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DEVELOPMENT OF A NEW PARALLEL KINEMATICS MACHINE TOOL

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Abstract

Development of the computer techniques has made possible the application of a new machine tool construction, the parallel kinematics. Hexapod robots can be used in several fields of the manufacturing and robotics. On the TU Budapest, Department of Manufacturing Engineering, we have developed a new 3 leg-parallel kinematics machine tool, we described the mathematical model of the kinematics, and completed the design necessary for the production. This paper gives summary about the parallel kinematics and our development activity.

Keywords: Hexapod, parallel, Tripod, machining, robot.

1. Introduction

Conventional machine tools use either orthogonal or rotational movements. They are often combined in a series of discrete stages, each providing a degree of freedom. The hexapod differs in that all six degrees of freedom are enabled by a parallel arrangement of variable length struts. For any given set of strut lengths there is a single fully constrained position for the mechanism. Controlling the legs enables the platform to be simultaneously positioned and orientated.

2. HEXAPOD Machines

The most important properties of the industrial robots are the high speed, fast acceleration and a large working area compared with machine tools. Whereas conventional machine tools have a greater load capacity and stiffness, but the speed and the working area is smaller. Parallel kinematics combines successfully these properties. The kinematics is very simple, and it consists of three sections

- Struts (legs), which can change their length
  Generally ballscrews are used as these struts.
- One fixed and a movable platform

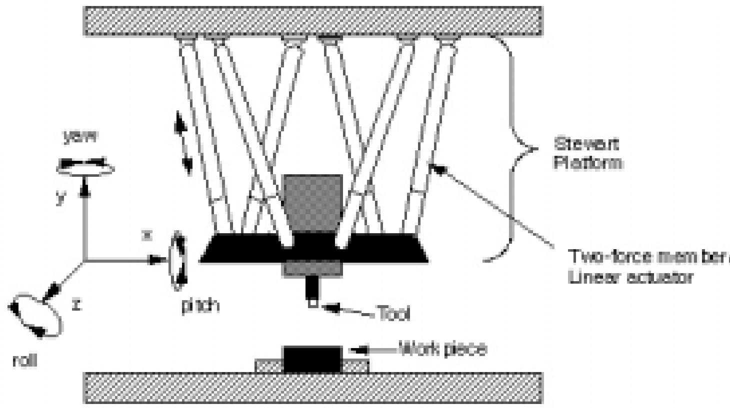

Fig. 1. Schematic of a hexapod six-axis machining center

- The fixed platform serves as a rigid frame, which does not deflect under load, and this platform contains the drive mechanism. The ballscrews joint at the moving platform and this platform gives place to the main spindle, gripper or any other unit (LASER or waterjet).
- Joints, connect the legs and transfer the load and energy.

The advantages of the parallel kinematics are reduction of moving masses and a higher stiffness.

Bending moments do not take effect or they are minimized, therefore a small diameter strut can be used to make a stiff structure. Struts under compression have a tendency to buckle, usually it sets limit to the load.

Conventional machine tools often have to move the heavy slides and the workpiece. The masses of the moving platform and the struts are the tenth of the conventional machine tool's or less. By reducing the mass of moving parts a very high acceleration can be achieved.

The disadvantage is the relatively small rotating range of the moving platform. Therefore an additional rotating head unit with two rotating freedom is applied. It makes the kinematics redundant and the control system complicated. Due to the kinematics of the hexapod even a simple linear movement requires the simultaneous control of 6 axes. The necessary calculations can only be carried out by high-performance CNC controllers.

The typical applications are rapid metal prototyping and HSC, multi-axis milling and grinding, drilling at compound angles.

The ability to scale the hexapod allows large format machines to be constructed.

Because of the high speed and the fast acceleration hexapods can be used as industrial robots, for carrying heavy load, or they can be applied for waterjet or LASER cutting.

