Special Interest Group Meeting on Thermal Issues
Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen, Germany, February 2020
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Efficient FE-Modelling of the transient thermo-elastic machine behaviour of 5-axes machine tools.

Christian Brecher[1], Stephan Neus[1], Mathias Dehn[1]

[1]Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, Germany

m.dehn@wzl.rwth-aachen.de

Abstract

The demand for more accurate machine tools is continuously rising. Therefore, thermal error compensation methods need to get more precise under thermo-elastic real time conditions. This paper introduces a simulation model architecture that combines the accuracy of geometric measurements with the adaptability to transient thermal distributions of simulation models. It is shown, how a geometric measurement result can be processed to be fed back into the simulation model to increase its accuracy.

Machine tool, Deformation, Thermo-elastic behaviour, Simulation

1. Introduction

Machine tools like milling and turning machines have become an integral part of the production process. They must cope with continuously rising requirements on workpiece complexity and accuracy. To achieve these requirements, machine tool manufacturers are working on reducing potential machine error sources to a minimum. A major part of the total error is the error resulting from thermal influences, which can have a share of up to 75% on the total error [1]. This high error share is even more concerning, when looking at the trend of small batch sizes to custom fit products to consumer needs [2]. Since machining conditions change more frequently with small batch sizes, the machine is constantly in a transient state. In this transient state, thermal compensation methods are less accurate, which leads to an increase of the thermal machine error. To reduce the error from this transient machine behaviour, this paper introduces an architecture for an FE-model that can simulate the machine distortion and the resulting displacement of the Tool Centre Point (TCP). Furthermore, a procedure is shown how the results of geometric measurements can be fed back into the model to compensate inaccuracies resulting from the model abstraction.

2. Thermal error machine compensation

Machine tool manufacturers take different approaches to compensate thermal machine errors. Besides design measures to control heat flow in and out of the machine structure to homogenize the thermal field in the structure, also Numerical Control (NC) based approaches are well established. Traditionally, this compensation is implemented by measuring the displacement of the TCP in the machining area at one or more positions, for example using an ETVE test according to ISO 230-3 [3]. The measurement results are used to compute a compensation table with which the NC compensates the geometric error [4, 5]. Since geometric machine measurements tend to be either inaccurate or time consuming, current research efforts focus on solving this conflict of objectives. Brecher et. al. were able to develop a measurement procedure that is able to compute axes errors from a dynamic R-Test measurement in under eight minutes [6]. Due to the combination of a short measurement time and accurate measurement results, the dynamic R-Test is used for the geometric measurements in the experiments discussed in this paper. However, all geometric measurements including the dynamic R-Test have in common that they only pose a snapshot of the machine distortion. They are valid for as long as the thermal distribution in the machine structure is nearly constant. For transient machine behaviour the measurement process has to be repeated often, reducing the productivity of the machine.

More recently, there has been a focus on modelling the machine tool deformation. In contrary to a real measurement of the machine geometry, modelling of the machine behaviour, has the benefit that it can be compensated in real time [7, 8]. Turek et. al. created a model which includes the whole machine structure, but in order to integrate it into the machine they needed to simplify the model. This leads to a significant decrease in precision [9].

In order to use the benefit of the accuracy of geometric measurements and the ability to adapt the compensation for a transient heat distribution of the simulation, this paper develops a model architecture to combine the two methods. The resulting theoretical compensation is depicted in Figure 1. The figure shows the displacement of the TCP of a machine tool. In the example, a geometric measurement is conducted at three time points. The TCP displacement at these points is used in a traditional compensation method to compensate the TCP displacement. Since this kind of displacement is not adaptive to the transient machine distortion, the compensation error increases over time. In contrary to this static approach of the traditional machine compensation, the proposed compensation method estimates the TCP displacement between two R-Test measurements using a white box simulation model. The results of the simulation model can be used to compensate the TCP position in between measurements. When the model uncertainty and thus the machine positioning error get too high, the R-Test is repeated. The figure shows how the difference between the actual TCP displacement and the compensation value is much smaller for the proposed method compared to the traditional method, thus decreasing the positioning error.

