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ANALYSIS OF PARAMETERS AFFECTING THE QUALITY OF A CUTTING MACHINE

Iveta Onderová[a,*], Ľubomír Šooš[b]

[a] *Slovak University of Technology in Bratislava, Faculty of Mechanical Engineering, Institute of Manufacturing Systems, Environmental Technology and Quality Management*

[b] *Slovak University of Technology in Bratislava, Faculty of Mechanical Engineering*

[*] corresponding author: iveta.onderova@stuba.sk

Abstract. The quality of cutting machines is affected by several factors that can be directly or indirectly influenced by manufacturers, technicians and users of machine tools. The most critical qualitative evaluation parameters of machine tools include accuracy and stability. Investigations of accuracy and repeatable positioning accuracy were essential for the research presented in this paper. The aim was to develop and experimentally verify the design of a methodology for cutting centers aimed at achieving the desired working precision. Before working on the topic described here, it was necessary to make several scientific analyses, which are summarized in this paper.

We can build on the initial working hypothesis that by improving the technological parameters (e.g. by increasing the working speed of the machine, or by improving the precision of the positioning) the quality of the cutting machine will also be improved. For the purposes of our study, several investigated parameters were set affecting positioning accuracy, such as rigidity, positioning speed, etc. First, the stiffness of the portal structure of the cutting machine was analyzed. FEM analysis was used to investigate several alternative structures of the cutting machine, and also an innovative solution for beam mounting). The second step was to integrate two types of drives into the design of the cutting machine. The first drive is a classic rack and pinion drive for cutting machines. To increase (improve) the working speed of the machine, linear motors were designed as an alternative drive. The portal of the cutting machine was designed for a working speed of $260\,\mathrm{m\,min^{-1}}$ and acceleration of $25\,\mathrm{m.\,s^{-2}}$. The third step was based on the results of the analysis. In collaboration with Microstep, an experimental cutting machine in a portal version was produced using linear synchronous motors driving the portal on both sides, and with direct linear metering of its position. In the fourth step, an experiment was designed and conducted to explore the positioning accuracy and the repeatable positioning accuracy.

Keywords: cutting machines, quality, positioning accuracy, repeatable positioning accuracy.

1. Requirements for cutting machinery and quality requarements

Cutting centers must meet several requirements. Some of the requirements are mandatory and are specified by current standards, while others are either generally anticipated or the customer determines them himself. A summary of all the requirements is a set of parameters affecting the quality of the cutting center. The parameters are divided into various classes, e.g.: structural, technological, ergonomic, operational, etc. Based on the degree to which the parameters of the center fulfill the prerequisites, we can say that the quality of the cutting center is bad, good or excellent.

The quality of a cutting center can be defined as the degree to which the set of cutting center parameters meets the requirements for cutting centers. For the purposes of the experiment described here, the selected qualitative parameters are: parameter A - positioning accuracy, and parameter R - repeatable positioning accuracy.

2. Eexperimental equipment and experiment descign

The technical solutions and features of this machine must reflect the high requirements for dynamics, speed and precision of cutting shapes that are difficult for machining, and also parts of small dimensions. A new design for the mechanics and the drive system of the CNC cutting machine was developed for force-free material cutting technology. The design of the machine is of gantry execution with extreme dynamics, and is designed on the basis of advanced structural materials (mineral alloys - polymer concrete, sandwich tubular structures), applications of linear actuators driving the portal on both ends and direct linear position measurements. The portal support is equipped with a drive unit for height control of the technological head above the material that is being cut (the workpiece). The technological table is designed to work at speeds up to $260\,\mathrm{m\,min^{-1}}$ and acceleration of $25\,\mathrm{m\,s^{-2}}$.

Particular attention was paid to the design of the installation of the linear actuators, and to the design of the connecting node of the X axis to the beam of

