.1a) or

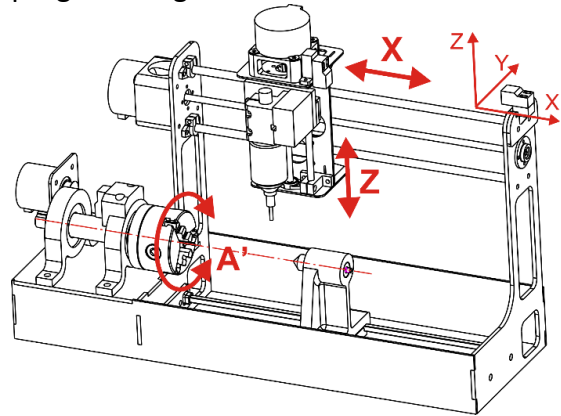
4-axis with three translational and one rotary axis (Fig. 1b). This kind of machining is also possible with a 5-axis machine (Fig.1c) where the rotary axes can be positioned so that one of the rotary axes is horizontal.



**Figure 1.** CNC machines with horizontal rotary axis [2]

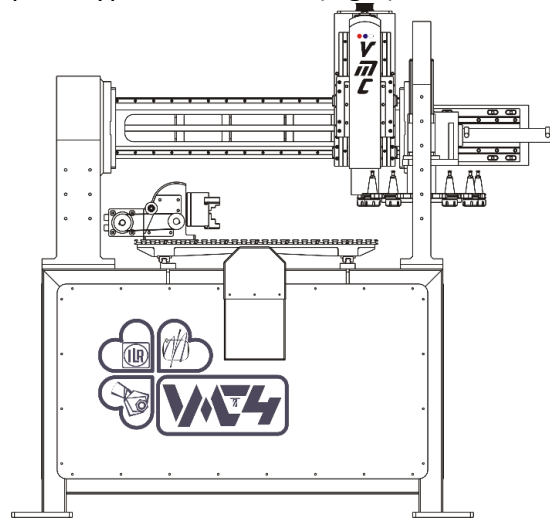
The structure of the machine from Fig.1a is  $A'O'XZ$  and has a horizontal rotary axis  $A'$  on which the workpiece is mounted, and the tool is carried by two translational axes  $Z$  and  $X$ . This machine was developed, as an educational

machine – Multiprodesk (Fig.2) and this paper considers an adequate system for its programming.



**Figure 2.** Multiprodesk - CNC machine with kinematic structure  $A'O'XZ$  [3]

The structure of the machine from Fig.1b is  $A'Y'O'XZ$  and also have a horizontal rotary axis  $A'$  and translatory  $Y'$  axis on a workpiece side. This machine is also developed, as an industrial prototype LOLA VMC 4 (Fig.3).



**Figure 3.** LOLA VMC4 - CNC machine with kinematic structure  $A'Y'O'XZ$

And the last machine in the considered class is a plan for future development, and in relation to the basic structure, it would have a two-axis rotary table. Its planned structure is  $C'A'Y'O'XZ$  (Fig.1c) and it is possible to plan machining with a horizontal rotary axis. This kind of machining is possible when axis  $A'$  occupies a position such that axis  $C'$  is rotating around the horizontal axis.

### 1.1 Programming methodology

Available standard CAD/CAM systems, as well as specialized CAM software, can be used as a programming system for machine tools with a horizontal rotary axis [4,5].

Depending on the model format and the CAD system used for model preparation, the choice of programming system also depends. If we are talking about a machine for rapid prototyping, then most often it is a model in STL format, so the choice of specialized CAM systems that can work on the basis of such models is common. In this work, the developed educational 3-axis machine for rapid prototyping - Multiprodesk [4] will be used to verify the environment for programming such class of machines.

### 1.2 Programming based on CAD/CAM system

The system for programming CNC rotary machining using the CAD/CAM system [6] is shown in Fig.4.

It is possible to exchange geometric workpiece models with other CAD systems and generate toolpath.

Toolpath verification is possible by simulating moving tools along the tool path, material removal simulating, and simulating the working of virtual machine according to the given program in CLF format [1].

Tool path programming was performed using PTC Creo Parametric CAD/CAM software, resulting in a CL file containing the tool path. The toolpath defined in this way contains data on the position and orientation of the tool during machining in relation to the coordinate system of the workpiece and as such cannot be used directly on the machine, but must be postprocessed in order to obtain G-code were defined necessary movements of the axes of the machine tool. Program verification is also performed after postprocessing based on G-code in the Vericut environment.

