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Determination of Static Error of the Machine with Parallel Kinematics

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Abstract: This article is devoted to improve the accuracy of the final machining of details with complex geometry. Shown that in the processing of complex details of small and large size is the most important task of improving high-speed milling based on the new processing technologies using parallel kinematics machines. In this article considered class machines with parallel kinematics, an example of such a processing unit of the machine. Shown that important problem at creation machine tools with parallel kinematics to provide desired machining precision. The analysis methods for improving the accuracy of machine tools with parallel kinematics and their classification. Defined center of the positioning error of movable platform. Presents an algorithm that allows us to calculate the error caused by tool offset by the force of the cut. Based on the proposed algorithm, a program in Matlab to find errors caused by tool offset by the force of the cut. Received by the program in Matlab were built according linear and angular displacements of the center platform of cutting forces.

Key words: Machine with parallel kinematics · High-speed machining · Precision machining · Error · Cutting force algorithm.

INTRODUCTION

Lately in the areas of engineering, as aircraft construction, shipbuilding, automobiles, observed trends in the use of new materials: composites, high-strength, plastics, transition from prefabricated parts to monolithic [1, 2]. This, in turn, creates new challenges for machine tools, in particular significantly increase metal removal rate in the processing of aluminum alloy particularly large size and complex configuration. Priority metalworking industry in this regard is to achieve high-performance processing of materials with strict compliance level of product quality. And one of the main focuses here is considered high-speed machining (HSM).

Main Part: Improving performance when processing is achieved through the use of higher cutting speeds that are two to three times higher than the normal (Fig. 1). For small sections cut in the speed range most of the heat concentrated in the chip, without having to go into the workpiece.

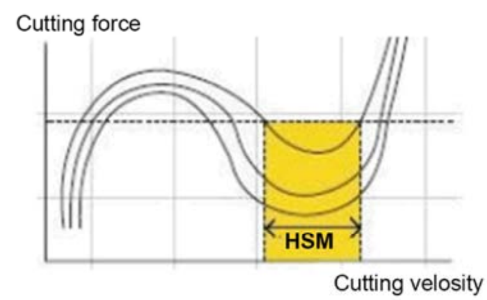

Fig. 1: Dependence cutting forces cutting speed

Basic principles of high speed maching (Fig. 2): a small section of a cut taken from the high-speed cutting, high speed spindle and high minute presentation.

In the requirements for machine tools for high speed machining appears related to the speed of the mechanical and control systems: spindle speed up to 40,000 rev/min, the power of the main drive of more than 22 kW, the speed programmed innings - 40 to 60 m/min moves fast rate - 90 m/min, resolution - from 5 to 20mkm axial acceleration / deceleration> 1g, NC speed - from 1 to 20 ms data baud

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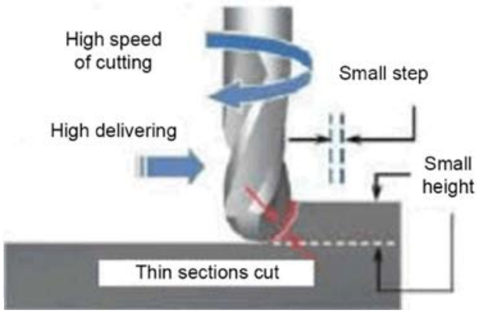

Fig. 2: Cutting parameters for high speed machining

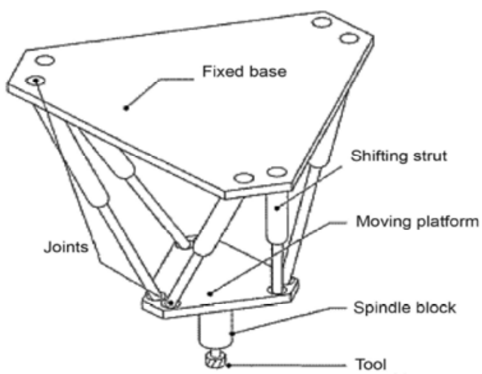

Fig. 3: Processing module machine with parallel kinematics.

rate - 250 kbit/sec (1 ms), high stiffness and heat resistance spindle, high preload and good cooling spindle bearings, spindle blowing air or liquid cooled, rigid frame machine with the ability to absorb vibrations, different error compensation - temperature, lead screw, - the ability to install more sophisticated and advanced CNC systems.

Obviously, machining centers with a rectangular coordinate system, supplemented by additional processing for the bulk coordinates, in the processing of such high feed its large inertia, not always able to implement new technology in a complex product configuration.

Meet these requirements with parallel kinematics machines, which first appeared in 1992 and has since firmly fill its place in the production of [3-6].

