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THE DEVELOPMENT OF HEXAPOD KINEMATIC MACHINE

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ABSTRACT
At the University of Zilina is solved a project oriented on development of mechanisms with parallel and hybrid kinematic structure during the last three years supported by European found for regional progress. This paper describes some steps and particular results of development process of the first mechanism with hexapod kinematic structure. It is designed as a machine tool for 5D machining. Components and subsystems of machine tool are designed and chosen to meet required parameters of whole mechanism.
Keywords: parallel kinematic structure, control system, CNC machine tool

1. INTRODUCTION
Over the last fifty years the posed requirements for NC tool machines' conception have changed very quickly. Every year the productivity and parameters of machining got increased. There the idea to cut material with high level of cutting speed, so-called HSC (High Speed Cutting) was created. Progress of HSC was deeply wedded with the production in aeronautical and space industry.
Even though the high-speed integrated spindles and linear motors make it possible to reach highest cutting velocities and feed rates for HSC applications, the practice all utilization of these parameters is limited by mechanical problems of machines [8]. With respect to these limits of machine tools with conventional serial kinematics, it appears as better to use for HSC just the machines with parallel or hybrid kinematic structure. These mechanisms are characterized above all by higher stiffness and higher dynamic parameters (thanks to the reduced moving mass). Few years ago also a research group at the University of Žilina was started to deal with this field. During this period there were designed some construction concepts of PKS and different kind of simulation software for these types of mechanism.
One of the well-known fully parallel manipulator in general is called Hexapod. It has been investigated in many industrial applications such as machining or positioning. The machine tool with hexapod kinematic structure is also the subject of this paper.

2. DESIGN OF MACHINE TOOL BASED ON MECHANISM HEXAPOD
Hexapod known as Stewart platform too, is multi-axis machining centre capable of full six degrees of freedom (DOFs) motion plus spindle rotation at the tool head. Hexapod machines inherit all of the advantageous attributes of parallel mechanisms to enable more potential capabilities for manufacturing. Among these advantages, higher structural rigidity along with large payload capability and high speed motions will be capable for high speed and high accuracy machining.

2.1. The structure, whole design and cowling of a machine tool

Designed machine tool can be divided into the 6 basic features or subsystems:

- main frame
- moving platform wit main milling spindle
- telescopic actuators
- system of automatic tool changing
- system of automatic part changing
- electrical switchbox with control and power part

In figure 1, there is shown a basic structure of designed machine tool, the connection points, places for part changing by operator, moving platform with main milling spindle, electrical switchgear, etc. The main feature is a mechanism with PKS (hexapod) located in the middle of whole machine tool.

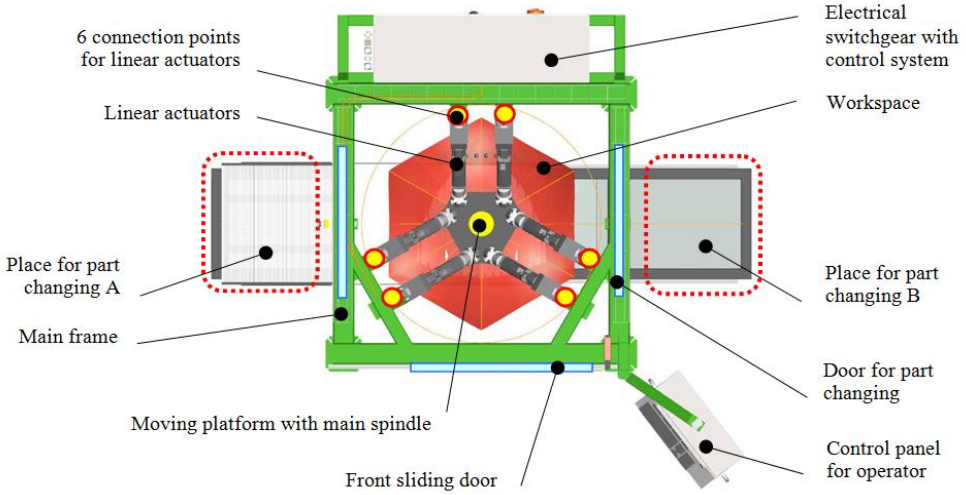


Figure 1. The structure of a machine tool based on parallel kinematic structure called hexapod.

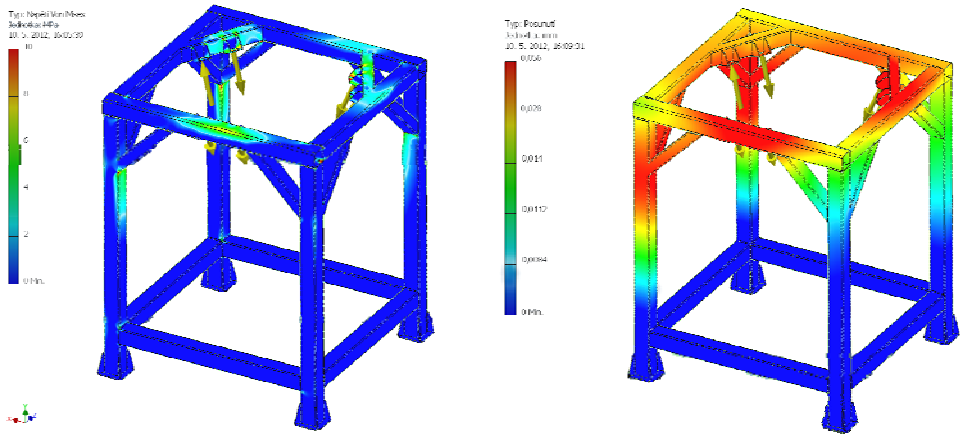
The view on a machine tool with and without cowling is shown in figure 2. A cowling (cover) protects the operator from injury and also the environment from pollution caused by the machining process (chips removed from workpiece and processing liquids). In the same time it creates the look of a machine. The cowling contains also three doors except the fixed sheet metal parts. The front face is covered by horizontally sliding door which is monitored by sensors and lock via safety lock Euchner TP3-4141. Both side-entries for part and workpiece changing are covered by two vertically sliding doors. Their position is monitored by two limit switches fixed on pneumatic actuators and also by independent safety switch Euchner NZ1WO.

