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Measurement of tool centre position change on horizontal boring machines

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Abstract
This paper focuses on the development and implementation of integrated measuring systems for the identification of geometry deviations primarily on horizontal boring machines. Based on analysis of the mechanical structure, the key nodes are determined for contributing most to the formation of geometric errors of an operating machine. The paper describes in detail the proposed integrated deformation measurement of an extensible ram. The measuring system enables to measure two displacements in a direction perpendicular to the ram extension and the rotation around two axes perpendicular to the ram extension. The device consists of a base platform equipped with a laser source, position sensing device (PSD) elements and a reference branch for the correction of laser beam divergence. The measuring platform is fitted with a passive reflector without any additional active elements, which makes the platform highly suitable for implementation in a place near the cutting tool. The advantage of the proposed position measurement lies mainly in the calibration of the geometry deviation and in obtaining the information about deformation at constant external load (e.g. tool or head weight, temperature load). Next, the paper presents design concepts of the measuring device of selected nodes including a mathematical and CAD model, as well as design construction and testing on a real machine. Last but not least, the article includes problems connected with implementation in current production machines.

Keywords: Geometry, deformation, deviations, measuring, compensation, calibration, laser beam, horizontal boring machine

1. Introduction

Monitoring tool centre position is a comprehensive task involving several areas. The key task is to divide the machine tool into smaller parts and classify the partial issues. The scope of this paper is limited to horizontal boring machines. It introduces a hardware tool for measuring deformation of the ram. The measurements presented were carried out in laboratories and on the shop floor on a WRD series machine tool from the machine tool builder TOS Varnsdorf. The objective was to design an additional measuring device aiming at minimum constraints on technological possibilities and maximum contribution to measuring geometric accuracy.

2. Static analysis of a WRD series machine tool

An analysis of the contribution of components to compliance in the intended place of the cutting tool makes it possible to identify components whose properties influence the static properties of the whole machine tool structure the most. The measurement system was designed for the component with the highest contribution to the compliance.

2.1. Numerical solution

Material constants were modified for selected machine tool components. The stiffness of a component was increased by changing the modulus of elasticity to the value E = $1{,}1*10^{14}$ Pa. The directional stiffness of k = 10^{12} N/mm is used for linear guideways modification. Individual modified components were monitored for displacement in the place of the cutting tool expressed as compliance p_x. The contribution of the displacement of the individual modified components z was determined in the main directions XYZ according to (1) as a quotient of the compliance of the original part p_0 to the difference of both compliances.

By applying the approach of gradual modification of individual components, the resultant compliance value on the cutting tool may increase and this may seemingly result in a decrease in overall stiffness of the machine frame. Interaction between the compliance of individual machine tool components is actually a general non-linear problem. The above-mentioned approach would be entirely appropriate only if the machine tool structure could be considered as an ideal system of serially ordered springs.

$$z = \frac{p_0 - p_x}{p_0} \cdot 100\ [\%] \qquad (1)$$

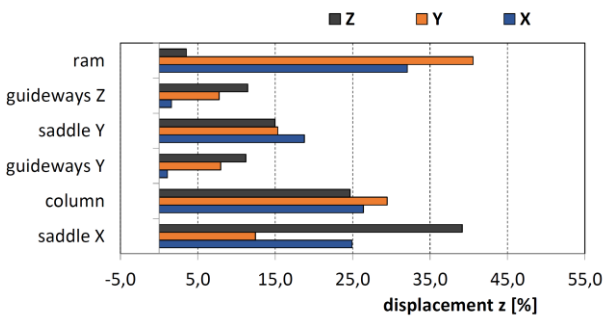

Figure 1. Share of machine tools components on total deformation based on FEM.

2.2. Measuring contributions of static deformation on the machine tool

Static loading on the real machine tool showed that deformation is mainly evident in the quill, Z axis and Y saddle.

Based on the numerical solution and the real experiment, the additional measurement was proposed on the quill deformation [2]. Scheme of the horizontal boring machine and

the quill deformation is shown in the Fig. 2. Deformations were measured in 4 directions.

3. Ram deformation measurement

Fig. 2 symbolically shows the monitored part of the horizontal boring machine together with the installed additional measuring device. The measuring device consists of two parts. The basic part is equipped with a laser source and sensing electronics. The secondary part, which is mounted on the front part of the ram, is a passive laser beam reflector [1].

