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EXPERIMENTAL VERIFICATION OF THE STRUCTURAL AND TECHNOLOGICAL PARAMETERS OF THE PKS

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Abstract. This paper presents the theoretical design for experimental verification of the structural and technological parameters of the Parallel Kinematic Structure. The experimental equipment was developed at the Faculty of Mechanical Engineering, STU in Bratislava. It is called Tricept, and due to its kinematics it is classified as a parallel structure. The previous phase of the project dealt with developing a mathematical model of the tool path. We have worked with two methods, a Monte Carlo method and the use of a mathematical analytical geometry structure. The calculated values were verified by comparing the results of the two methods. Based on the equations that were obtained, we can design the control of the tool path during cutting.

The next stage focuses on the test methods and on verifying the structural and technological parameters of Tricept. The experiment is designed on the basis of the EN ISO 9283 standard, and involves testing the technological parameters: one-way positioning accuracy and repeatability of the position, changes of multidirectional positioning accuracy, repeatability and accuracy of the distance, position overshoot, drift of the position parameters, path accuracy, and repeatability of the path. This paper classifies the measurement methods and presents the measurement processes and the equipment for the experiment.

Keywords: parallel kinematic structure, quality, positioning accuracy, repeatable positioning accuracy, design of the experiment.

1. Introduction

The current trend is toward high-speed machining, which encourages the development of machine tools with high dynamics, improved rigidity and reduced moving masses. In general, parallel robots — the basic mechanical tool — are referred to as parallel kinematic machines. Parallel kinematic mechanisms offer higher stiffness, lower moving mass, greater acceleration, potentially higher precision, lower installation requirements, and greater mechanical simplicity than existing conventional machine tools.

On the basis of these attributes, parallel kinematic mechanisms offer the potential to change current production forms. They have the potential to be highly modular, highly configurable, high-precision machine tools. Other potential benefits are high dexterity, simpler and smaller tools, a multiple mode of production capacity, and a small footprint.

Conventional machine tools are usually based on a serial structure. There are as many degrees of freedom as necessary, and the axes are arranged in series. This results in a single kinematic chain. The axes are generally arranged by Cartesian axes, which means that there is an x-axis, a y-axis and a z-axis, and rotation axes if necessary. These machines are easy to handle, because each axis directly controls one Cartesian degree of freedom, and there is no connection between the axes. Parallel kinematic machines are machines in which the movement of the tool is based on the principle of parallel mechanisms. A parallel mechanism is a closed mechanism, in which the end-effector (the mobile platform) is connected to the base by at least two independent kinematic chains.

2. Tricept

Research being carried out at the Institute of Manufacturing Systems, Environmental Technology and Quality Management is developing a parallel kinematic structure of the Tricept type. A fixed platform is connected with a moving platform with three telescopic rods with drives and one central rod without any drive.

Between the moving platform and the central rod there is a fixed connection. The central rod placed on the fixed platform allows translational motion without any turning.This type of mechanism is created from kinematic pairs of HPS type (universal, sliding and spherical joints).

The universal joint is formed by two swivel joints. Its role is to transmit the rotary motion of the telescopic rod, with sufficient accuracy, stiffness and low friction in the joint. The location of the primary points is important in creating the program that will be used to manage the ejection of the telescopic rods. The movement of these swivel joints is ensured by a pair of bearings, which are located in an axis perpendicular to another pair of bearings. The bearings

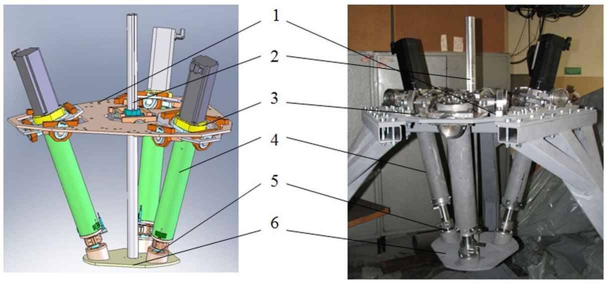

Figure 1. A computer model and a real model of Tricept: 1–solid platform, 2–central pole, 3–universal (primary) joint, 4–telescopic pole, 5–spherical (secondary) joint, 6–movable platform.

