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Research Article

IMPACT OF THE TECHNOLOGICAL CONDITIONS OF PLANE SURFACE MACHINING ON A TRIANGULAR MILLING CUTTER ON THE RESIDUAL HYSTERESIS OF THE MOVEMENT AXIS OF THE MACHINE

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ABSTRACT
The paper deals with the possibilities of measuring the residual displacement or hysteresis on the lateral direction of the movement forces caused by the cutting forces of the machining. A special adjustment of laser interferometry assemblies was used for measurement. The measurement results indicate that the positioning accuracy in addition to the cutting forces also influences the position of the displaced moving substances and the temperature. The complex effect of these parameters is greatly dependent on the design of the machine.

Keywords: machine tools, laser interferometer, hysteresis.

INTRODUCTION

The resulting working precision of NC machine tools creates a complex of different impacts. If imminent technological conditions are considered, then the most important factors affecting accuracy are the static stiffness of machine components, the dynamic stiffness of the machine, the effect of thermal deformations and the positioning accuracy [1, 3, 6].

An important complex parameter characterizing work precision is the location of TCP (tool center point). That complex parameter depends on temperature, kinematics, rigidity and load. This is the subject of work [7, 4, 5].

It is possible to measure individual impacts on work accuracy in several ways. Each method can be the source of a new parameter that distinctively characterizes the complex condition of the machine. The individual impacts are so interconnected that only one state-of-the-art approach can be used. For example, by measuring the surface temperature of the work table, it is not possible to determine the main direction of the temperature deformations. This is because some significant temperature deformations are caused by the internal parts of the kinematic chain of drives. In addition, there are additional changes given by the oil layer of lubricated functional surfaces [8, 2, 6].

This paper is aimed at measuring the deformation of the three-axis milling table using a laser interferometer. The choice of the measurement process greatly affects the discovery of new effects on the resulting work precision.

ARRANGE EXPERIMENT

Based on the static stiffness measurement of the milling table in one direction, it is evident that the position of the table varies depending on the size of the load, but also on the size of the previous load and the load direction in the given axis. Figures 1a and 1b show the static char-

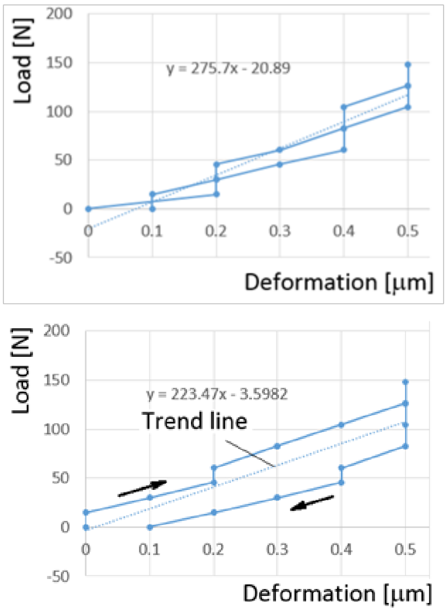

Fig. 1. Static characteristics of the table: at the first load (above), at the second load (below)

acteristics of the table in the X-axis direction. The first load is greater hysteresis and a lower stiffness (223 N/µm). At the second load under unchanged conditions, the hysteresis decreased and the stiffness increased (275 N/µm). This example indicates that, even during cutting, due to cutting forces, the positioning characteristics of the table can be changed, which will be stable after the end of the load.

The aim of the proposed experiment is to measure the displacement of the table due to cutting forces after machining a plane surface using a laser interferometer. The measurement method makes it possible to measure the displacement to the accuracy of one-tenth of the micrometer. The first proposed arrangement is shown in Figure 2. The working procedure would consist in measuring the position of the table at a single point before machining and after machining. The spindle shifts in the X-axis direction during machining. Subsequently, the movement of the table at the same point when machining the opposite side would be checked. This would change the orientation of the cutting forces towards the Y-axis.

This procedure was eventually replaced by the modified simplified experiment. This change has proved to be significant because it has demonstrated a new phenomenon influencing accuracy. In the first set-up, this fact could not be ascertained.

The second arrangement is shown in Figure 3. The spindle moves in the direction of the Y-axis and the planar surface is machined by the end-milling cutter.

