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VARIANTS OF HYBRID KINEMATICS MACHINE TOOLS BASED ON O-X GLIDE MECHANISM WITH ADDITIONAL ROTARY AXES

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Abstract: *The paper discusses the variants of upgrading the basic concept of the machine with hybrid kinematics based on the O-X glide mechanism, by adding one or two rotating axes on the work table. The variant project was realized at the level of virtual prototypes, which were used to simulate the operation of the machine according to the given program. In this way, the programming environment was created and programming verification was performed on the virtual machining system. The simulations were carried out on selected workpieces of certain dimensions, taking into account the available working space of the machine. In this way, machining simulations on a virtual prototype of four-axis and five-axis machining demonstrated and verified the possibility of machining with additional rotating axes.*

Keywords:*Hybrid kinematics machine, rotary axes, CAD/CAM, simulation.*

1. INTRODUCTION

Due to the constant change in the type and volume of production, machine tool users constantly demand the development of new machine tools improved with the characteristics of accuracy, rigidity, speed, compactness, and a greater number of control axes (four, five and more). The appearance of machines with parallel kinematics (in 1984) opened up new directions of research in order to fulfill the set requirements and caused a significant research momentum at that time. With the development of machines with parallel kinematics, a new approach was adopted in the design of machine tool mechanisms, where the emphasis was placed on the analysis and improvement of existing ones, but also on the development of completely new machines with parallel kinematics (PKM). The reason for analyzing and studying PKM is the advantages provided by parallel compared to serial mechanisms: i) smaller mass of moving parts; ii) better ratio of mass and stiffness of parts; iii) greater flexibility; iv) good dynamic characteristics [1,2]. In addition to the mentioned advantages, PKM is also characterized by disadvantages such as: i) an irregularly shaped workspace; ii) useful working space of small dimensions; iii) complex solutions to kinematic problems; iv) complex construction of the mechanism [3]. Hybrid mechanisms, which represent a combination of serial and parallel mechanisms, contain the advantages of both types of mechanisms with a significant reduction in disadvantages.

Hybrid mechanisms can be very different. Here the addition of 1 or 2 degrees of freedom series mechanisms to a parallel mechanism will be considered. The main reasons for combining mechanisms are as follows: (1) to increase the number of degrees of freedom, such as in the case of a DELTA or TRICEPT mechanism [4], (2) to translate machining from three-axis to four-axis or five-axis, and (3) to increase the range of tool orientation which is small in purely parallel mechanisms with 6 degrees of freedom (e.g. Geodetic Hexapod [5]), (4) to increase the working space.

2. HYBRID KINEMATIC MACHINES

The machine tool based on the O-X glide mechanism in the basic version enables three-axis machining. With the addition of one rotary axis, four-axis machining can be achieved. This type of machining can be of two types: index and continuous. Continuous machining enables simultaneous interpolation of all available axes. Index machining implies a rotary axis as a positional one, that is, it enables the workpiece to be correctly positioned and processed on 4 different sides, without the need for special auxiliary screening and basing, which are necessary when the machine is three-axis.

In addition to three translational movements (X, Y, Z), five-axis machining also has two rotary ones, which enables the machine to perform simultaneous interpolation along several axes. Machining on such machines can be continuous with a 5-axis or positional with a 3+2-axis. With 3+2 axis machining, the desired orientation of the workpiece is taken with two rotary axes, after which the machining is carried out with the remaining translator axes.

This paper plans to analyze the possibility of upgrading the basic machine, with one [6, 7,8] or two rotating axes [6,9], taking into account the limitations that come from the shape and dimensions of the working space. Simulations of four- and five-axis machining on virtual prototypes of the machine, in the various considered variants, were used for the analysis.

3. VARIANTS ANALYSIS OF O-X GLIDE MECHANISM

The development of the basic configuration of the machine tool with hybrid kinematics, the variants of which are discussed in this paper, was presented to the scientific and professional public in papers [10,11], Fig.1.