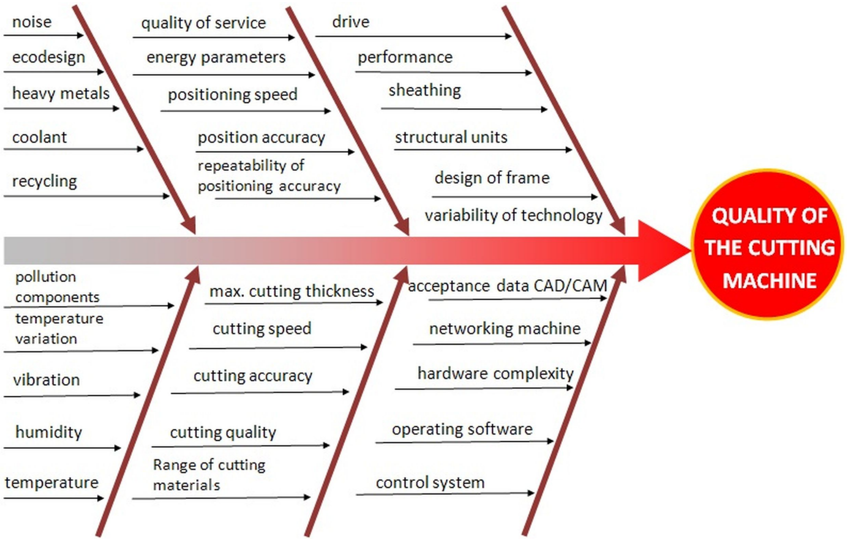

FIGURE 1. Parameters affecting the quality of a cutting machine.

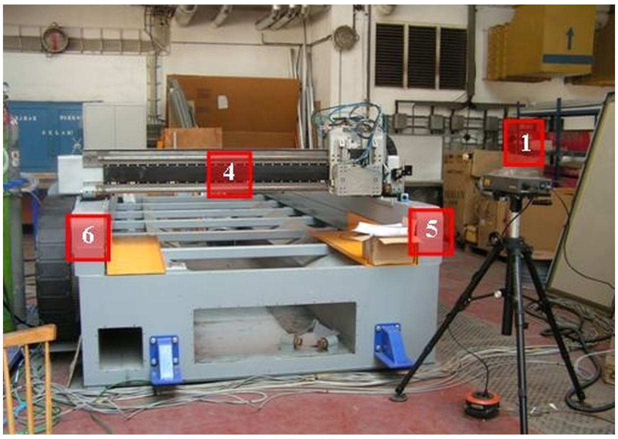

FIGURE 2. Experimental measurement of parameters A and R — axis X_1 (1–interferometer, 4–axis Y, 5–axis X_1, 6–axis X_2).

the Y axis. The frame of the cutting machine was also developed, and its design was gradually modified [1]. The main part is the exhausted technology table, with an area of $4.5\,\mathrm{m}^2$, i.e. $3000 \times 1500\,\mathrm{mm}$, and with three holes that are used to connect the filtering device. The portal of the machine for the purposes of the experiment was designed with a reversible linear actuator in the X axis.

The cutting machine is equipped with its own conveyor, which is located inside the frame, and its motion is realized through a chain gear on both ends of the conveyor.

The goal of the experiment is to determine the value of the A and R parameters across the technological table or in the range of motion of the technological head.

The experiment based on the parametric method was realized by a Renishaw ML 10 interferometer. In combination with the unit for compensating the environmental effects, it achieves extremely high accuracy up to 0.7 ppm. Its resolution is 1 nm at a sampling frequency of $1\,\mathrm{m\,s^{-1}}$

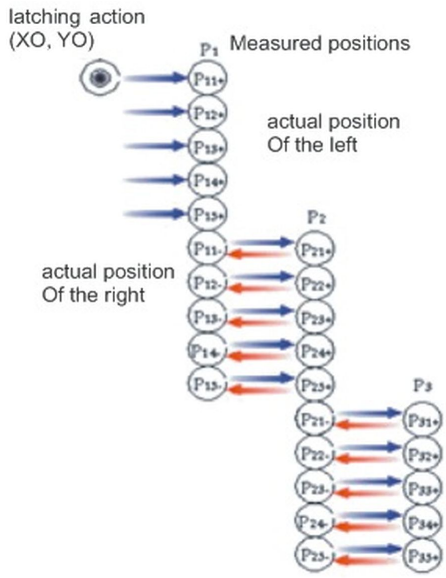

FIGURE 3. Measuring cycle.

In order to determine the values of parameters A and R in the full range of the technology head motion, we had to split the experiment into two parts: measurement of the Y axis (axis length: 1500 mm), and measurement of the X axis (axis length: 3000 mm). For the required position P_i, ten measurements were performed in the direction from the right, and ten measurements in the direction from the left. Measured positions P_i are designed in accordance with the formula

$$Pi = (i-1)p + r, \tag{1}$$

where P_i is the measured position, i is the number of the measured position, p is the measuring interval, r will take a different value in each measured position. It is used to prevent periodic errors.