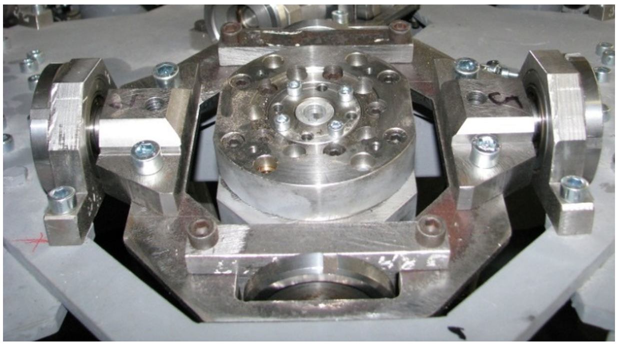

Figure 2. Primary joint.

allow smooth and accurate turning of the telescopic rods, which are connected by universal joints to the fixed platform of the mechanism.

The sliding joint is formed by a telescopic rod that transmits the rotary motion of the motor to the moving platform. The telescopic rods are the most important and the most exposed parts of Tricept. They convert the rotary motion of the actuator into linear motion. Ejection is performed by the inner cylinder, which ejects from the outer cylinder. The inner cylinder is fixed with one part fixed on the platform secondary joint onto the carrier. The outer cylinder is fixed by the primary joint onto the fixed platform. The inner cylinder is slidably placed in the outer cylinder. As both rods are slim, the telescopic rods are the most stressed parts. The accuracy of the bars has the greatest effect on the final position of the tool. The telescopic bars are stressed in terms of force transmission, and they are also sensitive to phenomena arising from long and slim rods. They are also stressed to buckling and, in a wide temperature range, also to shortening and lengthening as a result of thermal expansion. The telescopic rod is created by a moving screw. It can be ejected a distance of 300 mm.

The ball joint transmits the movement of the telescopic rods to the carrier. It must allow spherical motion of the telescopic rod against the carrier. Not only the functions of the joint are important, but also its location on the carrier. The location must be as close to the center of the carrier as possible.

Figure 3. Pull-rod of the Tricept.

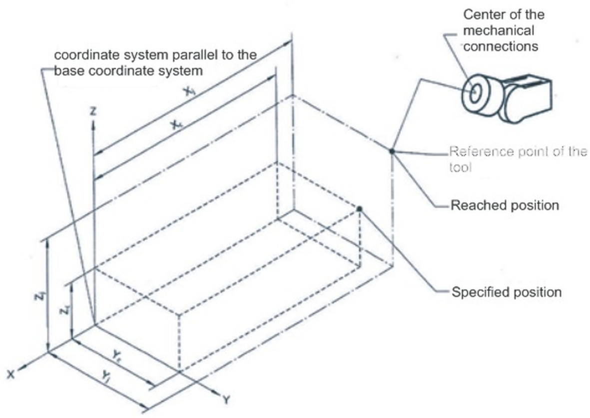

Figure 4. The relationship between the specified position and the reached position.

We therefore we reduce the dimensions of the carrier, and this minimizes the secondary circle.

Previous analyses have shown that the location of the joint is also important in terms of the tensions that arise. The incline of the telescopic rods to the central rod is important for the tensions. The smaller the incline is, the greater tensions are generated in the telescopic rods with the same force applied. A dynamic analysis shows a minimum incline of the telescopic rod to the central rod, which must be maintained even in the most unfavorable position. If the inclination is lower, the tension in the rods will increase significantly. The ball joint itself is formed by a spherical pin fastened in a bed with the inverse shape of the pin. To make it simple, it contains no rolling elements but is secured slidably.

