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AUTOMATICALLY OPERATING CALIBRATION METHOD FOR A THREE-AXIS PARALLEL KINEMATIC MACHINE

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Abstract*: This article is intended to show how to automatically calibrate a parallel-kinematic structure on the use of the QCM measuring device. The device allows the simultaneous determination of up to six degrees of freedom, three translational and optional three angular displacements. The additional QCM-software provides measuring data for calibration on the basis of parameter identification. Calibrating a parallel-kinematic structure is done in two steps. During Step 1 the software provides information on adjusting the parallel layout of three pairs of struts, which has to be done manually. Step 2 deals with the translational deviations and can be done automatically. The QCM-software delivers correction values for an adjustment of parameters in the machine control.*
***Key* words**: *Parallel kinematic machines, calibration, Quickstep, Error compensation, tooling machine*

1. INTRODUCTION

Machine tools have to be calibrated to be able to meet the demands of accuracy. Limited accuracy in the positioning or guiding of the tool can be the result of a measurement error in determining the position of machine axes, of model parameters not representing the actual machine geometry and/or geometric or kinematic effects not taken into account in the kinematic model. Two different degrees of freedom can be distinct: Active and passive ones. Active degrees of freedom can be influenced by adjusting the kinematic model in the control to the given machine geometry. Passive degrees of freedom which are decisive for processing have to be adjusted to the nominal position best as possible.

Main problem in using parallel-kinematic machine tools for industrial applications is the lack of automated calibration methods, necessary for a simple and quick calibration in manufacturing environment.

The process of calibration basically consists of the following three steps:

- Measurement of the actual positions of the tool centre point (TCP) at the desired positions
- Calculation of adapted kinematic parameters or adjustment values from the measured deviations
- Implementation of the calculated parameters in the control or adjustment of the structure according to the values obtained

An overview on calibration techniques and the calibration of the parallel kinematic machine Quickstep with three degrees of freedom was already shown in detail in (Bleicher, 2003), (Bleicher, 2002) and (Bleicher & Janner, 2001).

To evaluate the structural accuracy measurement methods in six degrees of freedom are required. Most common methods are based on the following techniques:

- Optical systems (e.g., laser-tracker, Hexscan)
- Mechanical systems (e.g., Omnipage, measuring tripods)
- Scanning of test parts (Stengele, 2002)

Optical systems allow multi-dimensional measurements, but generally do not achieve the required accuracy. Mechanical devices can usually be determined for up to three degrees of freedom regarding to larger measuring ranges. Main disadvantage in using test parts is limited flexibility in application though it seems the most expedient solution by now.

Up to now measurement for calibrating the Quickstep structure has taken place independently for the individual degrees of freedom. A large number of various equipment and measurement devices have been used, and therefore inaccuracies in the definition of the geometric dependencies of the individual series of measurement appeared. The measuring procedure was both, time- and labour-intensive. Main aim was to simplify the whole process and to enable automated data collection. The multi-dimensionally operating measuring device, so-called Quickstep Calibration Machine (QCM) was developed.

The three-axis structure of the parallel-kinematic Quickstep machine requires a two-phase method of calibration:

- A mechanical adjustment of the parallel layout of the three pairs of struts (corresponds to a calibration of the rotational deviations) as well as
- An adjustment of parameters in the machine control (corresponds to a calibration of the translational deviations)

The measuring machine provides the measuring data in a defined data format. This allows implementation of an automated measuring and calibrating method which comprises a PC-solution for evaluating position measuring data as well as identifying parameters and enables communication to the machine control.

2. QUICKSTEP CALIBRATION MEASURING MACHINE –QCM

Direct measurement of geometric structural features of real machine geometry is in the majority of cases not feasible and therefore mainly of theoretical relevance. Practically relevant strategies are based in measuring the deviations between desired and actual coordinates in at least one of the degrees of freedom of tool movement. This is where the QCM should be used. Consisting of a serially structured three-axis moving construction the QCM was optimised with regard to the error influence due to weight forces and geometric deviations resulting from manufacturing tolerances. Movement space and therefore range of measurement extends over X=600mm, Y=600mm and Z=250mm. The base axis (Z-axis) and the transverse axis (X-axis) are equipped with two linear encoders (Type Heidenhain LS 487). This enables to take the rotational displacements of the slides in account. Both measured values of one axis are converted into a position value of a virtual measuring system, so-called phantom scale, which is located at the actual position of the tool interface. The detection of the yaw movement of the slide allows the reduction of dimensions, especially slide length. This results in smaller dimensions of the measuring unit. The vertical axis (Y-axis) only comprises one scale (Type Heidenhain LS 487), which is positioned centrically under the Y-Slide to minimise error influences resulting from rotational displacements. Thus five linear encoders are used determining the position.

