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CONFIGURING OF VIRTUAL 5-AXIS HYBRID KINEMATIC MILLING MACHINE

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Summary: *This paper presents a part of research results obtained during the configuring of 5-axis hybrid kinematic milling machine tool. This machine tool configuration consists of 3-axis developed parallel mechanism and 2-axis serial mechanism that is placed on platform of parallel mechanism. Using realized mini-laboratory and desktop 3-axis PKMM (parallel kinematic milling machine) pn101_st research is continued aiming to develop 5-axis HKMM (hybrid kinematic milling machine). Configured 5-axis hybrid kinematic milling machine has been verified by successful making of the virtual machine with control and programming system. The paper describes the structure of the hybrid kinematic milling machine, configured virtual prototype and control and programming system based on PC real-time Linux CNC platform.*

Key words: hybrid kinematic milling machine, configuring, virtual machine, EMC2

1. INTRODUCTION

Many different topologies of parallel mechanisms with 3–6 DOF, including hybrid parallel–serial mechanisms, have been used. In order to realize machine tools with the advantages of parallel and serial kinematics mechanisms it is appeared hybrid solutions of machines that combine parallel and serial mechanisms. Many researchers have contributed to the study of the hybrid type 5-axis CNC milling machine [1-5].

By adding serial mechanism on the movable platform of parallel mechanism, basically it can be achieved: increasing the number of degrees of freedom, as well as increasing the range of the tool orientation angles. In the first case, the serial two-axis mechanism is added to the parallel mechanism with three degrees of freedom that results with a five-axis machine with high ranges of tool orientation angles. In the second case, to the parallel mechanism with six degrees of freedom is also added serial two-

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axis mechanism that results with increasing the range of tool orientation angles, but with the problems of redundancy, complexity and price of the construction.

The examples of potential hybrid configuration of machine tools as well as combinations of serial and parallel mechanisms are presented in Table 1. In this paper it is selected configuration type T4, that is a combination of a parallel mechanism with 3 degree of freedom and the serial mechanism with two degrees of freedom.

Table 1 *Potential hybrid configurations [1]*

Type →	T1	T2	T3	**T4**	T5	T6
Serial	5	4	3	**2**	1	0
Parallel	0	1	2	**3**	4	5
Total DOF	5	5	5	**5**	5	5

A selected configuration T4, that is considered in this paper, is a logical extension of the previous research, that includes upgrading of mini-laboratory and desktop 3-axis parallel kinematic milling machine pn101_st, into a 5-axis variant of this machine. This can be achieved in two ways. The first is the addition of two-axis spindle-tilting head to the movable platform, and the second is addition of two-axis rotary table. For this research, two-axis spindle-tilting head is appropriate solution that is often case in order to upgrade machines with parallel kinematics.

The rest of the paper is organized as follows. In Section 2, a concept of 5- axis hybrid kinematic milling machine is presented. Development of the virtual 5-axis hybrid kinematic milling machine is presented in section 3. Programming and control system, that includes the virtual machine is shown in section 4

2. CONCEPT OF 5- AXIS HYBRID KINEMATIC MILLING MACHINE

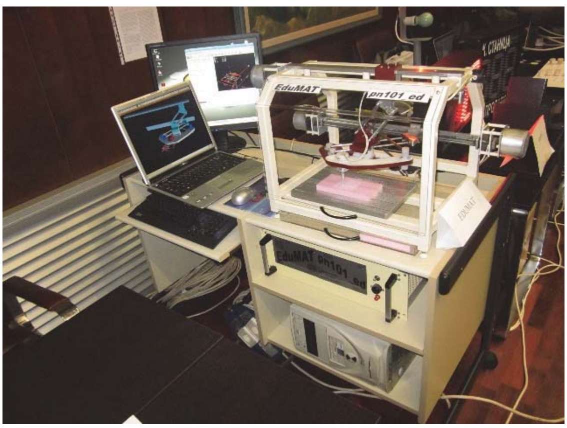

Fig. 1 *Developed mini-laboratory and desktop 3-axis PKMM pn101_st*

Using previous experience in the field of PKMM and successfully developed mini-laboratory and desktop 3-axis parallel kinematic milling machine pn101_st [6], Fig.1, the idea about developing a low-cost desktop educational 5-axis hybrid kinematic milling machine, with virtual machine is came up.