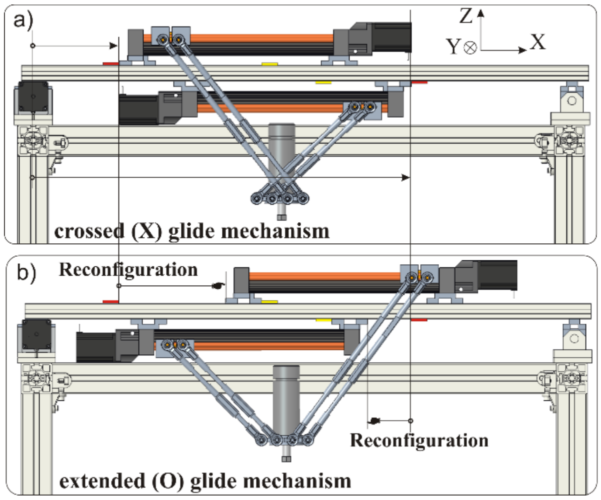

Figure 1. Basic configurations of O-X glide hybrid machine tools [10]

The three-axis machine with hybrid kinematics is based on a hybrid O-X mechanism, which was created by combining a plane parallel mechanism and a serial translator axis (HM0), which are mounted on the supporting structure of the machine. Conceptual solutions of multi-axis machine tools defined by upgrading the basic machine concept with one more (HM1) or two serial (HM2) rotary axes are considered here. The basic conceptual solution and upgrade variants are shown in Table1.

Table 1. Variants of O-X glide hybrid mechanism

Type	HM0	HM1	HM2
Description	Hybrid mechanism Basic	1 additional rotational axis	2 additional rotational axis
Kinematic structure	$OYXZC_v$	$A'OYXZC_v$ $B'OYXZC_v$	$A'C'OYXZC_v$ $B'C'OYXZC_v$
Serial	1	1	1
Parallel	2	2	2
Serial	-	1	2
DOF	3	4	5

The table also shows the kinematic structure of the considered machine tool variants, the defined number of degrees of freedom of the serial and parallel parts of the mechanism, as well as the total number of CNC axes.

For further analysis of the upgrade of the basic machine, adequate CAD models have been prepared for the purpose of checking the placement and basing of these rotary axes on the supporting structure of the machine in the selected coordinate directions, in the direction of the X or Y axis, Fig.2.

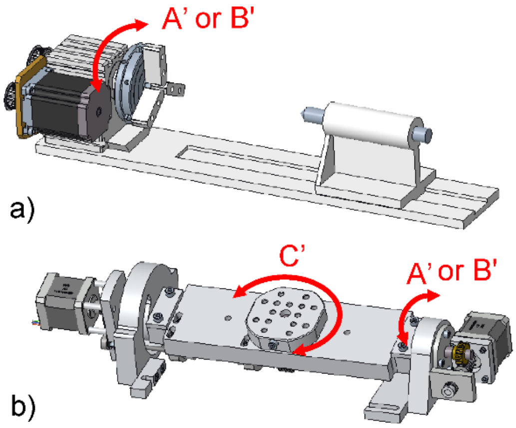

Figure 2. Variants of kinematic modules with rotary

Fig. 3a shows the basic variant of the O-X glide of the hybrid mechanism in the X configuration (HM0) in the reference and arbitrary position with the contours of the working space of the parallel mechanism in the XZ plane. At this stage of the research, the analysis is not performed on the O variant of the mechanisms, although all this may also apply to that configuration of the mechanism.

Respecting the shape and dimensions of the working space, it is necessary to check the possibility of installing additional serial rotary axes. In the HM1 variant, a rotary axis A' was added, as a rotation around the X axis, Fig.3b. This axis of rotation can be set in the other direction as well. If this axis is rotated by 90° so that the rotation axis is parallel to the Y axis, the rotation axis B' is obtained.

In the HM2 variant, two rotary axes are added as a rotary tilting table with rotations A' and C', Fig.3c. Here, a variant of rotating the two-axis rotary table by 90^{O} is also possible, so that the rotary axes in this case become B' and C'.