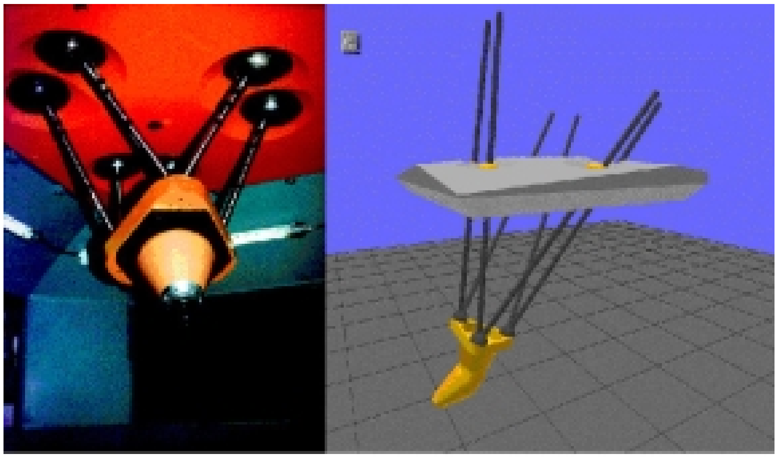

Fig. 2. Typical hexapod machine tools

3. 3-Leg Robots

If only 3 legs and a rotating head with 2 or 3 degrees of freedom is used, the kinematics and the control unit become simpler. With 3 struts only 3 degrees of freedom can be realized. Using an additional rotating head unit a 5-axis movement can be accomplished.

The disadvantages of these kinematics are the following:

- Weak torsion rigidity
- The struts have to take the torsion load as a bending moment.
- Less load can be allowed because of the bending moment.

4. Construction of a TRIPOD robot

On the TU Budapest, Department of Manufacturing Engineering I have developed a new 3 leg-parallel kinematics machine tool.

In order to test the kinematics I have produced a model with the same kinematical constraints as the final equipment will possess, and I have done the computer based simulation of the robot. According to the model and the simulation the mechanism is kinematically definite, and it can be realized.

The TRIPOD robot consists of 3 main parts: The fixed platform contains the bearings of the ballscrews, the drives and the 2-axis of freedom cardan joints. We use SINCROLFEX belt between the ballscrew and the servo drive..

The moving platform includes a one- and a 2-axis of freedom joint. One of the legs is fixed, the second and the third connect to the one-axis of freedom joint and

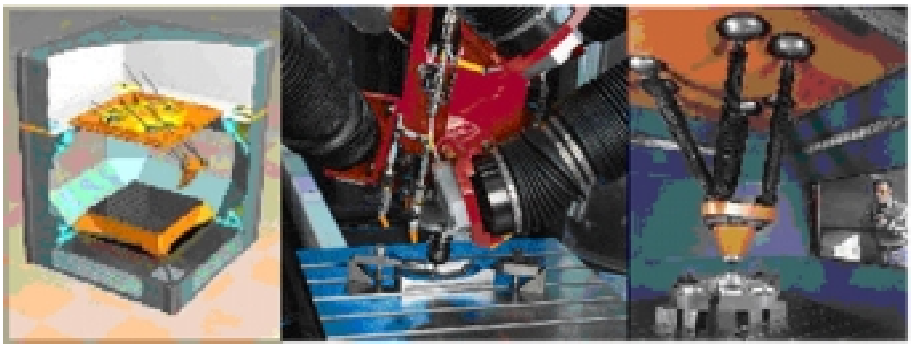

Fig. 3. Application of a hexapod robot for HSC

a cardan joint. This construction enables a 3D movement for the moving platform, but the orientation of the platform depends on what position it is in. We realize the 5-axis of freedom movement with the help of an additional rotating head unit.