The first step was to set the aims that can be summed up as follows: (i) low-cost desktop educational machine; (ii) soft materials can be machined; (iii) programmable in a common way; (iv) fully safe for user-beginners; (v) low-cost control system; and

(vi) possibility of development of virtual machine [6,7]. This machine type upgrades the possibility of educational system Edumat [8], that is applicable in the field of configuration, control and programming system, and operational work of the CNC machining systems. Such 5-axis machine with hybrid kinematics is controlled in world coordinates and the machine is programmed as machines with serial kinematics, with the same number of axes, so that such a concept is not a problem either for the operator or to developers.

Based on the experience gained so far, the new system is an upgrade of the existing in terms of hardware and control software. The hardware part of the existing parallel mechanism has been upgraded by adding two-axis spindle-tilting head on the movable platform. The part of the existing control system has been upgraded by new solutions of inverse and direct kinematics for 5-axis HKMM.

The concept of a 5-axis machine with the hybrid-kinematics, that includes a 3-axis mechanism with parallel kinematics with two-axis spindle-tilting head (with rotations B and C) on a movable platform, is shown in Fig. 2.

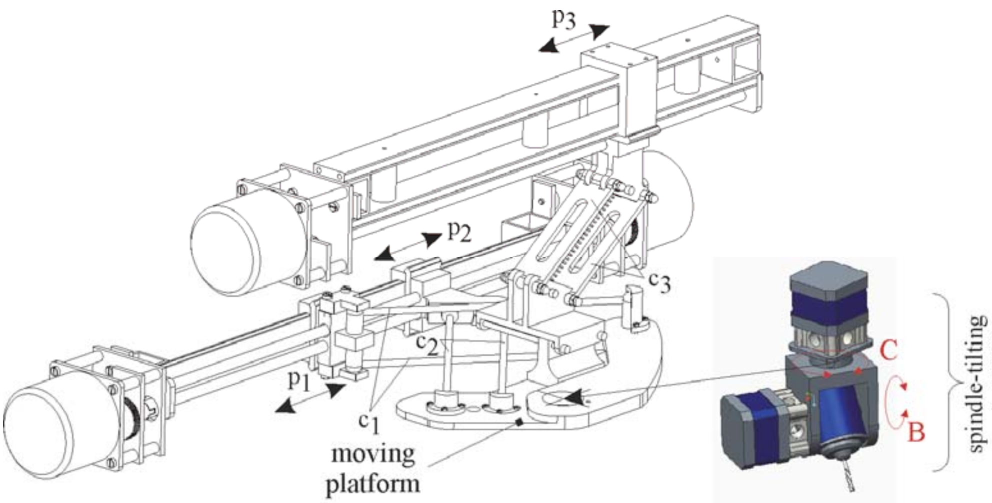

Fig. 2 *Model of the parallel mechanism pn101_st with two-axis spindle-tilting head*

Hybrid mechanism (pn101_V5) mechanism consists of the movable platform, three joint parallelograms c1, c2, and c3, and a stationary base with two parallel guideways. Two crossed parallelograms c1 and c2, with spherical and/or universal, i.e., cardan, joints, are connected with one of their ends to the movable platform and with their other ends to the independent sliders p1 and p2 which, with a common guideway, make two powered and controlled translatory joints. The third joint parallelogram c3 is connected with one of its ends, through passive rotating and translatory joints to the movable platform. Its other end is connected with rotating joints to the slider p3, which makes with the second guideway the third powered and controlled translatory joint. The actuation of sliders p1, p2, and p3 offers three degrees of freedom to the movable platform. On a movable platform, instead of the main spindle, it is added two-axis spindle-tilting head with rotations B and C, thus achieving the possibility of obtaining the tool orientation in 5-axis machining.