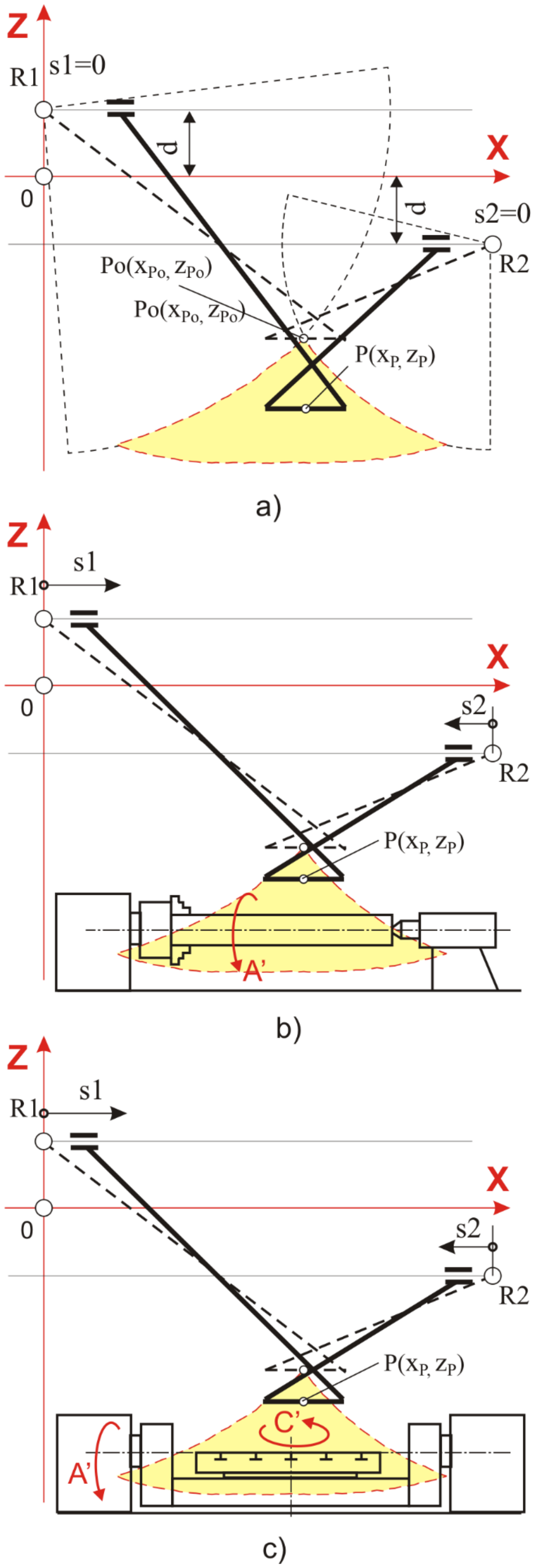

Figure 3. Basic kinematic variants of O-X glide hybrid machine tools

Prepared prototypes of the machine with added rotary axes are shown in Fig. 4. The CAD model of the machine with the folded fourth axis, i.e. axis A' is given in Fig. 4 a), while the variant with rotating axis B' is given in Fig. 4b). The model of the added two-axis rotary table on the virtual prototype of the machine with rotations A'C' is given in Fig. 4c), while the variant when this table is rotated by 90^{O}, i.e. it has rotations B'C', is given in Fig. 4d).

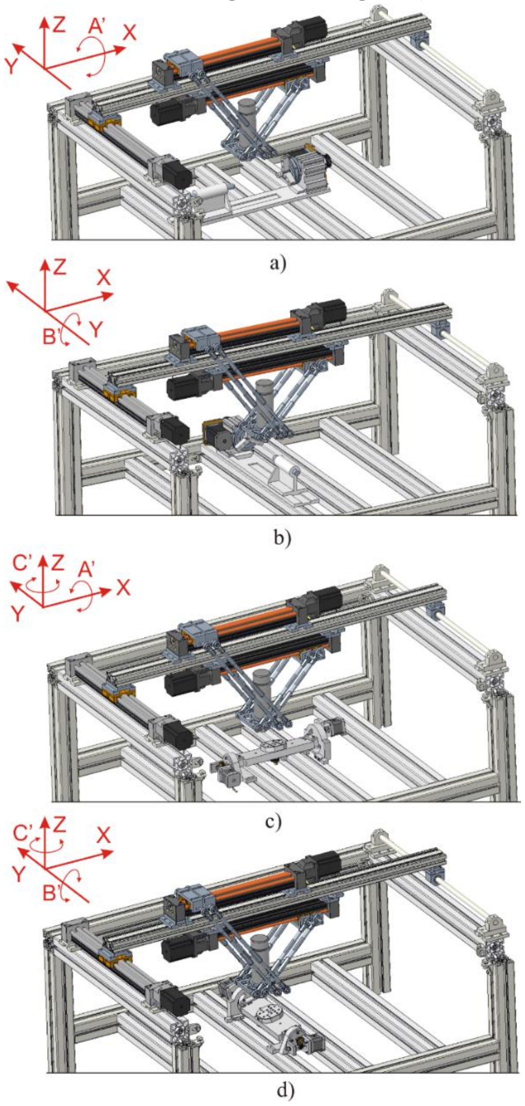

Figure 4. CAD variants of O-X glide hybrid machine tools with rotary axes

In order to check the possibility of using rotary axes within the limits of the available working space, a simulation of the selected workpiece machining was performed, which was shown in chapter 4.