3. The basic concepts

Desired (Programmed) Position — a position determined by programming with learning, manual data entry or explicit programming.

The programmed (desired) positions for robots specified using programming with learning must be defined as a measuring point on the robot. This point is obtained when programming a robot that approximates the points in a cube (P_1, P_2, etc.). When the accuracy calculation is based on the successive positions that are reached, the coordinates expressed by the measuring system are used as the programmed positions.

Reached Position — the position reached by the robot in automatic mode in response to the programmed position (see Figure 4).

The parameters of accuracy and position repeata-

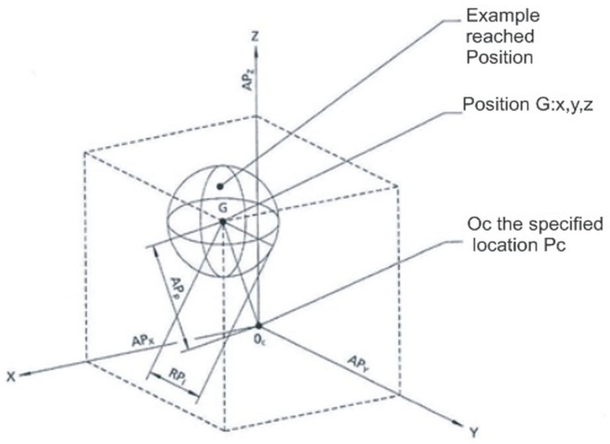

FIGURE 5. Unidirectional positioning accuracy.

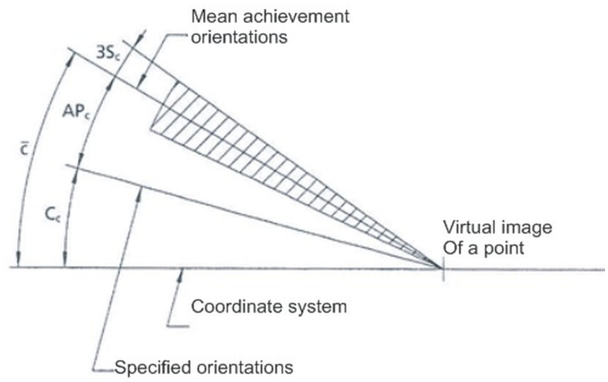

FIGURE 6. Unidirectional orientation accuracy.

bility express deviations that occur between the desired position and the reached positions, as well as variations in the reached position in a series of runs to the programmed position. These errors may be due to the properties of internal control functions, coordinate transformation errors, differences between the dimensions of joint structures and the dimensions used in the control system model, mechanical failures such as backlash, hysteresis, friction and temperature.

The method for recording data on the specified position is associated with options for controlling the robot, and significantly affects the parameters of accuracy. For this reason, the chosen method must be clearly stated in the protocol on the implementation of the test. If the desired position is programmed with explicit programming, the relationship (distance and orientation) between the different specified positions is known or can be determined, and is required for specifying and measuring the distance parameters.

4. Positioning accuracy and position repeatability

4.1. Unidirectional positioning accuracy

Unidirectional Positioning Accuracy (AP) expresses the deviation between the desired position and the diameter of the reached positions when moving to the desired position in the same direction. Unidirectional Positioning Accuracy. We distinguish:

unidirectional positioning accuracy — the difference between the desired location and the barycenter of the set of reached points (see Figure 5);

unidirectional orientation accuracy — the difference between the programmed orientation and the mean value of the achieved angular orientation (see Figure 6).

