The Positional Deviation in Two Numerically Controlled Axes

[1]E. Kureková, [2]M. Halaj, [3]R. Palenčár, [4]T. Loebl

[1, 3, 4] Slovak University of Technology, Faculty of Mechanical Engineering,
Institute of Automation, Measurement and Applied Informatics, Bratislava, Slovakia,
[2]Slovak Institute of Metrology, Bratislava, Slovakia,
E-mail: eva.kurekova@stuba.sk

Abstract. *Nowadays many modern production machines require positioning in thousandths of millimeter. Therefore a big attention must be paid to prepare positioning software that drives individual axes of the production machine with minimized deviations between the desired position and actually reached position – the so called positional deviation must be minimized. This goal requires a new methodology that enables estimation of the positional deviation in any point in a plane or in a space respectively, together with calculation of the uncertainty of such estimate. Such a methodology can be incorporated into a machine axis positioning system in the form of corrections enhancing positioning possibilities of individual axes. Such compensation can further improve the positional accuracy of machine tools.*

Keywords: Numerically Controlled Axis, Positional Deviation, Measurement Uncertainty

1. Introduction

The quality of the numerically controlled axis has a big influence on quality of final manufactures. Qualitative parameters of final product that are affected by numerically controlled axis can be traced down to surface quality and dimensional accuracy of the final product. Namely dimensional accuracy is widely influenced by the positioning accuracy of the numerically controlled axis. Therefore it is of the utmost importance to enhance the positioning accuracy of the numerically controlled axis.

The international standard ISO 230-2:2006 [1] is aimed at the precision of machine tools linear axes. The problem is that this standard does not provide solutions for creating a continuous compensation line over the whole length of a numerically controlled axis. To create suitable line one should use another approach being more mathematically complicated. With this approach it is possible to create compensation line that could be implemented into control system, thus decreasing the positional deviation of the linear axes.

2. Evaluation According to the Standard

Testing of the positional deviation of the numerically controlled axis (either rotary or longitudinal) is ruled by the international standard ISO 230-2:2006. This standard provides guide for design of the test, testing conditions and also describes evaluation procedure for processing the measured data. In general, the testing procedure is based on repeated measurements of the actual position of the tested axis in several discrete points (target positions), distributed equally along the axis travel. The measuring cycle must be used for the measurement, as measured data are processed after completing this cycle.

Measurements according to the standard require several conditions that should be met before the measurements starts. The surrounding temperature of 20 ºC and fully operational condition of the machine under test represent the main desired parameters. All types of corrective mechanisms in the control program of the axis shall be activated [1, 2].

3. Measurement model in two axes

Measurement according to the standard doesn't describe calculation of uncertainty and positional deviation in any point of axis travel. Positional deviation according to the standard can be evaluated only in discrete measured points (Fig. 1). It is not available in the form of a continuous function. Standard predicts that positional deviation is linear in between measured points that is not always true and cannot be simply stated. Regression analysis seems to be more useful in this case, providing the user with a continuous function of positional deviation [3, 4, 5].

If we want to obtain the estimates of the positional deviations also in other points than the measurement ones, we must approximate course of estimates (Fig. 2).

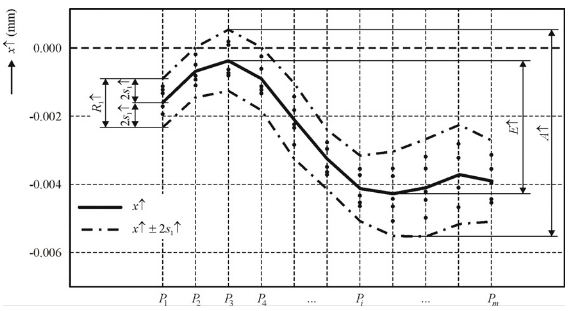

Fig. 1. Evaluation result according to the standard ISO 230-2:2006 Fig. 1

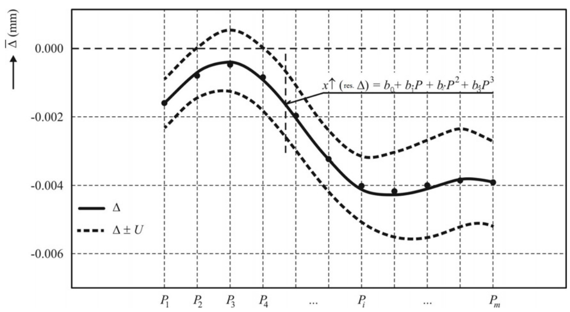

Fig. 2. Regression curve in x-axis together with uncertainties

The basic model without interactions for a regression plane (two-dimensional case) gets the form