Distance measurement note: the laser interferometer allows a very accurate measurement of the change in distance over a wide range. However, it also has its limitations. The main limitation is that the change in the distance of the measured objects can occur at a maximum speed of 4m/s. This is not a small speed, but vibrations that show higher speeds can also be transferred to the reflector. Such a speed control software cannot be processed and counts it as a change in distance, but cannot be detected at the end of the measurement. Therefore, the laser system must be physically separated from the machine during machining. For this purpose, a special beam with a flexible tilting device is provided for the reflector (Fig. 1). Even such a solution adds uncertainty to measurement. This uncertainty, but it can be experimentally verified and defined.

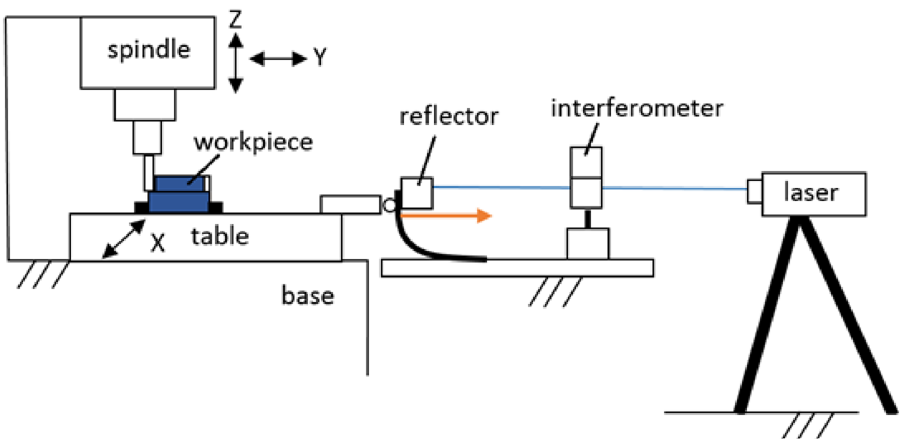

Fig. 2. The first proposed experiment layout

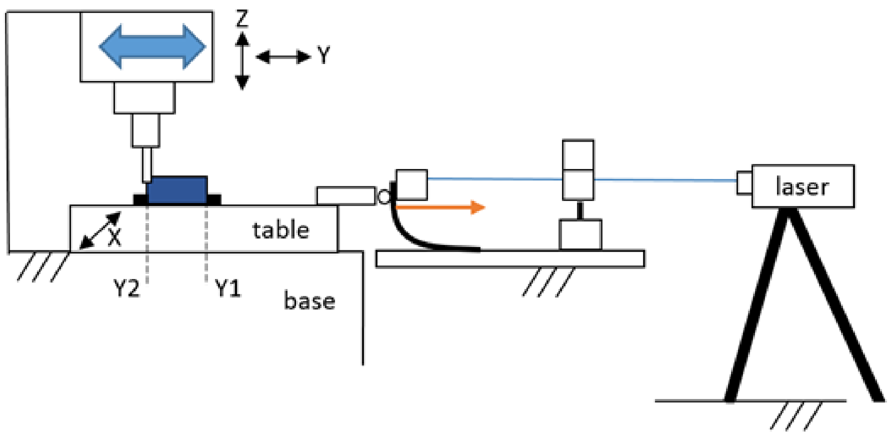

Fig. 3. Second experiment layout

EXPERIMENT NO. 1

The spindle moves along the Y-axis without any load. Movement is performed from Y1 to Y2 and back. The distance between points is 100 mm (Fig. 5). Measurement was done before the system was reset.

As can be seen from the six repeated measurements, hysteresis occurs, despite the fact that the table did not move or be loaded. A new parameter can be tracked when assessing the condition of the machine. Most likely, it is caused by a shift in the center of gravity of the spindle mass to the base of the machine. Such a movement causes additional deformation of all parts, which is also reflected in the transverse displacement of the table in the direction of the Y-axis. In the classical measurement under load, this change is attributed to cutting forces. In practice, the influence of temperature is assumed and this is not considered. In this regard, it is still important to note that the milling machine is of the three-point structure type.

Fig. 4. Measuring process

EXPERIMENT NO. 2

The spindle is loaded during machining along the Y-axis. The movement is executed from Y1 to Y2 and back. The size of the load is determined by the constant drawing of the material with a depth of 1 mm (Fig. 6). Technological conditions are the same in both directions.

Technological conditions:

- shaped material: Dural,
- spindle speed: 500 rpm,
- feed in the Y direction: 180 mm / min,
- tool: Shank cutter - diameter 18 mm, 6 teeth,
- cutting depth: 1mm.