Unidirectional positioning accuracy is calculated as follows:

$$AP_p = \sqrt{(\bar{x}-x_c)^2 + (\bar{y}-y_c)^2 + (\bar{z}-z_c)^2},$$

$$AP_x = \bar{x} - x_c, \qquad \bar{x} = \frac{1}{n}\sum_{j=1}^{n} x_j,$$

$$AP_y = \bar{y} - y_c, \qquad \bar{y} = \frac{1}{n}\sum_{j=1}^{n} y_j,$$

$$AP_z = \bar{z} - z_c, \qquad \bar{z} = \frac{1}{n}\sum_{j=1}^{n} z_j,$$

where $\bar{x}$, $\bar{y}$, $\bar{z}$ are the barycentric coordinates of a set of points obtained by repeating the same location n-times, x_c, y_c, z_c are the coordinates of the programmed (specified) position, and x_j, y_j, z_j are the coordinates of the reached position.

Unidirectional orientation accuracy is calculated as follows:

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$$AP_a = \bar{a} - a_c, \qquad \bar{a} = \frac{1}{n}\sum_{j=1}^{n} a_j,$$

$$AP_b = \bar{b} - b_c, \qquad \bar{b} = \frac{1}{n}\sum_{j=1}^{n} b_j,$$

$$AP_c = \bar{c} - c_c, \qquad \bar{c} = \frac{1}{n}\sum_{j=1}^{n} c_j,$$

where a_c, b_c, c_c are the angles of the programmers (specified) position and a_j, b_j, c_j are the angles of the reached position

4.2. Measurement procedure for unidirectional positioning accuracy

Tricept gradually moves with its mechanical connection (interface) from point P_1 to the following positions: P_5, P_4, P_3, P_2; then gradually back to P_1. Each position has to be achieved with a unidirectional approach, that is from the same direction. The individual measurements are performed only when

Tricept is in that position in a steady state. With the coordinates of the programmed positions, the mean values of the reached position coordinates and the mean value of the angle orientations at n-repetitions of the same position, we can calculate the unidirectional orientation and the positioning accuracy for each position using simple formulas.

4.3. Unidirectional positioning repeatability

Unidirectional Positioning Repeatability (RP) expresses the level of correlation between the positions and orientations of the reached positions after n-repetitions of the movement to the same desired position in the same direction. For a given position the repeatability is expressed by: the radius of the sphere RP_l, the center of which is the barycenter (see Figure 5); the dispersion of angles $\pm 3S_a$, $\pm 3S_b$, $\pm 3S_c$ around the mean values $\bar{a}$, $\bar{b}$, $\bar{c}$; where S_a, S_b and S_c are standard deviations (see Figure 6).

Unidirectional position repeatability is calculated as follows:

$$RP = \bar{l} + 3S_l,$$

where

$$\bar{l} = \frac{1}{n}\sum_{j=1}^{n} l_j,$$

$$l_j = \sqrt{(x_j - \bar{x})^2 + (y_j - \bar{y})^2 + (z_j - \bar{z})^2},$$

$$S_l = \sqrt{\frac{\sum_{j=1}^{n}(l_j - \bar{l})^2}{n-1}}.$$

Unidirectional repeatability orientation is calculated as follows:

$$RP_a = \pm 3S_a = \pm 3\sqrt{\frac{\sum_{j=1}^{n}(a_j - \bar{a})^2}{n-1}},$$

$$RP_b = \pm 3S_b = \pm 3\sqrt{\frac{\sum_{j=1}^{n}(a_j - \bar{a})^2}{n-1}},$$

$$RP_c = \pm 3S_c = \pm 3\sqrt{\frac{\sum_{j=1}^{n}(a_j - \bar{a})^2}{n-1}}$$

4.4. Measurement procedure for unidirectional positioning repeatability

The robot gradually moves with its mechanical connection according to the selected cycle the same way as when the unidirectional accuracy was measured, except that when measuring the unidirectional position repeatability RP and angle errors RP_a, RP_b, RP_c are calculated for each position of the sphere radius.

5. Conclusions

The Tricept experiments will take place when the wiring has been completed. The preparations are currently being finalized. The experimental results will form the basis for optimizing the design of Tricept, and also for adjusting the control system.

Acknowledgements

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