5. The Mathematical Model of the TRIPOD Robot

For the calculation of the inverse kinematics the input data are X, Y, Z, A, B where

- X, Y, Z are the co-ordinates of the programmed point
  A, B are the rotation angles of the additional rotating head unit
- The length of the fixed platform: L_0
- The length of the struts: L_1, L_2, L_3

  The coordinates of **a, b, c** vectors:

$$\mathbf{c} = \begin{vmatrix} x \\ y \\ z \end{vmatrix}, \tag{1}$$

$$\mathbf{a} = \begin{vmatrix} L_0 \\ 0 \\ 0 \end{vmatrix}, \tag{2}$$

$$\mathbf{b} = \begin{vmatrix} \frac{L_0}{2} \\ \frac{3}{2}L_0 \\ 0 \end{vmatrix}. \tag{3}$$

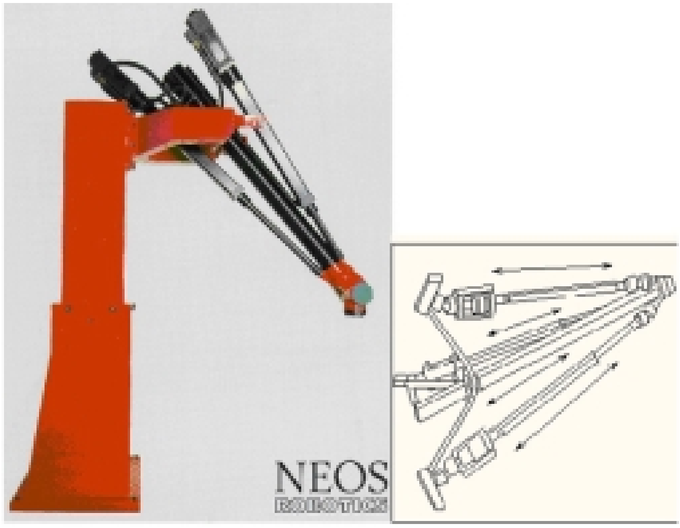

Fig. 4. The 3-leg robot of the NEOS Company

- The rotation angles of the additional rotating head unit are:
  $\alpha' = A - \alpha,$
  $\beta' = B - \beta.$

where $\alpha = \mathrm{arctg}\frac{x}{y}$ and $\beta = \mathrm{arctg}\frac{z}{\sqrt{(x^2+y^2)}}$.

- The projections of the rotating head unit are:

$$\begin{aligned} x' &= L \cdot \cos B \sin A, \\ y' &= L \cdot \cos B \cos A, \\ z' &= L \cdot \sin B, \end{aligned}$$

where the L is the length of the rotating head

- From the formulas (1) (2) (3) you can get formula (4), (5), (6)

$$L1 = \begin{vmatrix} x - L_0 \\ y \\ z \end{vmatrix}, \tag{4}$$

$$L2 = \begin{vmatrix} x - \frac{L_0}{2} \\ y - \frac{\sqrt{3}}{2} L_0 \\ z \end{vmatrix}, \tag{5}$$

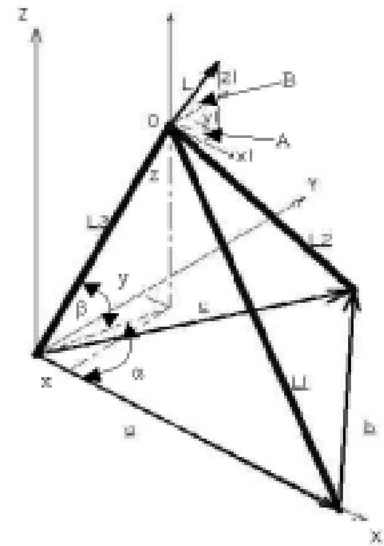

Fig. 5. Schematic model of the tripod kinematics

$$L3 = \begin{vmatrix} x \\ y \\ z \end{vmatrix}. \tag{6}$$

- From *Eqs.* (4), (5), (6) you can get the length of the struts:

$$L1 = \left(\frac{L_0}{2} - x\right)^2 + \left(\frac{\sqrt{3}}{2}L_0 - y\right)^2 + z^2, \tag{7}$$

$$L2 = (L_0 - x^2) + y^2 + z^2, \tag{8}$$

$$L3 = x^2 + y^2 + z^2, \tag{9}$$

where

$$\begin{aligned} x &= X - L \cdot \cos B \cdot \sin A, \\ y &= Y - L \cdot \cos B \cdot \cos A, \\ z &= Z - L \cdot \sin B. \end{aligned}$$

We solved the inverse kinematics with a LabVIEW program. This program calculates the lengths of the struts. The input data are the x, y, z coordinates of the programmed point of the moving platform. The output data are the lengths of the struts, the necessary extension of the legs and the axial speed of the ballscrews.