The basic part of the system consists of developed and implemented postprocessor, without using the postprocessor generator from CAD/CAM system.

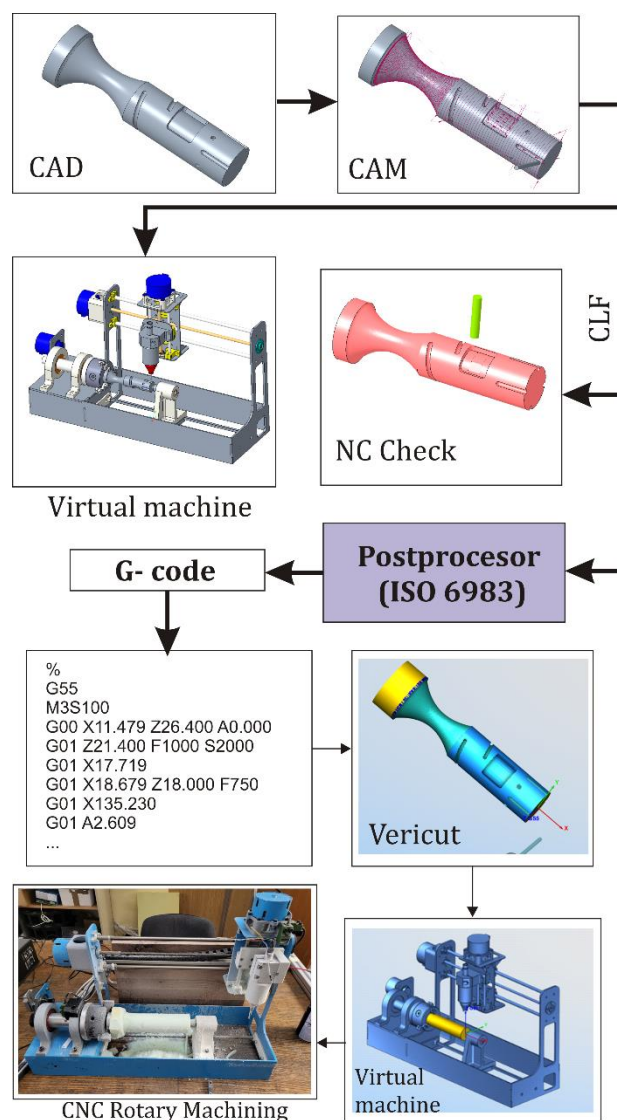


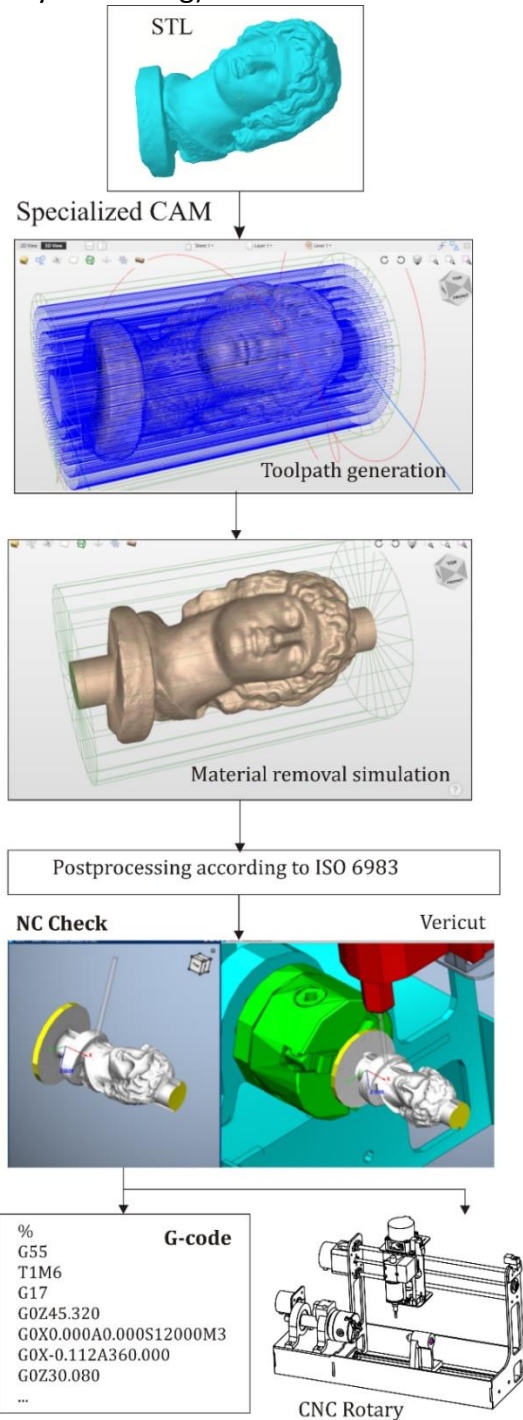
Figure 4. Programming based CAD/CAM system