4. MACHINE SIMULATION OF O-X GLIDE MECHANISM WITH ROTARY AXES

The verification of the operation of the machine with added rotating axes from Fig.2 was realized on a virtual prototype of the machine in the environment of the CAD/CAM system PTC Creo, which was used both for the development of the machines and for their programming.

During the development of the virtual prototype, a hybrid mechanism was modeled with all kinematic connections between the components, which give the possibility of moving the elements of the virtual prototype as a system of rigid bodies. Examples of such simulations can be seen in papers [7,10,11].

Fig. 5, presented the characteristic markings of the used kinematic connections, such as Pin, Slider, and Ball. This configuration of the machine assembly enables the movement of its moving components within the limits defined by the kinematic links, which is of particular importance for detecting possible collisions during the movement of the mechanism elements.

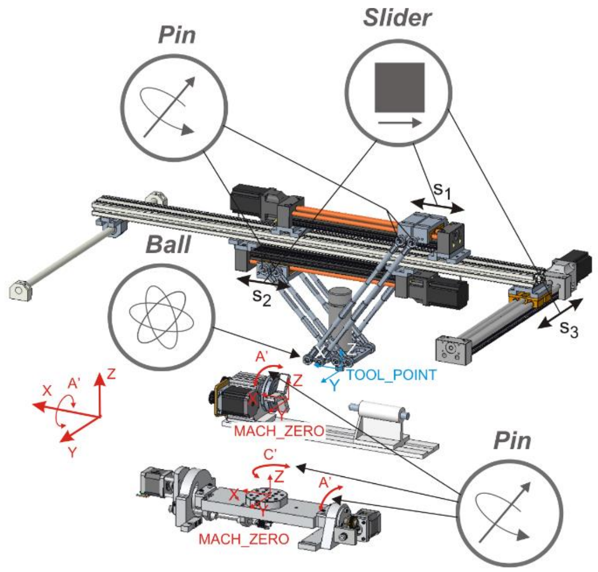

Figure 5. Coordinate systems

In the environment used for configuring the virtual prototype, it is possible to run a simulation of the operation of the virtual prototype that works according to the given control program, i.e. according to the defined path of the tool (Cutter Location File - CLF), in order to check the kinematics of the machine and possible collisions, as well as the feasibility and possibility of machining in the boundaries of the workspace.

On the virtual model of the workpiece, it is necessary to define the coordinate system MACH_ZERO. The coordinate system of the same name needs to be defined on that part of the virtual prototype of the machine that will carry the virtual workpiece, the chuck of the rotating axis or the work table of the two-axis rotating-tilting module (Fig. 5). The tool coordinate system is also defined on the virtual prototype of the machine, which is marked with TOOL_POINT and is located on the front surface of the main spindle. The Z axis of this coordinate system is directed in the direction of the tool axis, according to the rules for marking CNC axes.

Programming experiences with one horizontal axis of rotation can be seen in works [7,8], and here they are shown on the example of the considered machine with hybrid kinematics.