Optional an orientation measuring head can be placed on the unit for measuring the three spatial angles rotX, rotY and rotZ. Three measuring touch probes (Type Heidenhain MT

1281) are used for detecting angular displacements. Because of the measuring concept only angles around a defined reference pose with a range of ± 3° are to be determined.

A PC-based measuring software computes the current position and, if the orientation head is mounted, the angular deviation from the nominal position. Thus the QCM allows simultaneous measurement of six degrees of freedom. Additionally thermal displacements can be compensated by reading in temperature sensors.

3. CALIBRATION OF MEASURING SYSTEM

A plate was mounted on the measuring slide of the QCM where both the position and the spatial orientation could be determined with a coordinate measuring machine. Therefore several measuring points were defined to enable precise information in the entire movement space of the QCM. If the parameter of the geometric model differ from the real geometry deviations between the computed position of the QCM-software (based on the five encoders) and the desired position occur. These parameters can be optimised using the minimisation of the position error squares as a criterion. In conjunction with a compensation table, parameter calibration of the QCM allows an accuracy of about 12µm throughout the entire measuring range.

Similar to the calibration of the parameter model of the QCM-base a parameterisation of the angle measuring system is also being carried out. The rotation of the slides is therefore also taken into account by using the linear encoder of Z- and X-axis.

4. AUTOMATED CALIBRATION STRATEGY

Because of several disadvantages regarding redundant measuring systems in the machine tool (e.g. increase in system costs or reduction of dynamic performance) a calibration strategy is conceived which covers the demands for a flexible solution in a cost- and time-efficient way of use (Huang & Whitehouse, 2000; Yuan et al., 2002; Cenati et al., 2002). The QCM is thus based on conventional length measurement technology and designed as a simple mechanical solution. The calibration procedure comprises the following steps:

- Equipping and loading the QCM into the workspace
- Coupling the QCM with the main spindle
- Connecting the QCM to the measuring computer
- Measuring the PKM structure
- Parameter identification
- Adjusting of joints and adapting parameters in the machine control
- Control survey
- Repeating parameter identification and adaptation, if needed
- Decoupling and unloading of QCM

The pallet-exchanging system is used for loading the QCM into the workspace of the Quickstep PKM. The measuring slide is connected to the main spindle by means of an HSK machine tool interface.

The PKM Quickstep is positioned to predefined measuring points using an adequate NC-program. The QCM is moved only by the mechanical coupling through the main spindle. To minimise displacements as a result of friction forces a force-sensitive activation would be appreciated. When reaching a measuring point a binary signal coming from the machine control triggers the measuring computer to process the actual position datum of the QCM and store it into a file. This position data is used for calculating the deviation compared to the desired position that can be extracted from the NC-program. Integrating the QCM measuring software and the numerical parameter identification in one PC solution and providing a direct data transmission to the machine control result in an automatically operating calibration procedure.

Two different sets of parameters are computed for the Quickstep parallel-kinematic machine:

- Parameters for compensating rotational deviations
- Parameters for compensating translational deviations

During first calibration step the rotational deviations of the tool platform are minimised by means of a mechanical adjustment of the parallel-kinematic structure (Bleicher & Janner, 2001; Bleicher, 2002). To optimise the parallel layout of two struts the positioning errors of four joints are moved to one joint that has to be adjusted. This step has to be done manually by now. During step two the QCM-Software directly interacts with the machine control providing parameters for compensating the translational deviations.

5. OUTLOOK

At present various experimental measures are being taken to increase accuracy. The objectives are to improve the precision of measurement to about 5µm, with the dispersion of individual measured values in this scale being taken into account. The limits of mechanical possibilities are prefigured by the accuracy obtained by coordinate measuring machines. The constructive challenge lies in the mechanical implementation of improved solutions in a limited construction space. A small construction size simplifies the handling of the QCM and is seen as a precondition for greatest flexibility in the use of this measurement technique.

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