Development of methods for numerical error correction of machine tools : interim report no. 2

Development of Methods for Numerical Error Correction of Machine Tools

INTERIM REPORT No 2
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Project coordination: Eindhoven University of Technology, Metrology Laboratory.

Partners: Eindhoven University of Technology, Metrology Laboratory, Eindhoven, The Netherlands (TUE);
Physikalisch Technische Bundesanstalt, labor 5.32, Braunschweig, Germany (PTB);
Philips Export BV, Industrial Automation, Eindhoven, The Netherlands (Philips);
Maho Aktiengesellschaft, Pfronten, Germany (Maho).

SUMMARY

In this report all activities are presented during the second period of the project 'Development of Methods for Numerical Error Correction of Machine Tools'. A quick overview is given of the activities of the partners concerning the project according to the BCR-workplan. Also a summary of activities during the next period, which will end in May 1991, is shown.

INTRODUCTION

During the second period, May until November 1990, all partners in the BCR-project continued their activities. TUE has measured the thermomechanical behaviour of the Maho milling machine during warming-up and cooling-down periods. They are now using a statistical approach to predict the drift of the machine, based on the measured temperatures. In consultation with the TUE, Philips has worked out a proposal for an experimental setup that supports the manufacturing of workpieces for verification of this method.
PTB designed three types of workpieces to test a milling machine. With these workpieces they not only try to find a new way to determine the error components of a machine tool including thermomechanical effects, but also try to prove the validity of approaches, which determine the errors without machining processes.
Maho gave technical support and information about the hardware of the milling machine. They will also prepare and install a probe-system to utilize the milling machine for measurement of reference objects.

TUE prepared also an identification system for all relevant reports, concerning the project. With this system all partners are enabled to trace a certain report.

On June, 27th 1990, the third meeting of the BCR-project partners took place at Eindhoven University. During this meeting experience was exchanged, models and measuring methods were discussed. An appointment for the next meeting was also made, which will take place at December 20th 1990 at PTB, Braunschweig.

OVERVIEW OF ACTIVITIES ACCORDING TO THE BCR-WORKPLAN

In the next part the activities and results of the second half year period are described.

A. Classification of Machine Tools and their Specific Errors

Participants: TUE, Maho, Philips

Maho made a list of the most important type dependant geometric and thermal errors of the machine tools they deliver [BCR-90/006]. In this list Maho made a classification in knee type and bed plate milling machines.
PTB supplied the relevant part of the ISO-standard 1701.
TUE has made the proposal for the final version of a classification using both documents. During the next meeting this proposal will be discussed, after which TUE will finish the proposed classification.

B. Bibliographical Studies

Participants: TUE, PTB

TUE has provided a database system capable of containing all relevant literature. This system is operational. TUE will send an update to all partners, when new literature has been added to the database. The last update took place on November 1990. During the meetings these updates are discussed and, if necessary, changes will be made.

TUE will take care of all relevant reports concerning the project. Therefore they made an identification system to enable all partners to trace a certain report.

C. Agreements. Standardizations for the Exchange of Data

Participants: TUE, PTB, Philips, Maho

For the exchange of temperature and geometric data all partners agreed to use the VDA-data-format [DIN 66301]. PTB supplied all partners with a program (written in Turbo Pascal) and a manual [BCR-90/004] to support this data-format.
Both TUE and PTB agreed to exchange data concerning the drift measurements, which have been done at TUE. During the next meeting PTB will present a list of the measurements they like to use for testing their thermomechanical model. After evaluation, PTB will return their results to TUE, so both the thermomechanical models used by TUE and PTB can be compared.
PTB will measure a 2-D reference-object on the Maho milling machine to determine geometric errors. To utilize the milling machine, Maho will deliver a Heidenhain probe-system and the additional hardware.

D. Geometric Error Models Including Finite Stiffness

Participants: TUE, PTB, Philips, Maho

TUE has developed a general error model which can be applied to multi-axes machines of arbitrary configuration. This kinematic model describes the deviation of the tool to the workpiece, based on deviations in the relative location of coordinate frames attached to succeeding components. This error model will be based on geometric errors, finite stiffness errors and (later) thermal errors. TUE is preparing a draft version of this model. The final version will be presented to BCR May 1991.
To model and/or estimate the error components PTB and TUE are investigating a different approach. TUE directly measures the error components on the five axes milling machine using laserinterferometer, inductive displacement sensors and electronic levelmeters. These instruments, including the five axes milling machine, are controlled by an IBM compatible computer. These measurements have been started at the end of october 1990.
PTB focuses on the indirect acquisition of machine tool error components using testworkpieces. They have designed three types of test workpieces:
Type 'F1' Preliminary design, not used any more;
Type 'F2' A workpiece for mapping the error components of linear axes;
Type 'F3' A workpiece for mapping the error components of rotary axes;
Five test workpieces of type 'F1', manufactured on a milling machine under equal operating conditions (see previous interim report), were measured on a coordinate measuring machine. The repeatability of basic geometrical characteristics in the XZ-plane of the machine tool has been determined, after eliminating thermal drift.
The types of machine tool errors of the linear axes that manifest in and can be determined from a test workpiece depend on the orientation of the tool relative to the machine axes. Three positions (orientations) are required to detect all error components of a 3-cartesian-axes machine.

The machine-to-workpiece imaging characteristics of rotary table error components have been analyzed for milling processes by PTB. The 6 error components of the rotary axis manifest in the workpiece type 'F3', as shown in figure 1. They are determined by evaluating the characteristics of the cylinders.

