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LASER TRACKER MEASUREMENT FOR PREDICTION OF WORKPIECE GEOMETRIC ACCURACY

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Abstract: *The primary objective of this paper is to present a new method for measuring of geometric errors in the machine tool workspace in order to predict the accuracy of investigated workpiece. A general methodology for a three axis machine tool is described to map the volumetric errors and based on this map to evaluate the dimensional and geometric workpiece parameters. A measurement strategy uses a portable coordinate measurement system Laser Tracker and is intended principally for middle-size and large milling machines. For purposes of testing the strategy was applied on a small machine tool first. The relative discrepancies between the tool and the workpiece were estimated from the separate table and spindle measurements in contrast to application in large machine tools and other strategies. Based on the results and according to the required accuracy parameters, this method is used for locating the optimal workpiece position in the machine volume.*

Keywords: Optical alignment, Laser Tracker, Machine accuracy, Error prediction.

1. Introduction

As a basis to improve machining accuracy of machine tools (MTs), it is important to develop a methodology to measure it in an efficient manner. There are many error sources presented in a MT that affect the accuracy of a workpiece depending on factors such as kinematics, cutting conditions, workpiece material and dimensions (Aguado et al., 2012). The knowledge of MT accuracy is for MT manufactures essential, although the importance of geometric error measurement is by many of them not fully understood yet. It is a feedback that could affect both design and assembly. However, typical MT users concern accuracy when the MT performs actual machining. This paper therefore considers the strategy for measuring geometric errors in order to predict investigated workpiece accuracy. This strategy is the output of the project motivated by industrial demands solved in cooperation between the industrial partner TOSHULIN, a. s. and the Institute of Production Machines, Systems and Robotics (Brno University of Technology).

A laser tracker is a portable system that measures a position of a reflector in spherical coordinates. Among many benefits are easy setup and large range of possible applications. However, acquisition costs remain high and measuring accuracy that is affected by many error sources in spite of development in laser tracker technology (Aguado et al., 2013) and is lower than by standard measurement systems that are used for calibration of MTs nowadays. As a result, MT builders use laser tracker mainly for measuring, aligning and assembling of large parts (Holub et al., 2013). The application in measurement of volumetric accuracy, which is presented in this paper, is connected with many obstacles - expenses in raw costs and in lost production, for the time consuming procedure is mostly hard to find a space in demanding delivery terms and finally, the common measurement methods require a high degree of technical expertise. Finding a measurement strategy for geometric calibration of MTs, that is efficient, has low time requirements and is easy to apply, is the aim of this research project. Unlike other methods that

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concern calibration and compensation of MTs, this strategy presents different approach - direct evaluation of workpiece geometric parameters.

Eman (1987) stated that quasi-static errors constitute 60-70% of the final error and affect the MT repeatability. Based on this fact, the main object of this method is to find a relation between the results from static measurement and the final accuracy of an investigated workpiece. Undisputedly, other error sources presented in a MT depending on factors such as kinematics, stiffness, cutting conditions, workpiece material, etc. affect the accuracy of a workpiece too. However, these sources were in the first phase of the research neglected.

This paper presents the results from the first measurement. The positioning accuracies of the table and the spindle are measured separately. Another measurement of the clamping face is suggested as the workpiece is also affected by its flatness. After the data are collected, they are merged into a three-dimensional lattice where each point represents a tool position relative to the workpiece. These points are compared to their nominal positions and the discrepancies are considered as errors. Finally, based on the results of the first measurement, the paper suggests a new proposal for measurement strategy that eliminates the occurrence of systematic errors and enhances reachable accuracy of laser tracker measurement.

2. Method of Measurement

In principle, measurement conditions should be close to real working conditions. However, neither application of static and dynamic forces on the spindle or loading the table simulating the weight of a workpiece is applied because of the required space keeping left for the laser beam. Nevertheless, measuring of different load conditions is allowed fundamentally. Geometric errors as a result of the method are therefore valid under assumption of low static and dynamic forces during machining.

In order to map 3D errors in the working volume of the MT, both the table and the spindle are measured. This method presents an option to choose whether the whole or only a frequently used part of the machine space is measured and what accuracy is required. Both these factors significantly influence the overall time demands. The size of the machine volume does not allow placing the tracker directly on the table and it was attached next to the machine (Fig. 1). Because of the assumption that errors of the spindle (Z axis) and the table (X and Y axis) are independent, they could be obtained in separate measurements. First the reflector was attached to the table center point (1P). This position represented the most frequent placement of the workpiece on the table. The machine table was measured in two ways – at first, the measured points were approached in direction of X axis and then similarly in direction of Y axis. After both cycles were repeated three times, the reflector was moved and clamped in the spindle with an offset that corresponded to the tool center point of a preferred milling tool (2P). The data of Z axis were captured three times as well. The influence of different tool lengths was ignored since the determination of the spindle angular errors from one-point measurement is not possible.