The developed postprocessor is modified version of the software developed in [7]. The developed post-processing software has been modified using the kinematic equations describing the structure of the considered four-axis machine with horizontal rotary axis. The kinematic equations used within this software are derived based on the solution of the inverse kinematic problem, shown in [8] and [9].

### 1.3 Programming based on specialized CAM

As a system for programming the 3-axis CNC machine tools with two translatory and one horizontal rotary axis, considering that the machine is planned for rapid prototyping of soft materials, recommended by specialized CAM software packages which have the possibility of

programming machining with rotary axis (Rotary Machining).

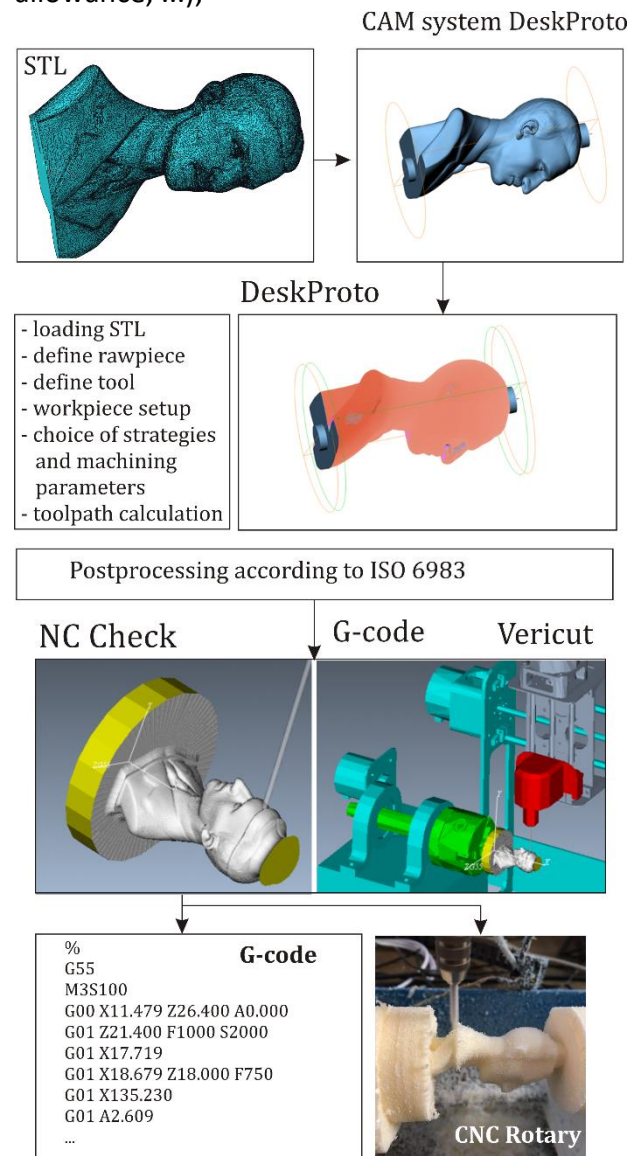


**Figure 5.** Programming based on STL model in Vectric Aspire environment

For rapid prototyping, models are mostly in STL or OBJ format. The paper analyzes the application of the software Vectric Aspire and DeskProto, which can be used for programming machine with a rotary axis.

An example of programming method based on specialized CAM software Vectric Aspire is given in Fig.5 with rotary machining option.

Programming includes the following stages: (1) defining job setup (single sided, double sided and rotary); (2) defining rawpiece dimensions; (3) define rotary axis; (4) loading of STL file and setting orientation and model size; (5) defining material setup - diameter, zero point; (6) selection toolpath operation (3D roughing, 3D finishing, etc.); (7) define parameters (tool, strategy, machining allowance, ...);



**Figure 6.** Programming based on STL model in DeskProto environment

(8) calculating toolpath; (9) previewing toolpaths - material removal simulation; (10) saving toolpaths in G-code using appropriate postprocessor for rotary machining; (11) NC Check in Vericut software environment using material removal simulation and machine simulation.

The second example of programming method based on specialized CAM software DeskProto is given in Fig.6 with rotary machining option.

