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Principle and verification of a structure model based correction approach

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Abstract

Structure model based correction is a new approach for the reduction of thermally induced positioning errors in machine tools. Herein axis-position dependent correction values are calculated in thermal real-time using thermal and thermo-elastic models. The correction values are used for the compensation of thermal errors. Necessary input data for the thermal model are captured in the control. This approach is verified at a 6-axis-machine using a camera based pose measuring system. The paper shows the principle of the correction approach and its verification by pose measurements. In conclusion the correction model meets the qualitative displacement in the workspace quite well.

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Keywords: machine tool; thermal error; compensation; measurement

1. Introduction

Thermal errors of machine tools influence the machining accuracy. Especially in high-precision processing the thermal error induces a significant geometric error of the machined work piece. Therefore different measures are taken to reduce this error [1]. The most common approach is to warmup or cooldown the machine tool to reach a thermal steady state. This approach requires a large amount of additional energy. An overview of investigated compensation approaches can be found in [2].

In the Collaborative Research Centres (CRC)/Tranregio96 of the German Research Council DFG "Thermo-energetic design of machine tools" different approaches for the compensation of thermal errors without additional energy consumption are investigated. Within the CRC three different model based corrections are researched. The first correction approach is based on characteristic diagrams. These diagrams describe the correlation between temperatures at selected points of the machine structure and the displacement at the tool center point (TCP) [3] in an empirical way. The second correction approach is the property model based correction [4]. This approach uses transfer functions (lag elements of first and second order) to determine the thermal error out of control internal data [5]. These correction approaches are advantageous for machine tools in series production.

The third correction approach researched in the CRC is the structure model based correction. This correction approach is the topic of this article. In contrast to the first two approaches the structure model based correction simulates the physical behavior of the entire machine tool. As simulation models FE models or node models are used. These models include the structure and the structural changes due to the moving of the machine. Until now these simulation models are mainly used to analyse machine tools. The structure model based correction uses these models for an online correction of thermos-elastic errors at machine tools. The prime requirement is that temperature field and deformation field of the machine tool can be calculated in thermal real time. Thermal real time is characterized by the smallest thermal time constant of the machine tool which is typically some minutes. Model input data are control internal data and the ambient temperature. No additional sensors are necessary. With this information the displacement at the TCP can be

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calculated. The advantage of structure model based correction is that the quality of the result is widely independent from the load cases which are carried out at the machine tool. So this correction approach is not only suitable for series productions but also for single-item production with a high variability of process loads and environmental conditions. Another advantage is that experimental investigations are only necessary for the adjustment of the model parameters.

The focus of this article is the verification of the structure model based correction. The verification is performed on the example of the mobile demonstrator (hexapod kinematics) of the CRC (Fig. 2). The thermal models of the struts of the mobile demonstrator have been verified with temperature measurements [6]. For the verification a new camera based photogrammetric measurement system is used [7].

2. Principle and implementation of the structure model based correction

The structure model consists of a set of different models. The models are *power dissipation* and *thermal conduction models*, *thermal model* (temperature field), *thermo-elastic model* (deformation field) and *correction model* (correction values for axes positions). The necessary functions for the structure model based correction can be divided into modules as shown in [8]. In Fig. 1 the modules for the implementation on the mobile demonstrator (Fig. 2) are sketched. The implementation is as follows: As control a Beckhoff TwinCAT3 is used. In a separate PLC (Programmable Logic Controller) in the control the necessary load data (axes positions, velocities, motor torques and ambient temperature) are captured. The PLC runs with a cycle time of 10ms. The high real time requirements for the load data capturing are fulfilled by this cycle time [9]. The simulation models are processed on a separate PC. As interface between the control and the simulation PC the ADS interface (Automation Device Specification) of Beckhoff is used. The industrial PC is connected via Ethernet to the simulation PC. A program (written in C ++) on the simulation PC accesses the load data with a cycle time of 10 ms and arranges them to blocks of 10 s. The models for power dissipation, thermal conduction and the thermal model are running in Matlab. As interface between Matlab and the C++ program a shared memory area is used. One load step of the thermal model is about 10 s. That’s why the calculated power dissipation and thermal conduction are averaged over 10 s.

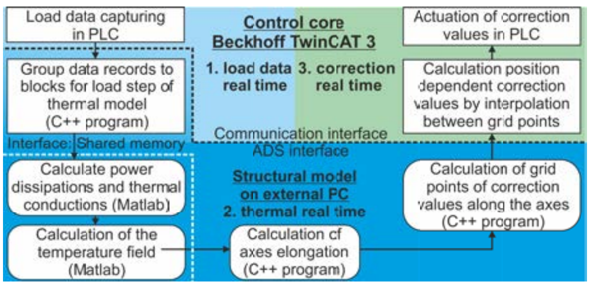

Fig. 1. Implementation of the structure model based correction on the example of the mobile demonstrator

Fig. 2. Structure of the mobile demonstrator (MiniHex).

The thermal model was created in Ansys. The original model can’t be calculated in thermal real time. In Matlab the model order of the thermal model was reduced [6]. The temperature field for one load step of 10 s is calculated in approximately 1.5 s. Afterwards the temperatures are written into the shared memory and read by the C++ program. In the program the thermo-elastic deformations of the axes in axis direction are calculated. For the axes of the hexapod can be assumed that they are able to expand freely in axis direction. Based on the thermo-elastic deformations grid points along the axes are calculated. These grid points are transferred by the ADS interface back into the control. In the control a second PLC is running in the interpolation cycle of the CNC (2 ms). In every cycle of the PLC new correction values are calculated by interpolation based on current axis positions and the grid points. Finally the correction values are actuated by adding offsets to the axes set points.

3. Measurement setup

Implementation and test of the structure model based correction are realized at the mobile demonstrator of the CRC/TR96. The mobile demonstrator is a Stewart platform (Fig. 2) and can move in 6 degrees of freedom. The workspace is about 600 x 600 x 600 mm in X, Y, and Z-direction. The six extendable axes are driven by servo motors, connected with toothed belt drives to the ball screw. The spindle ball bearings are mounted at the cases of the toothed belt drives. The axes are connected at both sides with universal joints to the base and the movable platform. Relevant for the thermal behaviour of the machine tool are servo motors, spindle bearings, ball screws, ball nuts and telescopes.

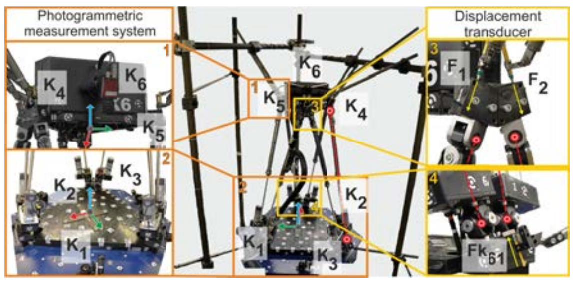

Fig. 3. Experimental setup.