Of the five repeated measurements, based on a comparison with the first experiment, the effect of cutting forces extends hysteresis on average by only 1 micrometer. However, the effect of temperature deformation on the table's displacement relative to the base is about 7 microns (Fig. 6).

EXPERIMENT NO. 3

The spindle is loaded during machining along the Y-axis. The load movement is performed in Y1 direction 30mm in length. At the end of the cycle, they return to the starting position. The values in the end and start positions are recorded. Each cycle increases the load by increasing the depth of the cut. After five cycles, the experiment repeats from the opposite direction (Y2 direction) and from the opposite side of the workpiece (the workpiece width is 100 mm). Measurement was done before the system was reset.

Technological conditions:

- shaped material: Dural,
- spindle speed: 500 rpm,

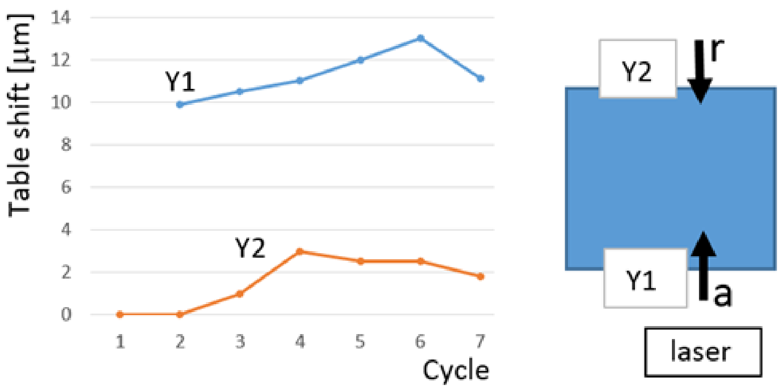

Fig. 5. Measurement of table displacement without load in the Y axis

- feed in the Y direction: 100 mm / min,
- tool: - as in experiment No. 2.

When compared to the values of experiment No. 1, the average hysteresis increased by 3 micrometers. Although the initial positions were not loaded, the component was added to the feed from the previous load.

Comparing the average hysteresis in experiments no. 2 and no. 3, it follows that in experiment 3 it is greater by 2 micrometers. This suggests that experiments 3 had greater cutting forces.

CALCULATION OF CUTTING FORCES

Based on input values, the following cutting forces were calculated. Calculations were performed using the Mechanical calculator program.

Max. angle $\phi_{max} = 180^{o}$.

The average and maximum thickness of the chips:

$$h_{max} = f_z . sin\varphi . sin\kappa_r = 0{,}06 . sin180° . sin90° = 0{,}0429\ mm \tag{1}$$

$$h_m = \frac{114{,}6}{\varphi_{max}} . f_z . sink_r . \frac{B}{D} = \frac{114{,}6}{180°} . 0{,}06 . sin90° . \frac{100}{18} = 0{,}1897\ mm \tag{2}$$

Spoon width calculation:

$$b = \frac{a_p . cos\lambda_s}{sin\kappa_r} = \frac{2 . cos0°}{sin90°} = 2{,}237\ mm \tag{3}$$

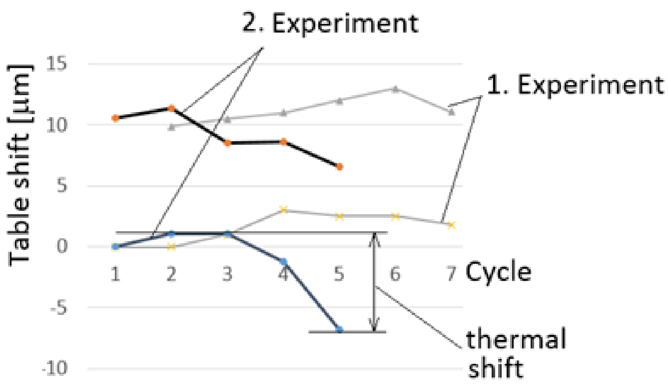

Fig. 6. Measure the displacement of the table with the load in the Y axis

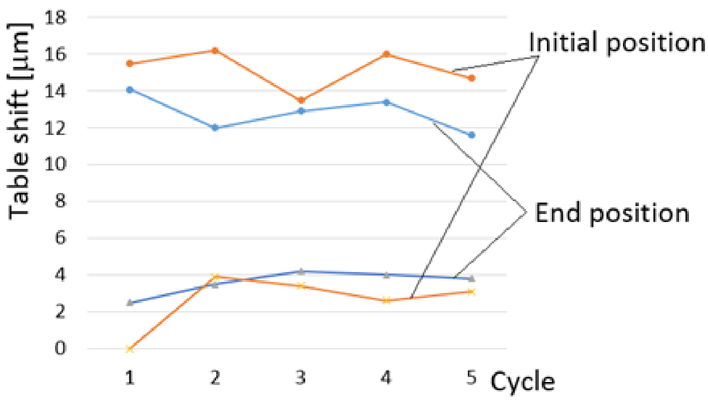

Fig. 7. Measuring the displacement table with a change in load in the Y axis

Calculation of teeth in engagement:

$$Z_i = \frac{\varphi_{max}}{\psi} = \frac{180°}{60°} = 3 \tag{4}$$

$$\psi = \frac{360°}{Z} = \frac{360°}{6} = 60° \tag{5}$$

Calculation of cutting resistance for the mean thickness of spoon:

$$k_s = \frac{k_{s1.1}}{{h_m}^m} = \frac{500}{0{,}1897^{0{,}25}} = 757{,}62\ N.mm^{-2} \tag{6}$$

$$k_{s1.1} = 500\ N.mm^{-2} \tag{7}$$

$$m = 0{,}25 \tag{8}$$

Calculation of the main component of the cutting force:

$$F_c = b.h_m.k_s.K_{v_c}.K_{\gamma_0}.K_{VB}.K_{NM} = 2{,}237.0{,}1897.757{,}62.1.0{,}94.1{,}3.0{,}95 = 388{,}9\ N \tag{9}$$

For experiment no. 1, the total cutting force was 283.5 N.
For experiment no. 2, the total cutting force was 388.9 N.

ASSESSMENT OF REPEATABILITY OF MEASUREMENT

Measuring chain with laser interferometer has a high accuracy (0,5 μm/m). During machining, was contact with the measured object intermittent by means of rope. The contact area on the table was grinded. An end scale was used for this purpose. From the side of the reflector, was used a glass ball to limit the effects of magnetic forces. To determine repeatability, repeat measurement of a single point was made under unchanging conditions measurement. Figure 7 shows the result of 135 repetitive measurements over a measuring interval of ten minutes. As we can see, the trend shows a trend component that is related to temperature changes throughout the machine system. Therefore, in order to assess the accuracy of the experiments, it is appropriate to select a section in which the trend component has minimally changed. The reference deviation of the values is in this range 0.54 microns.

CONCLUSION

The main benefit of the results from experiments of measuring the displacement of the table three-axis milling machines before and after machining is that the greatest impact on the size of hysteresis not cutting forces, but the change in position center of gravity the spindle towards to the machine base. The size of this change depends on

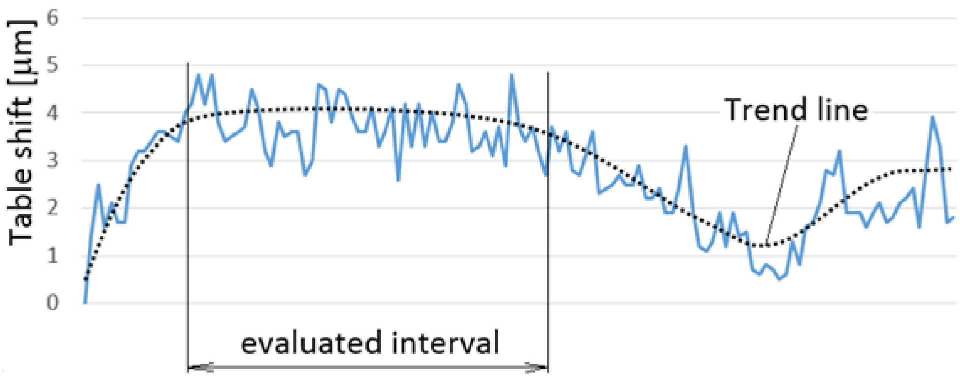

Fig. 8. Repeated measurement of a single point in the Y axis

the design of the machine and, of course, on the stiffness of the components. In Figures 5 and 7 it is seen that the influence of temperature is also evident, but this is a well-known thing.

Regarding the repeatability of the measurement, it would be preferable to use a non-contact measurement system. When considering a standard 4-sigma range, the measurement error can be in the order of + - 1 micrometer. For the above experiments, that is enough.

The proposed measurement methodology can be advantageously used in a comprehensive assessment of the condition of machine tools.

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