Fig. 3 shows an example of such a machine processing module with six degrees of freedom. The module is a fixed base, coupled with a mobile platform with six sliding rods with hinges on the ends. Located on the movable platform with the tool spindle unit.

The innovative character of machine tools with parallel kinematics, in addition to originality, is determined by their significant advantages in some areas before use machines with traditional kinematics, namely:

- Optimal conditions for the implementation of high-speed processing;
- A significant simplification of the design (simple frame, a significant decrease in the number of units and the total number of parts, all drives and move nodes measuring systems are the same, the frequency components);
- Significant reduction of the total weight of the machine;
- Bars only work on tension-compression, no flexure load;
- High stiffness of the support system;
- Easy to assemble the machine.

Using with parallel kinematics machines mainly limited to finishing parts with complex three-dimensional surfaces, such as stamps, molds, blades of aircraft engines.

Important when creating machines with parallel kinematics is the problem of second accuracy. Under precision machining is known to understand the extent to which manufactured parts specified size, shape and relative position of the surface.

For machines with parallel kinematics consider the following measures of accuracy:

- Static error handling defined in the processing of the workspace with stock and immutability of all external influences on the system;
- Stationary dynamic error handling, in particular surface error arising due to forced oscillations;
- Transient dynamic processing error resulting from deformities and other abnormalities in the system transients, such as insertion and output tools;
- Dynamic random error handling, which is a corollary effect on the system of various external factors, random nature.

Since the absolute values of the exponent y quality cannot be achieved, evaluate the significance of the error parameters. Under an error processing understand the deviation of the processing of e values or other geometric parameters of the set.

With tanks with parallel kinematics are oh precision equipment used in the most responsible and finishing operations, ensuring high accuracy. Thereby eliminating the influence of the majority of the dynamic parameters, since such operations cutting forces are relatively constant and differ only in the direction of the resultant.

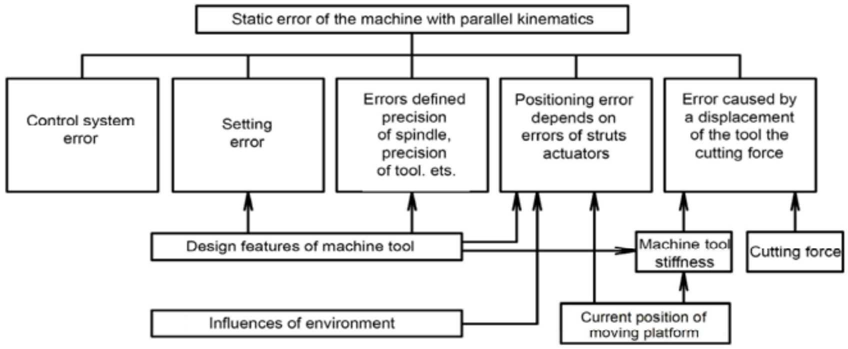

Fig. 4: Static accuracy of machine tools with parallel kinematics and its components

Static error handling in turn can be divided into its constituent error (Fig. 4).

Let us dwell on the components of the static error of robot with parallel kinematics machines and related factors have the greatest influence on their values:

- Error management system: The main factor influencing this error is the accuracy of the sensors used feedback. This component from further consideration can be excluded.
- Setting error, which include: error Position the workpiece on the desktop, setting error tool holder, etc. The main factors influencing this type of error are the design features of the machine. These errors can be compensated by the calibration of the machine prior to the beginning of the processing details. These components are static error from further consideration can be excluded.
- Errors defined precision spindle assembly, precision Hinge geometrical shape and precision used metal cutting tools. The definition of this static component of accuracy, the main factor is the precision components and tools used. These components from further consideration may also be deleted.
- Positioning error center movable platform depends on factors such as:

- Error departure rod;
- Structural features of the machine;
- Orientation of the mobile platform of the machine.

The error caused by a displacement of the tool the cutting force is dependent on factors such as:

- The magnitude of the cutting force and its direction;
- Rigidity of the machine.

In turn, the cutting force value depends on the selected cutting mode and its direction from the cutting mode is selected, selection of processing path and form a processed surface.

Stiffness is also one of the main characteristics of the machine vibration resistance [7, 8].

Stiffness parallel kinematics machine depends on several factors simultaneously:

- Sliding rods rigidity (depending on the characteristics and lengths of the rods and also the rigidity actuators);
- Structural features of the machine;
- Orientation of the mobile platform of the machine.

Improving machining accuracy can be achieved by improving the accuracy of each of the error components, reducing the number of components, decrease the sensitivity of the system to an input to the application of the automatic cancellation of all or the major components of the error.

Precision machine tools with parallel kinematics can be achieved in the following ways (Fig. 5):

The most common methods of ensuring the accuracy of machine tools with parallel kinematics are structural [9] and parametric synthesis.