Approximation to the desired position was carried

P_i	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
Measured positions [mm]	10.0	166.0	332.8	500.0	666.0	831.6	998.0	1166.0	1332.0	1489.0

TABLE 1. Table of desired positions for measurement of the Y-axis.

P_i	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}
Measured positions [mm]	10.0	250.0	500.2	749.9	1001.0	1248.5	1500.0	1749.3	2000.8	2250.1	2498.3	2749.9

TABLE 2. Table of desired positions for measurement of the X-axis.

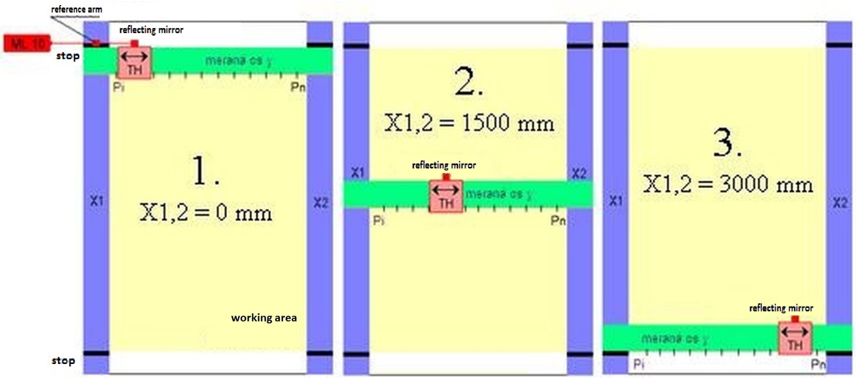

FIGURE 4. Scheme of measurement axes Y.

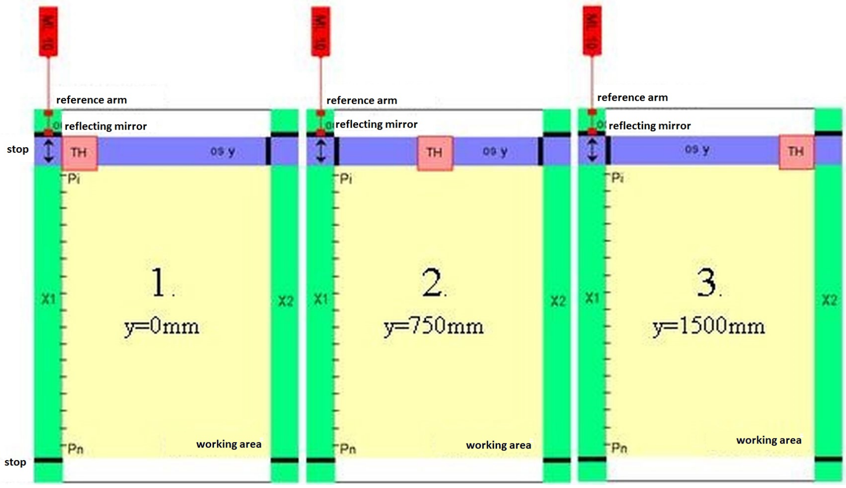

FIGURE 5. Scheme of measurement axes X.

out in both directions, i.e. from the right (marked as −) and from the left (marked as +). The measurement was carried out by the reverse movement cycle, as shown in Figure 3 The measuring cycle was maintained throughout the experiment for all measurements.

3. Evaluation of measurements

The measurements were evaluated under the conditions stipulated in ISO 230-2: 2006. The goal of the experiment is to determine the value of the A and R parameters. All results of the evaluation of measurements (maximum insensitivity B_{tmax}, average insensitivity B, mean bidirectional positioning error interval M, systematic positioning error E, *positioning repeatability* R and *positioning accuracy* A) for the Y and X axes published in [1].

The Y axis measurements are similar even for different positioning of the portal. For all measurements, the same phenomenon can be observed that when the linear axis increases the mean unidirectional positioning error increases up to the desired position. From this position, the unidirectional positioning error decreases again. The dispersion of the individual measurements is small, as can be seen in the narrow confidence corridor.