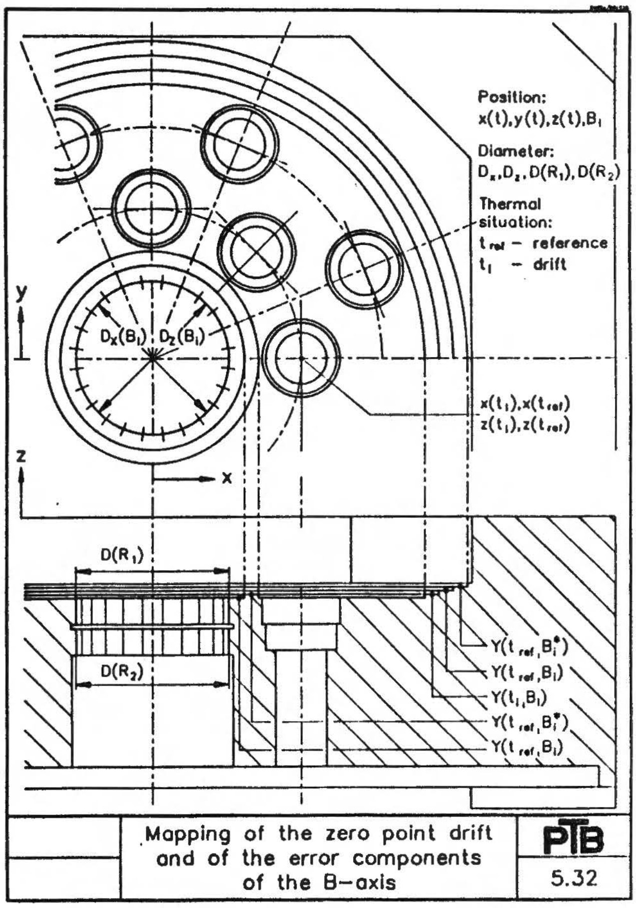

Figure 1: Workpiece type 'F3'.

For the evaluation of geometric data from a test workpiece the development of a three-stage evaluation program was continued. With this program the workpiece-oriented data shall be transformed into machinetool-oriented error data. The first stage of this program system for the evaluation of test workpieces has been finished. The second stage of the program system will calculate the machine errors, based on the geometrical errors of the workpiece as evaluated by the first part. In the third stage of the program simulations of the thermomechanical behaviour of the machine will be realized. The results of this simulation may be used for a numerical error correction. The validity of the simulation will be checked by comparison with the results from experiments with workpieces.

Maho supplied information about the hardware correction for the finite stiffness errors of the X- and Z-axis. The finite stiffness error in the X-axis is corrected by grinding the X-guide cylindrical. The error of the Z-axis is corrected partial by two tension rods.

E. Thermo-mechanical behaviour

Participants: TUE, PTB, Philips, Maho

TUE has measured the thermal behaviour of the milling machine by using six inductive displacement sensors and a 57-point temperature measuring system. The behaviour of the milling machine is measured during warming-up and cooling-down periods. They try to predict the drift of the machine based upon the measured temperature, using a statistical approach. As the drift will depend on the position of the axes of the milling machine, they made several drift measurements in the production volume of the milling machine.

The concept of PTB is that for each basic operating condition again several reference states are defined. This results in a relatively large total number of reference states for which the relationship "temperature distribution/geometric errors" is well known by experiment. Deviations from these known states are analytically calculated according to methods used already for coordinate measuring machines.
Different test workpieces and different machined tracks in the workpieces shall give evidence of the geometric errors related to the different thermal states. Test workpieces of the type 'F2' are continuously being manufactured and measured during last period. First results are expected during the next period, when the evaluation software will be ready.
The same type of workpiece as shown in figure 1 is used for the analysis of the errors of a rotary axis, in order to determine the thermal drifts. Three translational and two rotational drift components of the tool are mapped by milling the cylinders during the warming-up state of the machine.
The drift components will be evaluated by comparing the cylinder positions, orientations and diameters in the warming up state with those in the reference state. Experiments for this evaluation are under preparation.

F. Correction

Participants: TUE, PTB, Philips, Maho

Philips supplied information about the controller, which is used in the Maho milling machine. They described these features in the report 'Overview on machine error compensation in Philips CNC' [BCR-90/005]. They have also prepared a precise document of the current CNC software for thermal and geometric error correction, in order to facilitate future changes.
Philips will, in close cooperation with TUE, prepare a preliminary correction for the thermal and the most important geometric errors of the milling machine.

ACTIVITIES PLANNED FOR THE NEXT PERIOD

On December, 20th 1990, the 4th meeting will take place at Physikalisch-Technische Bundesanstalt, Braunschweig. During this meeting there will be a discussion about the final version of the classification. When all partners agree, TUE will finish the proposed classification.
Results of the experiments, which were carried out during last period, and developed workpieces will also be discussed during this meeting. Based on this discussion the research program for the next period, with special attention to software correction will be defined, following the schedule as given in table I of annex I.
All participants will continue their activities on modelling, development of reference objects, measurements and estimation techniques. TUE will measure geometric errors, including errors due to finite stiffness, on the Maho milling machine. Based on these measurements they will verify the general geometric error model and carry out simulations. The final version of this model will be presented to BCR May 1991.
Philips will, in close cooperation with TUE, prepare a preliminary correction for the thermal and the most important geometric errors of the milling machine.
PTB will continue its work by milling test workpieces and measure them afterwards. Experiments will be done to determine the zero point drift. They will finish their program system to transform the workpiece-oriented data into machinetool-oriented data.
Maho will deliver a probe system and additional hardware and take care of the technical support and information about the hardware.