3. DEVELOPMENT OF THE VIRTUAL 5-AXIS HKMM

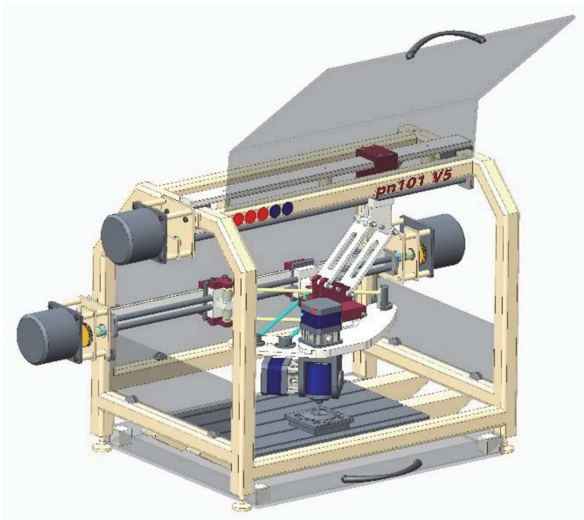

Fig. 3 *CAD model of mini-laboratory and desktop 5-axis HKMM, pn101_V5*

It is planned and realized the 5-axis virtual hybrid variants of this mechanism. A representation of the CAD model of the developed educational desktop 5 axis HKMM is shown in Fig. 3. It was adopted XYZBC structure of machine, where the XYZ position realizes a parallel mechanism pn101_st, while the BC orientation realizes two-axis spindle-tilting head with serial kinematics.

In order to verify the virtual prototype of this machine and analysis of collision of new added components on the machine, it is realized the simulation of this machine in the CAD/CAM environment. During these simulations the various examples of workpieces, which can be fitted within the boundaries of the workspace of the machine, are tested. One such example, the machining of the workpiece having the ellipsoidal shape, is shown in Fig. 4.

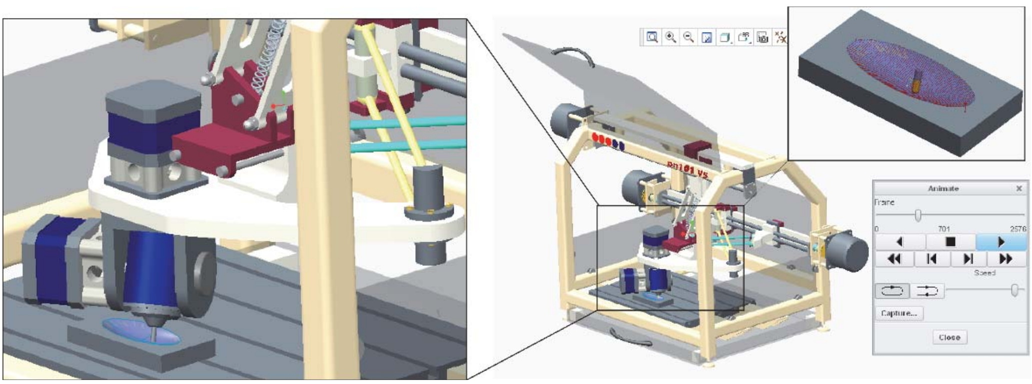

Fig. 4 *Example of the simulation of the virtual prototype machines during the machining of workpiece having the ellipsoidal shape*

The first testing examples on the virtual machine prototype have shown the possibility of the successful realization of such machine concept, that is a combination of parallel and serial mechanism.

4. CONTROL AND PROGRAMMING SYSTEM

Configuring of control system is a separate research task for each machine tool. Small project budget in local conditions implies that such a project can only be carried out using own resources. For control of machine tools with hybrid kinematics, it is suitable to choose available open architecture software, which allows free configuration control, according to the desired kinematics. For machines with parallel and hybrid kinematics, it is necessary to implement inverse and direct kinematics in control. As such software, Enhanced Machine Controller - EMC2 [9] was chosen. This is a real-time software for the control of CNC machine tools and industrial robots, whose code can be used, modified and distributed freely (GNU General Public License). EMC2 allows machine programming by functions according to the ISO 6983 standard.

For the realization of the control unit for 5-axis HKMM it is necessary to provide a stable hardware platform, real-time operating system and driver software with appropriate performance. PC platform was chosen as a hardware platform, along with the compatible operating system for the real time processing. Ubuntu Linux with real time extension (RTLinux) was chosen as a very reliable and widespread solution. Figure 5 presents a simplified structure of the control and programming system.