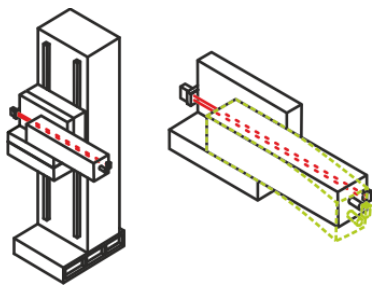

Figure 2. Symbolic representation of the horizontal boring machine and the installed measuring device.

3.1. Measurement model

Fig. 3 shows a model of the measuring device in the basic version for the measurement of 2 deviations. The type of measured deviations of the presented configuration (displacement and rotation) is marked by arrows. Both platforms are connected by the indicated linear guideways in the direction of the Z axis.

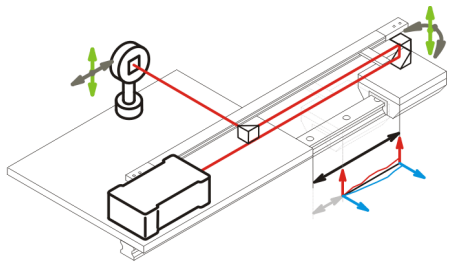

Figure 3. A scheme of measurement with one PSD for the measurement of 2 deviations.

Fig. 4 symbolically presents two measured motions of the reflective prism in the basic variation in the Fig. 3. This method of measurement can also be used for measuring displacement x and rotation φ_x [2], where a second reflective prism and PSD have to be used. The resulting device is designed for the measurement of 4 deviations (2 translations and 2 rotations).

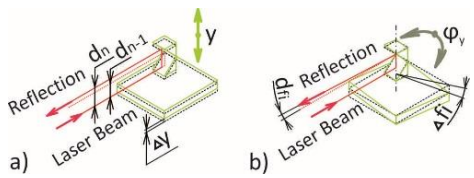

Figure 4. Two motions of the reflective prism, which can be measured.

3.2. Measurement simulation

Simulation of the additional measuring device was carried out in the Matlab/Simulink environment. It is easy to change both the geometry and configuration of the measuring device in the prepared programme. The graphical output from the programme allows visual checking of the designed equipment. The numerical output from the programme consists of equations (2) describing the dependence between the current position of the measuring reflectors and the point of laser beam impact on the PSD element. The measured values of rotations are dependent on ram extension l.

$$\varphi_x = f_1(x_{PSD\,1}, l), \varphi_y = f_2(x_{PSD\,2}, l)$$
$$x = f_3(y_{PSD\,1}), y = f_4(y_{PSD\,2}) \quad (2)$$

3.3. Design solution

An industrial variant of the measuring device was designed for real tests on machine tools. It consists of a measuring and reference branch. The left-hand side of Fig. 5 shows the CAD design of the device; the right-hand side shows the device ready for mounting on the machine.

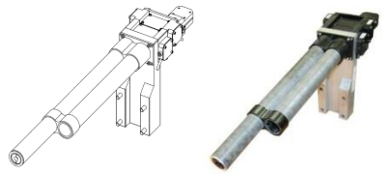

Figure 5. Main part of the measuring device with a reference branch for the measurement of deformation in four directions.

4. Measurements and tests

Laboratory tests were run prior to mounting the device on the machine. The main objective was to verify calibration algorithms and the stability of the measured signal. The testing ram with an installed measuring device allows an extension of 1 m and is equipped with position measurement.

Tests of static loading were run after mounting the device on the machine mechanically. A difference in the real deformation measured in two translations by a dial indicator and the optical device is shown in Fig. 6 and [3].

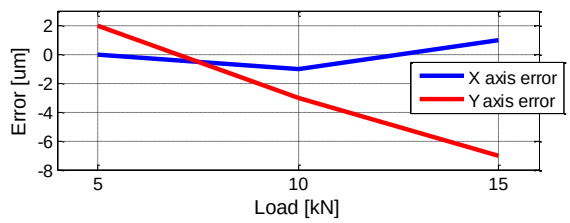

Figure 6. Difference in the real deformation measured with dial indicator and optical device in x axis (blue) and the y axis (red) translations.

The next development stage is going to address the integration and interpretation of the measured values on the level of the Siemens control system. National Instruments hardware tools were used for measurement. Both systems were connected using DP Profibus.

Acknowledgement

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References

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