Consider the components that contribute most to the total error.

Calculation scheme for positioning error can be the center of a movable platform is shown in Figure 6.

Positioning error can be the center of a movable platform according to the following equation:

$$\Delta\vec{P} = J \cdot \Delta\vec{q},$$

where $\Delta\vec{P} = [\Delta x, \Delta y, \Delta z, \Delta\varphi, \Delta\psi, \Delta\theta]^T$ - positioning error vector center of the platform;

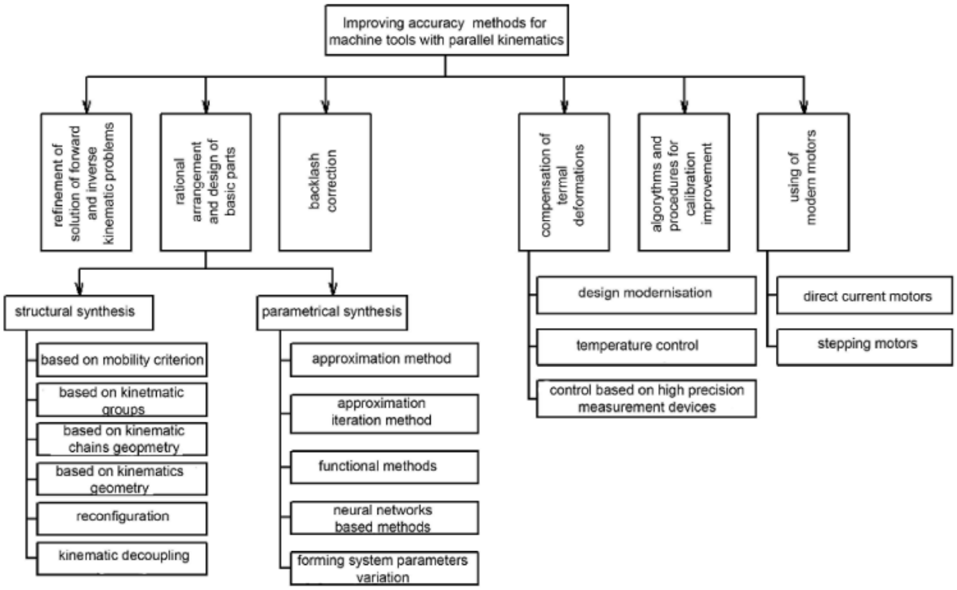

Fig. 5: Methods to ensure the accuracy of machine tools with parallel kinematics

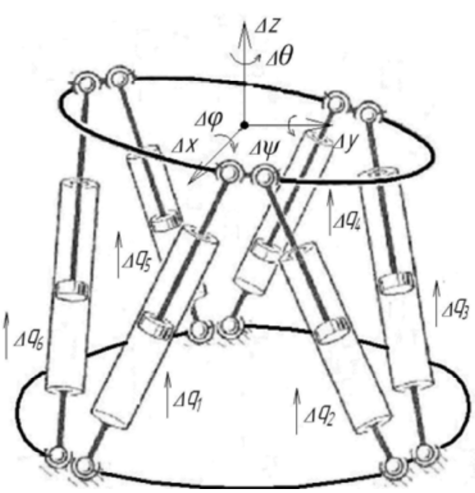

Fig. 6: Calculation scheme for positioning error can be the center of a movable platform

J - Jacobi matrix;

$$J = \begin{bmatrix} \frac{\partial f_1}{\partial q_1} & \frac{\partial f_1}{\partial q_2} & \frac{\partial f_1}{\partial q_3} & \frac{\partial f_1}{\partial q_4} & \frac{\partial f_1}{\partial q_5} & \frac{\partial f_1}{\partial q_6} \\ \frac{\partial f_2}{\partial q_1} & \frac{\partial f_2}{\partial q_2} & . & . & . & \frac{\partial f_2}{\partial q_6} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ \frac{\partial f_6}{\partial q_1} & \frac{\partial f_6}{\partial q_2} & \frac{\partial f_6}{\partial q_3} & \frac{\partial f_6}{\partial q_4} & \frac{\partial f_6}{\partial q_5} & \frac{\partial f_6}{\partial q_6} \end{bmatrix}$$

where $\begin{cases} q_1 = f_1(x,y,z,\varphi,\psi,\theta), \\ \vdots \\ q_6 = f_1(x,y,z,\varphi,\psi,\theta) \end{cases}$ - length of rods.

$\Delta\vec{q}_i = [\Delta q_1, \Delta q_2, \Delta q_3, \Delta q_4, \Delta q_5, \Delta q_6]^T$ - vector of error rods, where [Delta] q - flight error rods, which is dependent on its design.