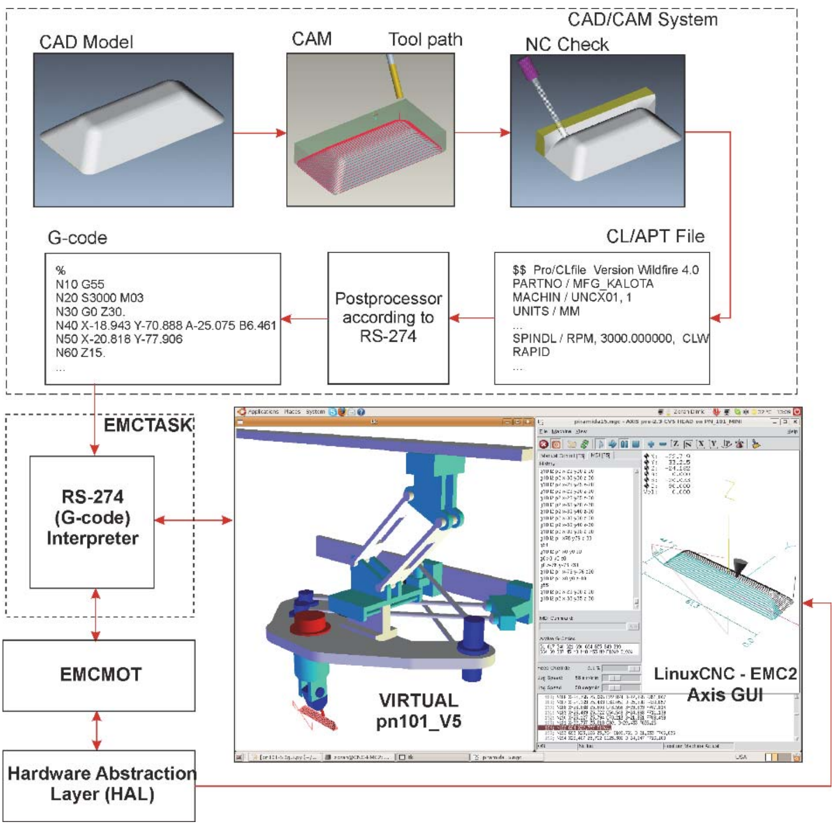

Fig. 5 *Programming and control system with virtual 5-axis HKMM*

Part programming is conventional, with the use of a postprocessor to convert CLF (Cutter Location File) into G code. The CAD/CAM systems are suitable solution for programming of 5-axis HKMM. In this case we use PTC Creo 2.0 as a programming system. For postprocessing of CLF it is used the configurator of postprocessor for 5-axis machine with structure XYZBC. During the G-code loading, EMC2 software performs tool path verification. Since this is an educational system with a complex kinematics, a virtual machine was included in the control and programming system too, Fig.6. Virtual machine is designed by using several classes predefined in object-oriented programming language Python. When the program starts running, G-code instructions are executed in real time and generated control signals that are directed to a real and/or virtual machine. The virtual machine makes possible simulation of the real machine for the user, i.e., verification of the program in machine workspace [6]. Verification is done on a virtual machine of vertical 5-axis HKMM, realised in the Python programming language, which is integrated with the Axis GUI (Graphical user interface). Figure 6 is shown 5-axis HKMM virtual machine which is integrated with Axis GUI of EMC2.