All measurements of the Y axis are characterized by a change in the range from to . This area will be further investigated. The results of the Y-axis measurements also show that the value for the positioning accuracy of A increased after moving the

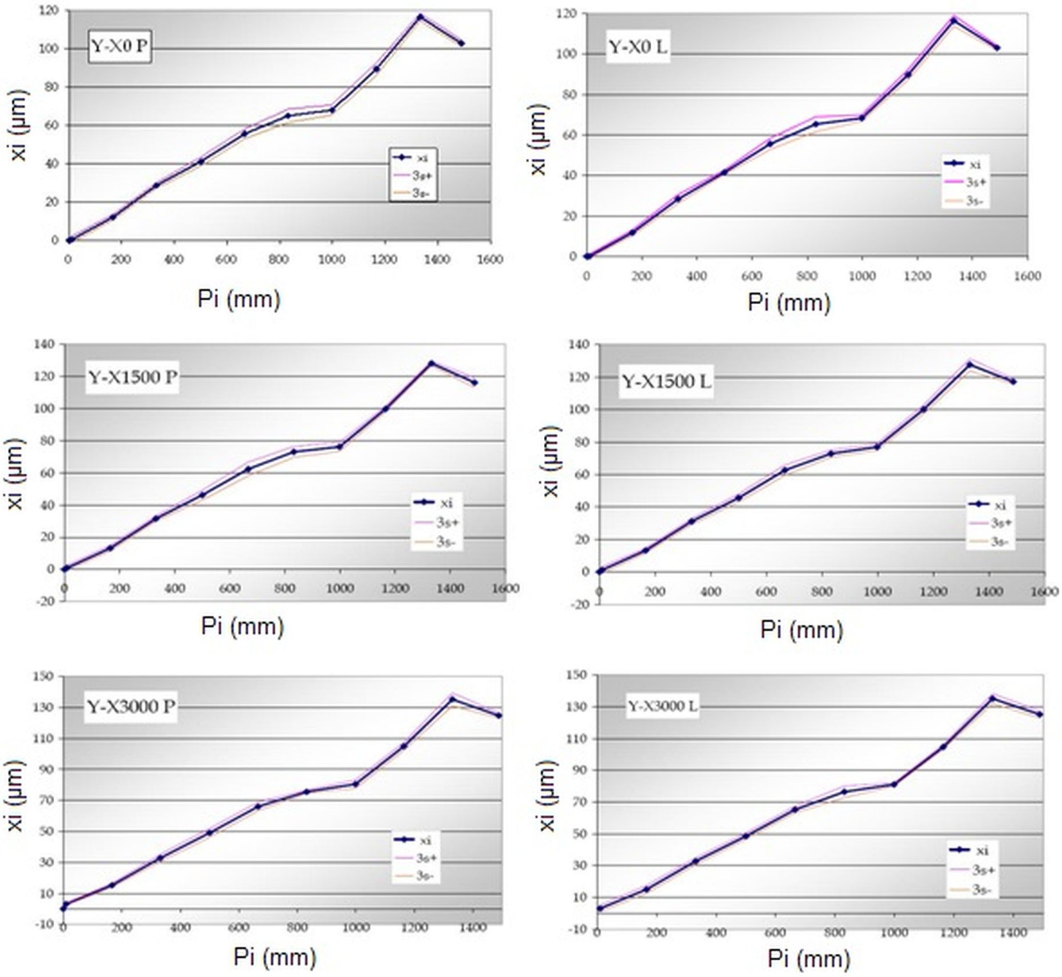

FIGURE 6. Graphical evaluation of direct measurements of the Y axis of the left and right sides.

portal. While measuring $Y - X_0$ the positioning accuracy was $A = 118.8$ microns, and while measuring $Y - X_{3000}$ the positioning accuracy was $A = 135.1$ microns. The unidirectional positioning error of the Y axis along the X axis thus increased by 16.3 microns.

The measurements of the X axis are similar even when the support weight is shifted along the Y axis. For all measurements, the same phenomenon can be observed that when the linear Y axis increases the mean unidirectional positioning error increases exponentially. The dispersion of the individual measurements is small, as can be seen in the narrow confidence corridor.

An interesting area of all measurements on the X axis is the area around the desired position At this point, a step change occurred for all measurements, but it did not occur for the next desired position. It is therefore necessary to make a further investigation at a later date.

The results of the X axis measurements also show that the value for the positioning accuracy of A increased after moving the portal. Measuring $X - Y_0$ the positioning accuracy was $A = 137.024$ microns; and measuring $X - Y_{1500}$ the positioning accuracy was $A = 184.632$ microns. The positioning accuracy of the X axis increased by 47.608 microns after moving the support along the Y-axis.