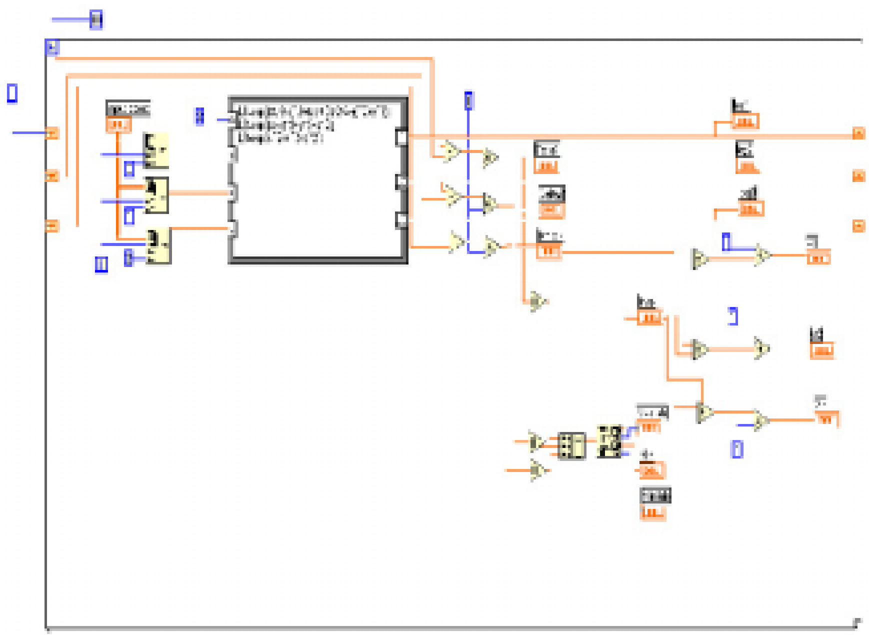

Fig. 6. The LabVIEW program

Fig. 7 shows the computer simulation of the 3-leg robot. We used the SOLID EDGE CAD program for the simulation using the data from the LabVIEW. The design of the mechanism and the computer simulation of the kinematics are completed, and the realization of the machine is in progress. Preloaded ballscrews are applied as struts, which were placed at our disposal by SKF. Further task is to compare the accuracy of the realized machine with the estimation of the computer simulation. We are planning to apply this new robot construction for Rapid Prototyping and 5D machining operations.

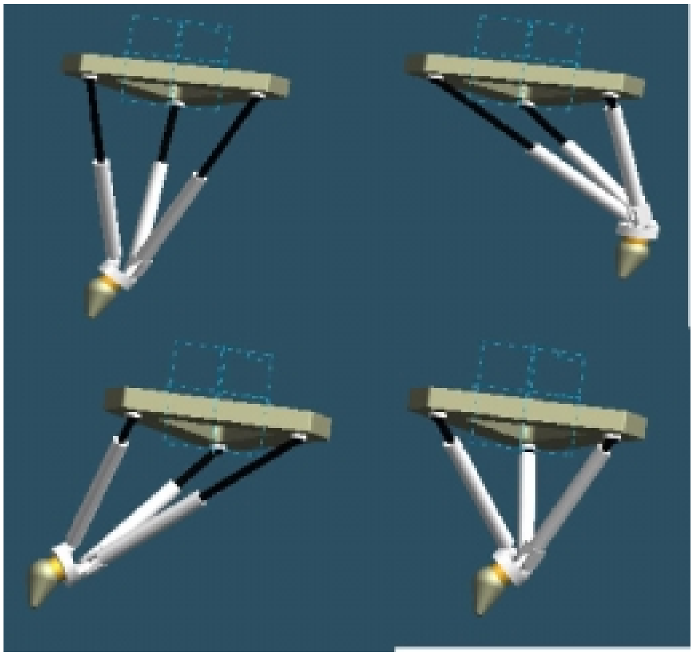

Fig. 7. The schematic model in SOLID EDGE

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