$$\varDelta = b_0 + b_1 \cdot P + b_2 \cdot P^2 + \ldots + b_n \cdot P^n + b_{n+1} \cdot R + \ldots + b_{n+k} \cdot R^k + e \tag{1}$$

where

b_i, $i = 1, \ldots n+k$ – unknown parameters of the polynomial function,

e – overall sum of random errors,

P – coordinate of a measured point in the 1st axis,

R – coordinate of a measured point in the 2nd axis,

$\varDelta$ – the overall positional deviation.

For estimate of parameters of the regress surface $\hat{\boldsymbol{b}}$ with use of least squares method and when considering the weighs of individual measurements with dependence on their uncertainty, following expression in matrix form is valid:

$$\hat{\boldsymbol{b}} = \left(\boldsymbol{X}^{\mathrm{T}} \boldsymbol{U}^{-1}(\boldsymbol{\varDelta}) \boldsymbol{X}\right)^{-1} \boldsymbol{X}^{\mathrm{T}} \boldsymbol{U}^{-1}(\boldsymbol{\varDelta}) \boldsymbol{\varDelta} \tag{2}$$

where

$\boldsymbol{U}(\boldsymbol{\varDelta})$ – is a variance-covariance matrix of a random vector $\boldsymbol{\varDelta}$, having the form:

$$\boldsymbol{U}(\varDelta) = \begin{pmatrix} u^2(\varDelta_1) & u(\varDelta_1, \varDelta_2) & u(\varDelta_1, \varDelta_3) & \cdots & u(\varDelta_1, \varDelta_m) \\ u(\varDelta_2, \varDelta_1) & u^2(\varDelta_2) & u(\varDelta_2, \varDelta_3) & \cdots & u(\varDelta_2, \varDelta_m) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ . & . & . & . & u(\varDelta_{m-1}, \varDelta_m) \\ u(\varDelta_m, \varDelta_1) & . & . & u(\varDelta_m, \varDelta_{m-1}) & u^2(\varDelta_m) \end{pmatrix} \tag{3}$$

where

$u(\Delta_1)$, $u(\Delta_2)$, ... , $u(\Delta_m)$ – are uncertainties of individual positional deviations.

$u(\Delta_1, \Delta_2)$ is the covariance between positional deviations in position Δ_1 and position Δ_2, …

$u(\Delta_{m-1}, \Delta_m)$ is the covariance between positional deviations in position Δ_{m-1} and position Δ_m.

Uncertainties and covariances of the matrix (3) are obtained upon the uncertainties analysis during the experiment. Both elements evaluated by the type A method and by the type B method are present.

4. Practical Results

A result of this analysis is a regression plane which represents positional deviations and uncertainty of positioning in any point of plane. Such a plane can be used as an input parameter for correction of linear axes positioning.

Theoretical results were adapted to a three-axis machine tool produced by Microstep, Ltd. Measurements were carried out at two axes of the machine. Each axis was measured in tree different positions of another axis. The overall positioning deviation in a single point of a plane is obtained by vector superposition of deviations of the two axes while individual components of vector are represented by deviation of individual axes (see Fig. 3). It means that two regress planes should be prepared for x axis – regress plane for approach from right (see Fig. 4) as well as a regress plane for approach from left (see Fig. 5). The same applies for the second axis.

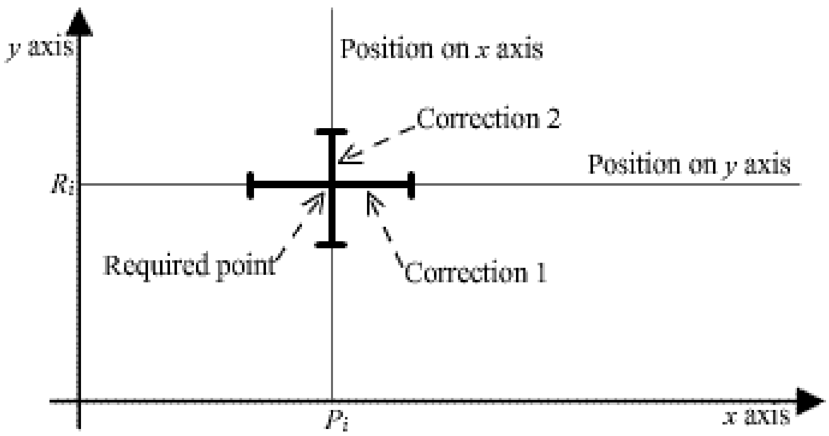

Fig. 3. Sketch of a desired point and necessary corrections

The equation describing the regress plane for the x axis and for approach from right is calculated according to (2) and has a form of