4. Conclusions on the measurement evaluation

The resulting positioning accuracy on the Y axis is equal to the maximum value of the evaluated positioning accuracy , and the resulting positioning accuracy for the axis is For the X axis, the positioning accuracy has the maximum value and positioning repeatability

The measurement results evaluated according to the standard do not define the positioning error in the whole range of the measured axis, only at the measurement points. Using these results, evaluated according to the standard, it is therefore not possible to determine the basic measurement parameters beyond the measured desired positions.

Between these points the positioning deviation is not known. The standard, however, assumes that the curve of the positional deviation value between the measured data items is linear. This presumption is critical for the evaluation of the measured data, but in terms of further processing of the measured data it is insufficient and not correct. For this reason we

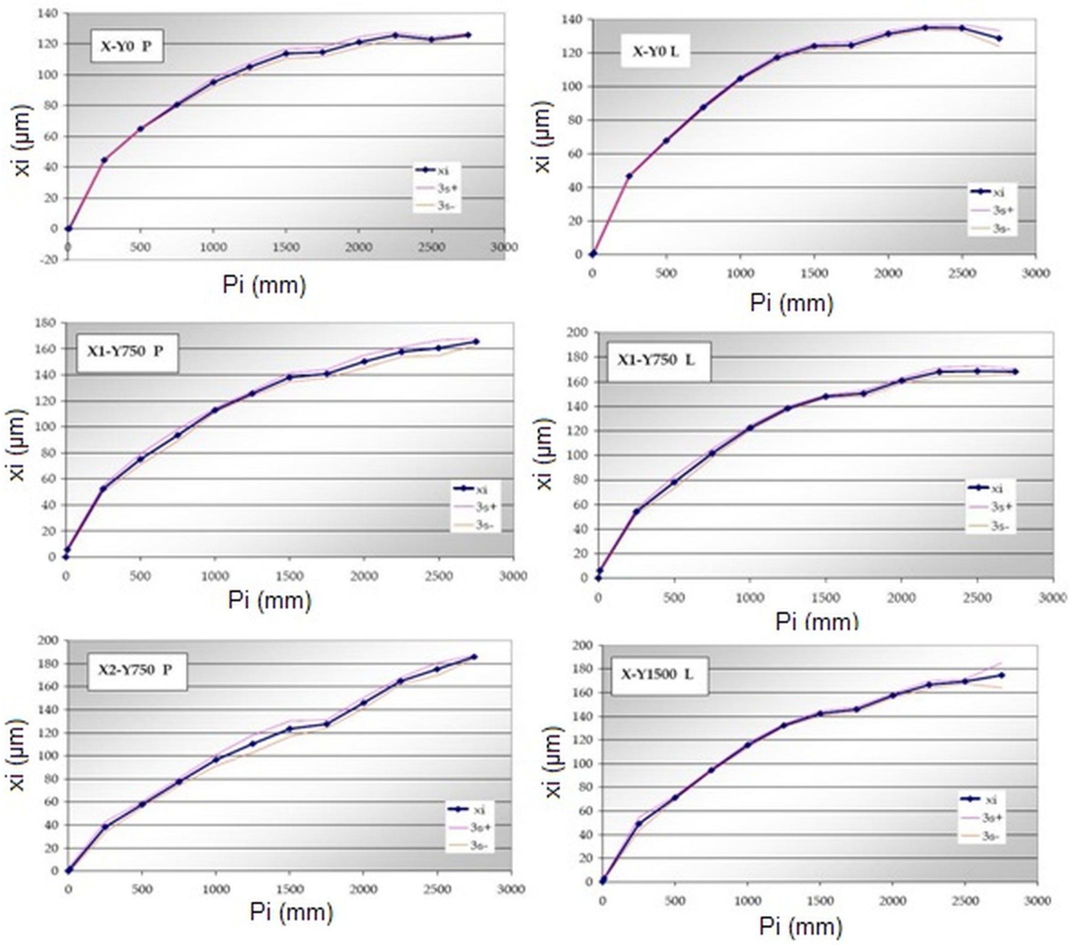

Figure 7. Graphical evaluation of direct measurements of the X axis of the left and right sides.

decided to estimate the positioning accuracy beyond the desired positions using regression analysis.

Acknowledgements

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