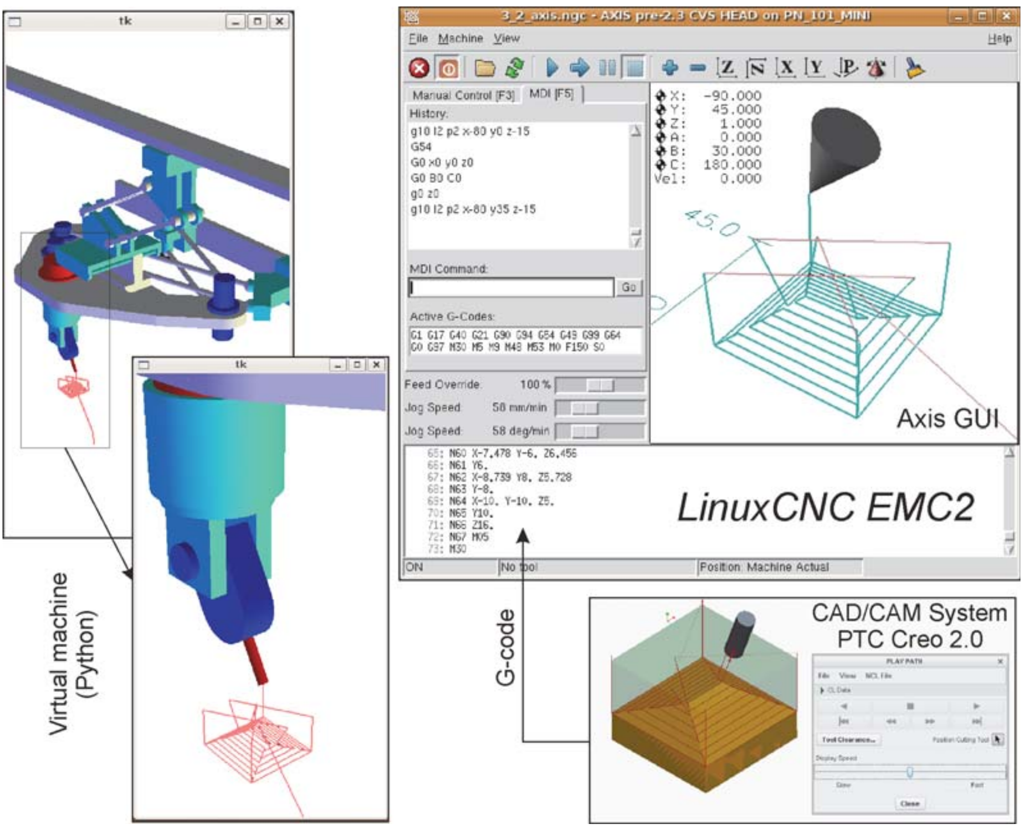

Fig. 6 *Inegrated 5-axis HKMM virtual machine in Axis GUI of EMC2*

Internal software structure of the EMC2, contains four basic software modules: motion controller (EMCMOT), discrete input/output controller (EMCIO), processes controller for coordination (EMCTASK) and a collection of text or graphic user interfaces.

EMCTASK (Task coordinating module) distributes commands in the machine. It performs interpretation of the program, G code, all according to ISO6983 standard, as well as RS274 NGC standard. EMCIO (Discrete I/O Controller) performs all communications that are not related to motion control. It has subordinate modules for the main spindle, tool change, auxiliary M functions, all stop mode, lubrication, etc. EMCMOT (Motion Controller) is a module that runs periodically in real time and performs path planning, calculations related to inverse and direct kinematics and generates control signals for the drives of the machine. It performs feedback loop closure, generates subsequent positions, interpolates path between programmed positions, controls border positions and axes' reference positions etc. To control the 5-axis HKMM, it is necessary to make changes to the core of the EMC2 control system. These changes relate to the replacement of the usual standard trivial functions of inverse and direct kinematics by corresponding inverse and direct kinematics functions for 5-axis HKMM.

The modular structure of the EMC2 has contributed to its flexibility in the applications on machines with complex kinematics, as well as in its connection with various hardware and software add-ons. This is possible primarily due to HAL (Hardware Abstraction Layer). HAL was conceived as a flexible interface between the movement controllers on one side and as an interface for connection between the user and the real machine or virtual machine on the other side. This also implies the multitude of hardware machines interfaces which provide motion controller interface with actuators and measuring systems.

GUI (Graphical user interface) is an external program which communicates with EMC by sending commands such as: machine turn on, switch to automatic mode, start the program, machine shut down, etc. GUI can also send manual messages, initiated by the operator, such as: moving machines axes in manual mode (JOG) or sending all axes in a reference position. Different GUI can be used, while Axis, Figs. 5 and 6, is the most commonly used user interface. This is very intuitive environment with recognizable icons that facilitate the operator's work. In addition, the convenience of the Axis environment is the possibility of integration with the virtual machine, which is here realized.

5. CONCLUSION

For 5-axis HKMM the current stage of development is realized CAD model of virtual prototype, virtual machine and control and programming system in EMC2. Verification of system for programming was performed using machining simulations on a virtual prototype in the CAD/CAM environment. Control system is verified using configured virtual machine in Python graphical environment that is integrated with the software EMC2.

Development of virtual machine such as simulators for programming and simulation of machine tools during the machining is important because it allows off-line programming with verification and testing of the program.

Working in the virtual environment is suitable in terms of training and education for programming of such manufacturing systems, especially in educational institutions in country, where there is shortage of multi-axis machine tools. In this way, and without existence of resources, i.e., new machines, it is possible to realized training for 5-axis programming.

In this paper is presented an educational system using the developed virtual educational 5-axis HKMM. The educational system is applicable in CNC training of programmers and operators, as well as in the training of CAD/CAM software users. The advantage of using educational system is the possibility of individual training of students, where each student has his own virtual machine for individual work.

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