$$\begin{aligned}\Delta = &-10,949 + 0,3569P - 0,8497\cdot 10^{-3}P^2 + 0,0013\cdot 10^{-3}P^3 - 1,0939\cdot 10^{-9}P^4 + \\ &+5,1413\cdot 10^{-13}P^5 - 1,2536\cdot 10^{-16}P^6 + 1,2355\cdot 10^{-20}P^7 + 0,0422R\ - \\ &-0,0206\cdot 10^{-3}R^2\end{aligned} \tag{4}$$

while the equation of regress plane for approach from left has a form of

$$\Delta = -11{,}538 + 0{,}3618P - 0{,}88858 \cdot 10^{-3} P^2 + 0{,}0014 \cdot 10^{-3} P^3 - 1{,}2008 \cdot 10^{-9} P^4 + \\ + 5{,}7354 \cdot 10^{-13} P^5 - 1{,}4148 \cdot 10^{-16} P^6 + 1{,}406 \cdot 10^{-20} P^7 + 0{,}0368R - \\ - 0{,}0144 \cdot 10^{-3} R^2 \qquad (5)$$

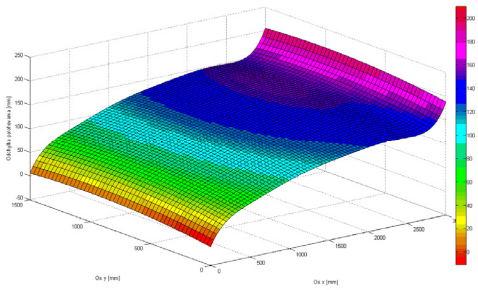

Fig. 4. Regress plane for *x* axis, approach from left

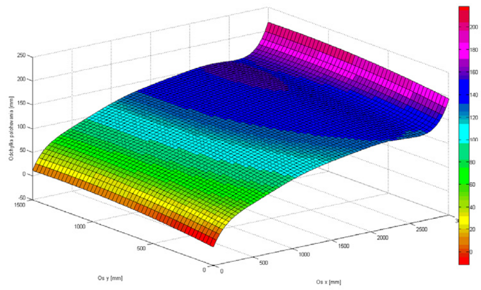

Fig. 5. Regress plane for *x* axis, approach from right

5. Conclusions

The international standard ISO 230-2:2006 provides scheme for calculation of positional deviation of the numerically controlled axis only in several discrete points. The procedure presented in this paper enables to estimate the positional deviation in any point of plane, no matter whether rotational or longitudinal axes are considered. Moreover it provides the estimate of the positional deviation with the respective uncertainty of such estimate. This gives the designer or programmer of the machine control system the information about behavior of the machine in any point of the axis travel. Thus appropriate corrections can be included into the control program or the adequate design corrections can be performed in the design of the machine.

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References

[1] ISO 230-2: 2006. Test code for machine tools – Part 2: Determination of accuracy and repeatability of positioning of numerically controlled axes.

[2] STN 20 0300-31 Measuring of geometrical precision of machine tools. Measuring method for measuring of positional accuracy - Meranie geometrickej presnosti obrábacích strojov. Metódy merania presnosti polohovania.

[3] V. Chudý, R. Palenčár, E. Kureková and M. Halaj, Technical quantities measurement - Meranie technických veličín. STU in Bratislava, Bratislava, 1999.

[4] R. Palenčár, P. Gros, M. Halaj, Evaluation of the positional deviation of numerically controlled axes. *Strojnícky časopis,* Vol. 57, n° 1: 1-12, 2006.

[5] J. Anděl, Statistical methods. - Statistické metody. Praha, Matfyzpress 1998.

[6] Shih-Ming, Wang - Han-Jen, Yu – H.ung Wei, Liao: A new high-efficiency error compensation system for CNC multi-axis machine tools. In: Int J Adv Manuf Technol 28 s. 518-526, 2006.