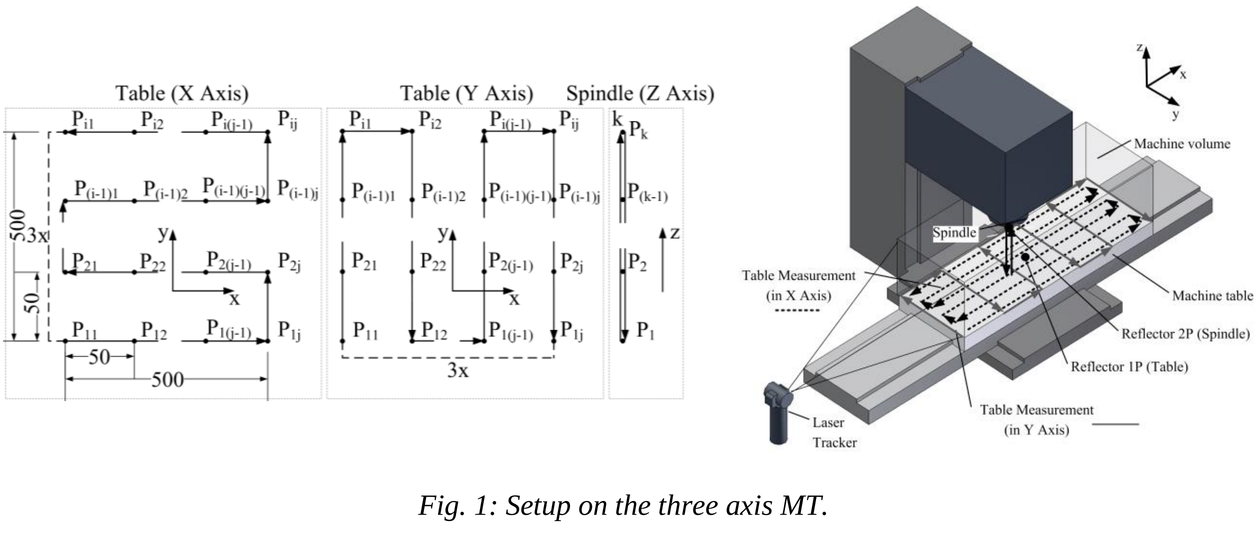

Fig. 1: Setup on the three axis MT.

All three-axis of the tested machine are equipped with high-precision ball screws and the movements are performed on linear guide ways with rolling elements. The measurement of positions is realized by means of direct linear measuring units with activated thermal compensation. The measurement was performed with a laser tracker, which accuracy is specified according the standards with MPE value as ± 15 µm + 6 µm/m. The achievable accuracy is, to the author's knowledge, improved when the rotational movements of the tracker measuring head are decreased to a minimum; thus to place the laser tracker in the direction of the longest axis is suggested, the X axis in the case of tested machine.

Since the flatness of the clamping face is also considered, the measured points are captured manually in positions constantly spread across the table face (Tab. 1). Before the machine volume is measured, the size of step is chosen with respect to the investigated workpiece. The fact of the constantly spread points makes more difficult to determine regular occurring systematic errors such as those caused by lead of the ball-screw. Nevertheless, the constant step is required for data processing and the occurrence of systematic errors is therefore neglected. Though, the reflector is attached in the table center point, an error in any other workpiece location on the table can be recalculated from the results of flatness measurement of the clamping face.

Tab. 1: Measurement setup summary.

	X[mm]	*Y[mm]*	*Z[mm]*	*Step [mm]*	*No. of Rep.*	*Total No. of Points*
Table (in X Axis)	*500*	*500*	*0*	*50*	*3*	*3x132*
Table (in Y Axis)	*500*	*500*	*0*	*50*	*3*	*3x132*
Spindle	*0*	*0*	*600*	*50*	*3*	*3x12*
Flatness	*500*	*500*	*-*	*-*	*1*	*16*

3. Results of the Original Measurement

The data are captured according to the method described in section 2. For further processing, mean values of each measured point are considered. Solely the result of the table measurement will be discussed as it showed up to be the critical part of the measuring strategy. Fig. 2 and Fig. 3 show the captured points of both sets of the table measurement; each set was interpolated with a quadratic polynomial surface to improve the clarity. Comparing the data of both sets in Fig. 2 and Fig. 3 together regular discrepancy in the measured motions occurs, although the sets should correspond to each other. The direction of the surface peaks corresponds to the direction that the measured points were approached. This occurrence of systematic error is explained by the hysteresis of drive mechanism in the laser tracker.

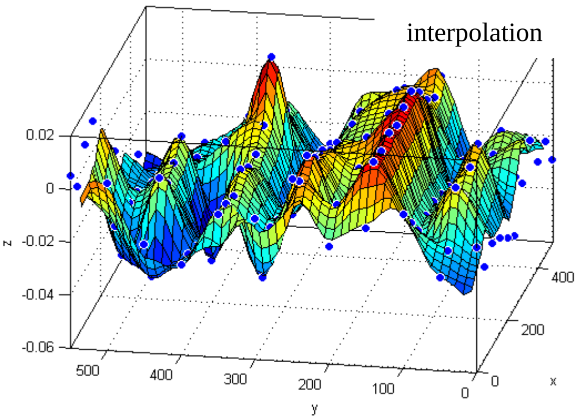

Fig. 2: Interpolated results of table measurement (in X axis direction).