DeskProto is a specialized CAM programming software that can load STL files, with the possibility of rotary machining, which can be either continuous or indexed rotation, with application of different machining strategies. Programming in the DeskProto environment is very intuitive and enables quick and efficient obtaining of G-code. The description of the programming procedure can be described in several stages: (1) selection of machine and type of milling (here machine with rotary axis and rotary machining); (2) loading model in STL format with the selection of the axis of rotation; (3) selection of tools, machining mode and strategy, depth per pass for pre-machining and machining allowance for finishing; (4) toolpath generation and display and (5) generation G-code.

## 2. EXPERIMENTAL VERIFICATION

Experimental verification of the programming methods was performed on a desktop 3-axis CNC machine tool with two translatory and one rotary axis, with a kinematic structure of A'OXZ.

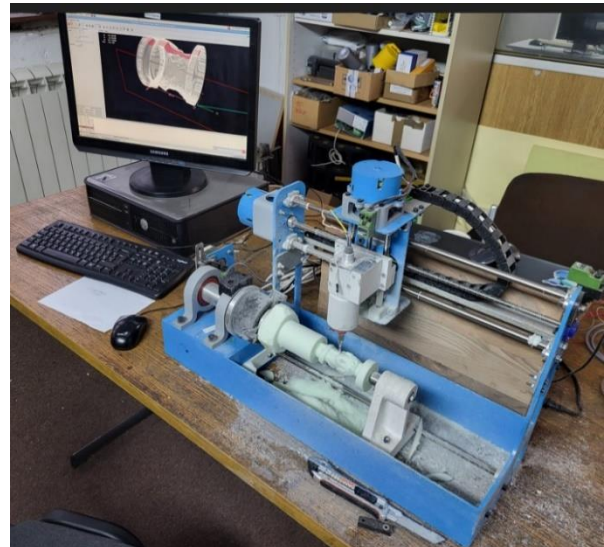


**Figure 7.** Example machining workpiece which is programmed using CAD/CAM system

The machining shown in this chapter is in fact a test of the considered programming methods on the machine, on selected

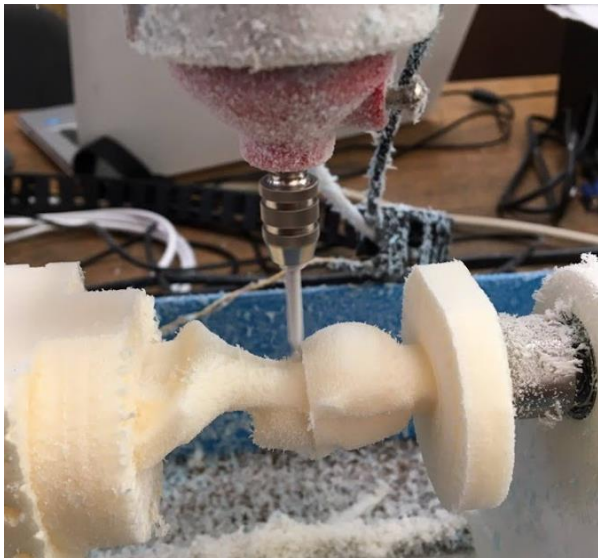
examples. The first example used CAD/CAM system for machining some trial part for rotary machining, Fig.7.

The remaining two examples considered a verification of programming based on specialized CAM software packages, Figs. 8 and 9.



**Figure 8.** Example machining workpiece which is programmed using Vectric Aspire

The machined parts verified the considered programming methods. Correct positioning, determination of the zero point was achieved, the machining was without collisions and without errors.



**Figure 9.** Example machining workpiece which is programmed using DeskProto

### 3. CONCLUSION

The paper presents programming methods and testing of a 3-axis CNC machine tool with two translational and one rotary axis (Multiprodesk-mill), with kinematic structure A'OXZ. Experimental verification of considered programming methods was carried out on the desktop variant of the machine, while in the coming period, testing of the operation of the rotary axis is also planned on the industrial variant of the LOLA VMC4 machine.

The considered programming methods for rotary machining on 3-axis CNC machine tool with two translatory and one rotary axis follows current trends such as: (i) adaptation to the specific needs of certain branches of industry, by introducing reconfigurable and adaptable machine tools; (ii) open architecture control system based on LinuxCNC; (iii) application of the developed machine and programming methods in education and research; (iv) consideration of new methods in CNC programming; (v) adoption of digitization and virtualization for program verification to improve industrial production within the framework of the Industry 4.0 paradigm

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