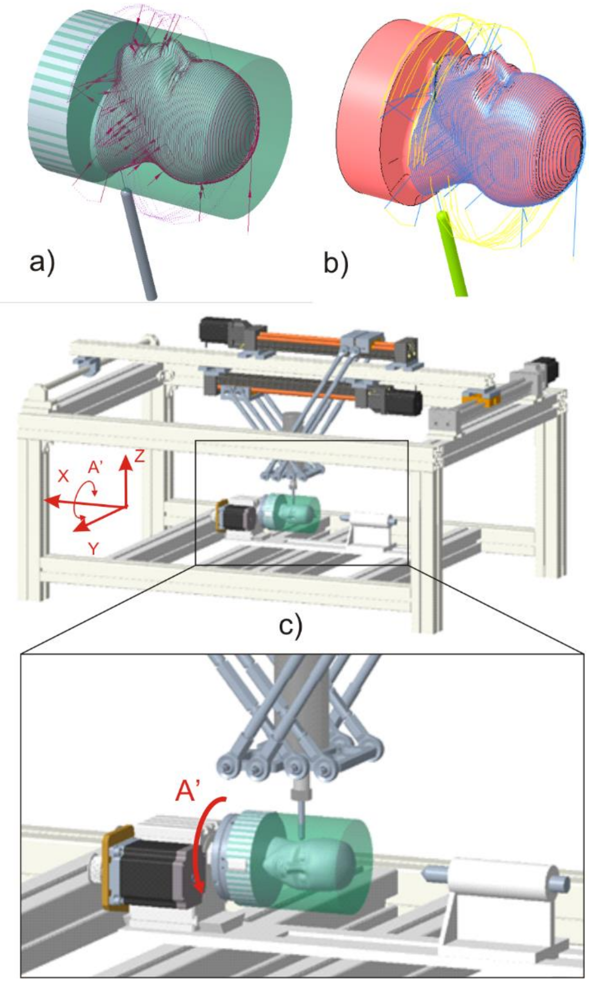

Figure 6. Machine simulation with rotary axis A’

Fig. 6 shows an example of the verification of the program for machining the model of the human head, which includes the simulation of the tool path (Fig. 6a), the simulation of material removal (Fig. 6b), and the simulation of the operation of the machine according to the given program with the rotary axis A' (Fig. 6c).

In Fig. 7 shows an example of simulation of five-axis machining of a convex calotte with rotating axes A' and C'.

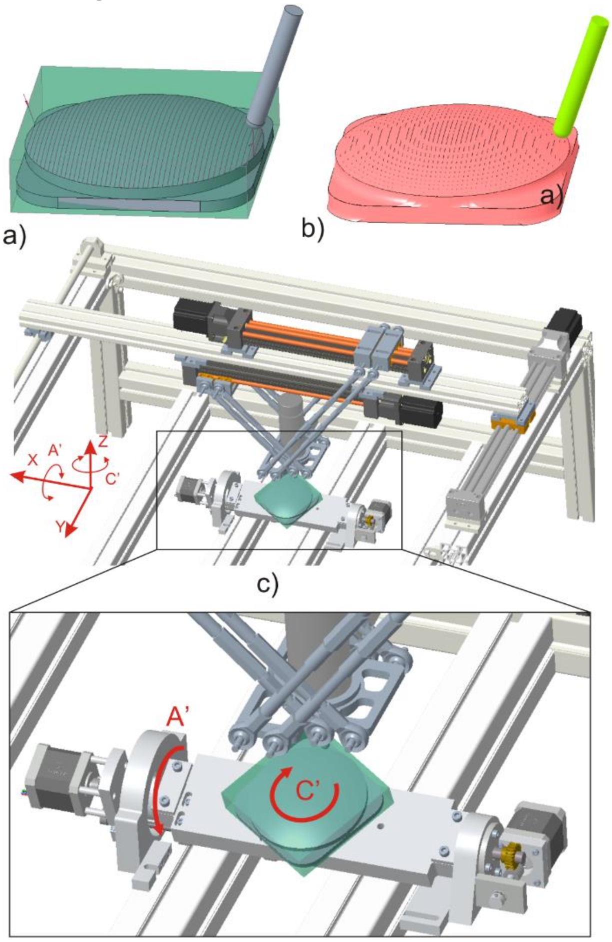

Figure 7. Machine simulation with rotary axes A’C’

Simulations of four-axis and five-axis machining in Figs. 5 and 6, the possibility of machining with additional rotary axes on the considered machine with hybrid kinematics was demonstrated and verified.

5. CONCLUSION

The paper shows the analysis of the upgrade of a three-axis machine with hybrid kinematics with additional serial rotary axes, so that the machine can be either 4-axis or 5-axis. Possible variants of adding rotary axes were considered with the analysis of machining simulations and the placement and basing of rotary axes, so as to check the possibility of machining within the limits of the available working space. The possibility of such machining was verified on a virtual prototype by simulations of the machine's operation when it works according to the set tool path (CLF). Experimental verification on a real machine is also planned in further research.

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