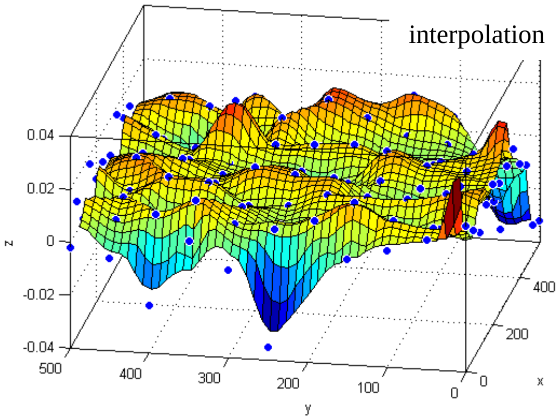

Fig. 3: Interpolated results of table measurement (in Y axis direction).

The matrix of ideal points P_{Id} was subtracted from the points obtained during the axis measurements according to Eqs. (1)–(2). The results were two three-dimensional lattices of errors $\Delta P_{dev,1}$ and $\Delta P_{dev,2}$ that describe the discrepancies in the machine volume.

$$\Delta P_{dev,1} = \left(P_{Table,\mathrm{X}} - P_{Spindle}\right) - P_{Id} \tag{1}$$

$$\Delta P_{dev,2} = \left(P_{Table,\mathrm{Y}} - P_{Spindle}\right) - P_{Id} \tag{2}$$

A distribution of errors in $\Delta P_{dev,1}$ and $\Delta P_{dev,2}$ differs significantly in both sets of data (Fig. 4 and Fig. 5).

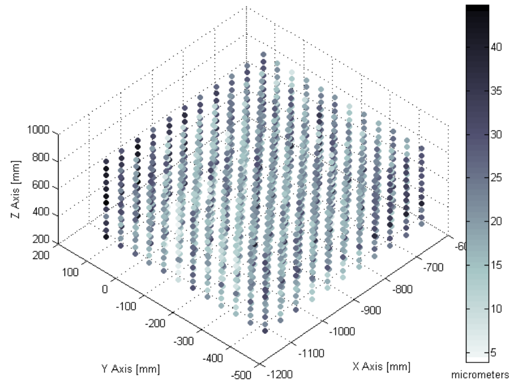

Fig. 4: 3D error lattice ($\Delta P_{dev,1}$).

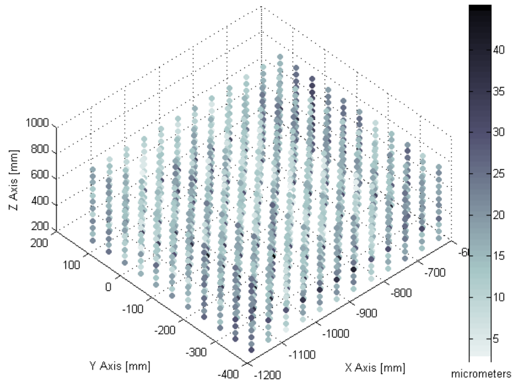

Fig. 5: 3D error lattice ($\Delta P_{dev,2}$).

4. Proposal of the New Method of Axis Measurement and Conclusion

Based on the results of the original measurement, a new proposal of a measuring strategy is developed that has its basis in the standard ISO 230-2. It was determined during the first measurement that it is necessary to approach the points from counter directions to minimize the impact of hysteresis. Furthermore, the number of the measurement repetitions must be increased to improve the resulting accuracy. Based on these facts, the new method suggests the measurement strategy as shown in Fig. 6, where P_{ij} and P_k refer to measured positions, r to reversal path, k to number of measuring repetitions and s to the size of a step.

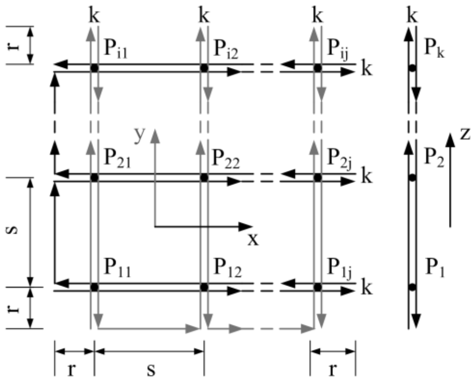

Fig. 6: New measurement strategy.

A simplified method of machine measurement for workpiece accuracy prediction was developed and tested. Based on results the new proposal is suggested that is tailored to the laser tracker specific demands with the aim of increasing achievable measurement accuracy. This new method of measurement will be applied in further work on the project with the main objective of locating the most suitable workpiece position in a machine volume and is intended primarily for the middle-size and large MTs as the small MTs operate generally with high accuracy that is beyond the common laser tracker measuring capacity.

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