a) b)

Figure 2. Design of a hexapod machine tool with (a) and without (b) cowling.

2.2. Main frame

Main frame was designed as a welded construction made of thin-walled steel profiles squared and rectangular sections. It contains six connection points for linear actuators connected to them by universal joints (each has 2 DOFs). Main frame has to restrain any forces and couples propagated from moving platform to the frame by 6 independent guiding chains contained linear actuators. Therefore we decided to carry-out stiffness analysis of a main frame. There we placed at least one force into the each connection point. Forces values are changing from 600 N up to 2000 N in both positive and also negative direction. Frame fulfills defined requirements. The results of a simulation are shown in figure 3, where we can see that the stress and deformations are within a permitted range.



a) b)

Figure 3. The results of a stiffness (a) and deformation (b) analysis of a main frame for hexapod.

2.3. Hexapod mechanism composed from telescopic actuators and motors

We selected linear actuators Exlar IX30 (fig. 4) for positioning and orientation of a moving platform. These actuators present a new range of alternatives for linear motion solutions. Compared to the low performance spur gears provided by most ball screw actuators, the I Series' planetary gears offer an extended life, high input speed and output torque and quiet operation. For its acting we selected the motor 1FT7 made by company Siemens. The main spindle made by company Suhner, type UAD 25-RF (1050W, 230V and revolutions: 3500 - 25000 min^{-1}) is fixed in the middle of the moving platform.

Figure 4. Linear electrically driven actuator Exlar IX30 with Roller Screw drive system [6]

Table 1. Basic properties of actuator Exlar IX30 [6] and motor Siemens 1FT7-034 [7]

Linear actuator Exlar IX30-1602								
Parameter	Continuous force (N)	Stroke (mm)	Speed at Max. Rated RPM ($mm.s^{-1}$)	Life at Rated Cont. Force (mm)	Screw lead (mm)	Allowable Continuous Input Torque (Nm)	Max Rated Input RPM (min^{-1})	Backlash (mm)
Value	4026	406.4	338	$136.5x10^6$	5.08	4.07	4000	preloaded

Motor Siemens 1FT7-034								
Parameter	Nominal power (kW)	Nominal output torque (Nm)	Nominal revolutions (min^{-1})	Accuracy	Increment number pre revolution (-)	Weight (kg)		
Value	1	2	6000	± 40"	2048	4		

2.4. Workspace of a machine tool based on hexapod

The shape and dimensions of a mechanism workspace by defined configuration of actuators and joints is shown in figure 5. Workspace has complex shape composed from several spherical sections. There can be placed the workpiece of quadratic shape with dimensions up to 400 x 400 x 200 mm.

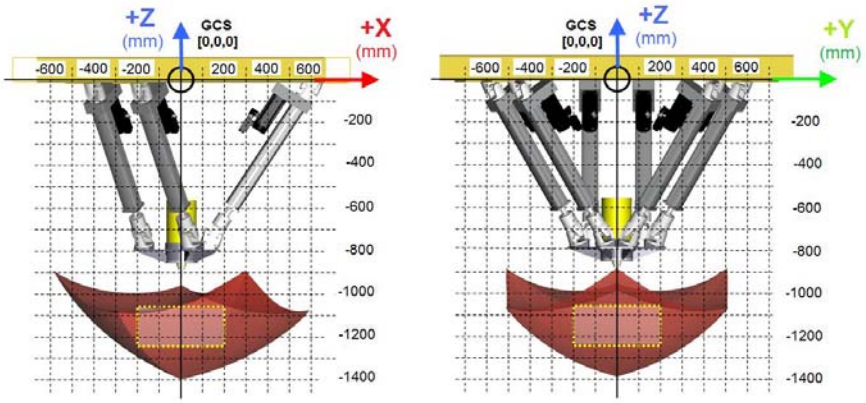


Figure 5. Workspace (by 0° tilt angle of moving platform) and dimensions of a workpiece

3. REFERENCES

Nowadays the mechanisms with parallel kinematic structure have become a common part of mechanical engineering praxis. They can be found in various equipments, but their most widespread applications are still machining and manipulation. One of the best known mechanisms with PKS is Hexapod. It can be considered as the general parallel mechanism with complex DOF because it produces 6 DOF of the general rigid body motion. At the University of Zilina we have decided to design and build a machine tool based on this kinematic principle. The particular results like information about the general structure, main frame, actuators and workspace are described in this paper.

4. ACKNOWLEDGEMENT

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