When known errors departure rods Δq. You can determine the error of the output link ΔP. Conversely, setting the desired error ΔP calculate error Δq which is necessary to provide.

Thus, to solve the problem of precision machine tools with parallel kinematics is necessary to solve the direct and inverse problems and kinematics. Solve problems kinematics possible methods Denavit-Hantenberg (matrix), geometric, with a screw and a vector. For solving the direct kinematics problem you need to know the geometric parameters of the machine (such as the radius of the base and the mobile platform, the maximum and minimum radius rods, the height of the machine) and to solve the inverse enough to know the trajectory of the platform.

The error caused by a displacement of the tool under the influence of an applied force can be obtained from equation [10]:

$$\delta\vec{P} = K_c^{-1} \cdot \vec{F}_p$$

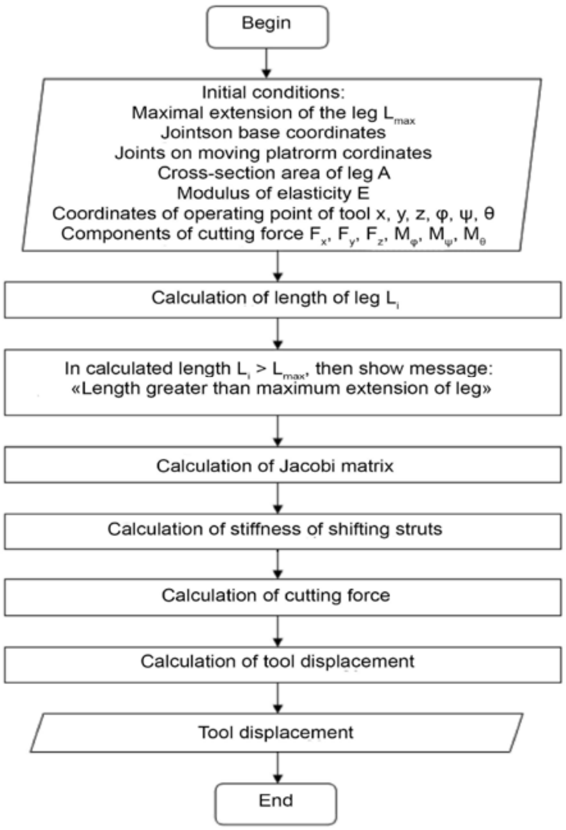

Fig. 7: Block diagram of the algorithm is a calculation and error.

where K_c^{-1} - stiffness matrix machine with parallel kinematics; $K_c = J^{-T} \cdot K_s \cdot J^{-1}$ spatial stiffness matrix mechanism Cartesian base where k_s - spatial stiffness matrix translational and spherical mechanism

$$K_s = \begin{bmatrix} j_{H1} & 0 & 0 & 0 & 0 & 0 \\ 0 & j_{H2} & 0 & 0 & 0 & 0 \\ 0 & 0 & j_{H3} & 0 & 0 & 0 \\ 0 & 0 & 0 & j_{H4} & 0 & 0 \\ 0 & 0 & 0 & 0 & j_{H5} & 0 \\ 0 & 0 & 0 & 0 & 0 & j_{H6} \end{bmatrix}$$

where j_{Hi} - stiffness of the rods, $\vec{F}_P = \left[F_x, F_y, F_z, M_x, M_y, M_z\right]^T$ - cutting force.

Block diagram of the algorithm is a calculation error and caused displacement of the tool under the action of the cutting forces is shown in Fig. 7.

In the basis of the proposed algorithm and the composition of the county programs in Matlab to find errors caused by tool offset by the force of the cut.

Received by the program in Matlab were built according to the following:

- Dependence of the linear displacement of the Center platform from the cutting force Fz
- Dependence of the angular displacement of the platform from the center of the cutting force Fz

Resume: Finally, it should be noted that t Quantizing strength treatment is the main indicator of the quality of the technological system. The greatest influence on the static error have: error center of the platform, I induced error sliding rods and error caused displacement of the tool under the influence of cutting forces. The most common methods of ensuring the accuracy of machine tools with parallel kinematics are structural and parametric synthesis. Reduced block diagram allows to make a program for calculating the error caused by the displacement under the action of the cutting force. Upon receipt of the program in Matlab built following dependencies: linear displacement of the center of the platform from the cutting force and the dependence of the angular displacement of the platform from the center of the cutting force.

CONCLUSIONS

Obtained According to the Following Conclusions:

- Linear displacement error increases with the cutting force, so it is recommended to use with parallel kinematics machines for high-speed processing when the cutting force is small.
- Angular displacement of the center platform so small that they can be disregarded.

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