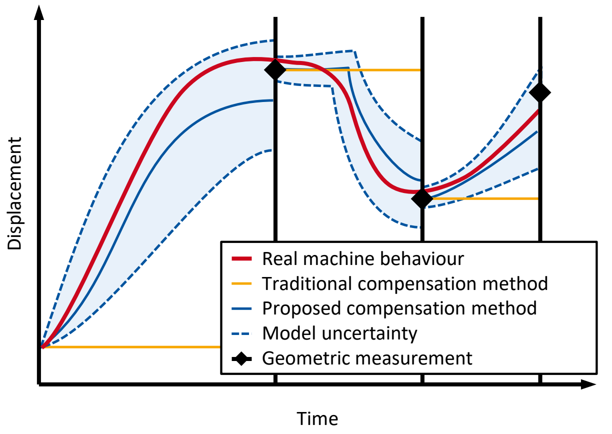

Figure 1. Proposed machine compensation method in comparison to traditional method.

3. Model architecture

The most important requirement for the model architecture is a high computing speed. The computation time needs to be short enough to model in thermal real time, which is considered to be one minute. To achieve a high speed, the simulation will have a high degree of abstraction, which inevitably results in a larger computing error. The model architecture, shown in Figure 2, is designed to cope with this error.

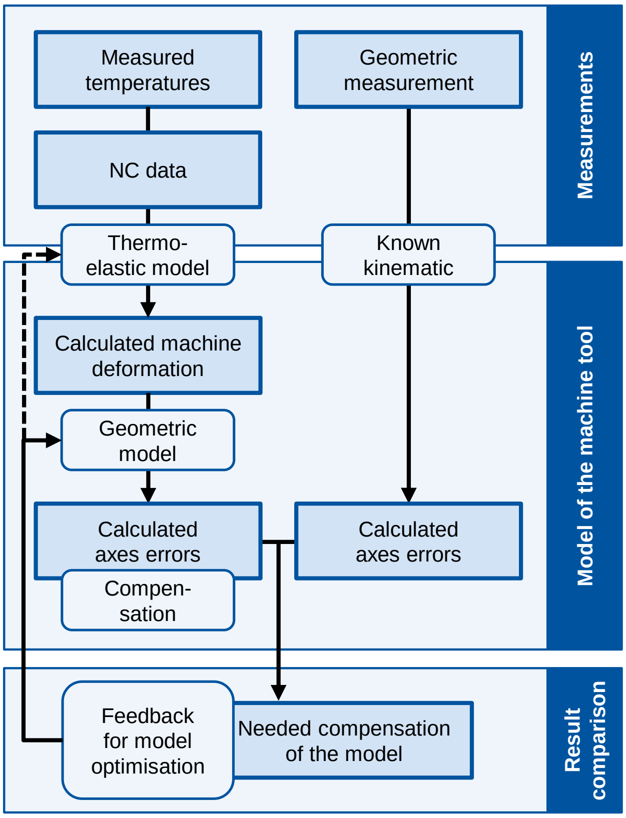

Figure 2. Model architecture for a real time machine compensation with geometric measurement feedback.

The basis for the model are the measurements gathered on the machine. Temperature sensors are placed onto multiple points of the machine structure. Together with the NC data, which provides information for instance about the introduced power, they deliver continuous information about the state of the machine. Next to this continuous data, a dynamic R-Test measurement is conducted in regular intervals and provides accurate “snapshots” about the machine distortion for the point in time of the measurement.

While the individual axes errors can be computed from the geometric measurement directly by a reverse transformation, the temperatures and NC data is fed into a thermo-elastic model of the machine which calculates the machine deformation. The machine deformation is then analysed to give the axes errors which can be used for the compensation of the machine. At this point, the model has two values for axes errors. One of them comes from the geometric measurement and one from the simulation of the machine. The vector between the results is calculated and used to increase the accuracy of the simulation model.

4. Summary and outlook

This paper proposes a model with which it is possible to improve the thermal compensation of machine tools. It is presented how the model combines the existing approaches of geometric machine measurements and white box simulation models. Furthermore, a model architecture is proposed which describes how the method can be integrated into the machine compensation procedure.

In further work, it needs to be explored how precise the model can simulate the machine deformation. Estimating the accuracy of the simulation model can give information about when a geometric measurement needs to be conducted. It should be investigated how the model accuracy develops and how a change of the measurement interval changes the measurement effort and accuracy of the model.

5. Acknowledgment

This IGF Project ‘TheKo 5 – Thermo-elasctic error compensation for 5-axis machining centers’ (AiF 20377 N) was supported via AiF within the programme for promoting the Industrial Collective Research (IGF) of the German Ministry of Economic Affairs and Energy (BMWi), based on a resolution of the German Parliament.

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages
Forschungsnetzwerk Mittelstand AiF

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