Special Interest Group Meeting on Thermal Issues
Laboratory for Machine Tools and Production Engineering (WZL) of
RWTH Aachen, Germany, February 2020
www.euspen.eu

Development of a method for the evaluative comparison of procedures for the correction and compensation of thermally induced errors on machine tools

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Abstract
The demands for increased productivity and manufacturing accuracy mean that the relevance of thermally induced displacements of the TCP on machine tools is constantly increasing.
In order to avoid errors in the resulting workpiece geometry, the SFB/TR 96 "Thermo-energetic design of machine tools" develops various solutions for correction and compensation.
This work presents a comprehensive assessment method of these solutions. In addition to the purely technical aspects, economic factors are also taken into account in order to be able to assess the solutions holistically. The aim is to classify the entire implementation effort and the benefits of the solutions.
With the help of this method it is possible to offer potential users an optimal selection taking into account their operational requirements and their requirements for the correction or compensation procedure.

Evaluation, Knowledge management, Methodology, Thermal error

1. Introduction

In order to increase the productivity of machine tools, it is often necessary to increase the drive power. The associated power losses lead to increased thermally induced deformation.
With the simultaneous demand for increased manufacturing accuracy, the resulting displacement of the TCP can lead to relevant errors in the workpiece geometry.
The aim of the project SFB/TR 96 “Thermo-energetic design of machine tools” is to research and develop compensation and correction procedures in order to solve the conflicting goals of energy input, precision and productivity within the chipping production. Within this project, a holistic evaluation of the developed procedures will be conducted, which considers both technical and economical aspects. A suitable valuation metric should take into account the thermo-energetic efficacy of each procedure, its applicability for defined use scenarios, as well as the impact on the amount of resources needed. To address the complexity of such a valuation method, an approach is being conducted that, on the one hand, evaluates the applicability of each procedure for predefined operational scenarios through measurements and, on the other hand, captures the procedure’s impact on all phases of the product life cycle by conceptual semi-formal modelling.
In the following section, the method of assessing the overall effort and costs for each solution procedure will be displayed. In section 3, the approach for the assessment of the efficiency will be explained. Furthermore, a concept of a rule-based recommender-tool will be presented in section 4, which will make the designed valuation method available. In the end, an outlook will be given on future work that needs to be conducted.

2. Assessment of the overall effort

In order to carry out a detailed and transparent assessment of the costs and effort, each developed solution procedure is being modelled with the Business Process Model and Notation (BPMN). BPMN is a modelling language for the representation of business processes and allows the illustration of actions, responsibilities, decision processes and artefacts such as documents or resources. The BPMN was chosen since it is broadly accepted in research and industry [1] and, moreover, allows a light-weighted definition of language extensions, which facilitates the representation of artefacts that are specific for the project context. For the inquiry of the process steps, an interview is being conducted with one expert each of the according solution procedure. For each process step, the material and immaterial resources needed are being displayed, as well as eventual related risks. Figure 1 illustrates an extract of a modelled procedure.
Furthermore, each expert is being asked to estimate the life cycle costs of the method examined. Therefore, the costs given in the VDMA guideline 34160:2006 are being used, which are subdivided into the phases installation and implementing, operations and recycling and dismantling [2]. Thus, the modelling of processes has two objectives. On the one hand, the procedures are made comprehensible and on the other hand, the estimated effort and costs become transparent and reasonable. Next to the assessment of effort, the interviews should enable a statement to be made about the flexibility and long-term behavior of the procedures. The estimations conducted in one-on-one interviews will be evaluated with an expert panel according to the Delphi method, if necessary in several runs [3].
Since the procedures that are to be examined are part of a

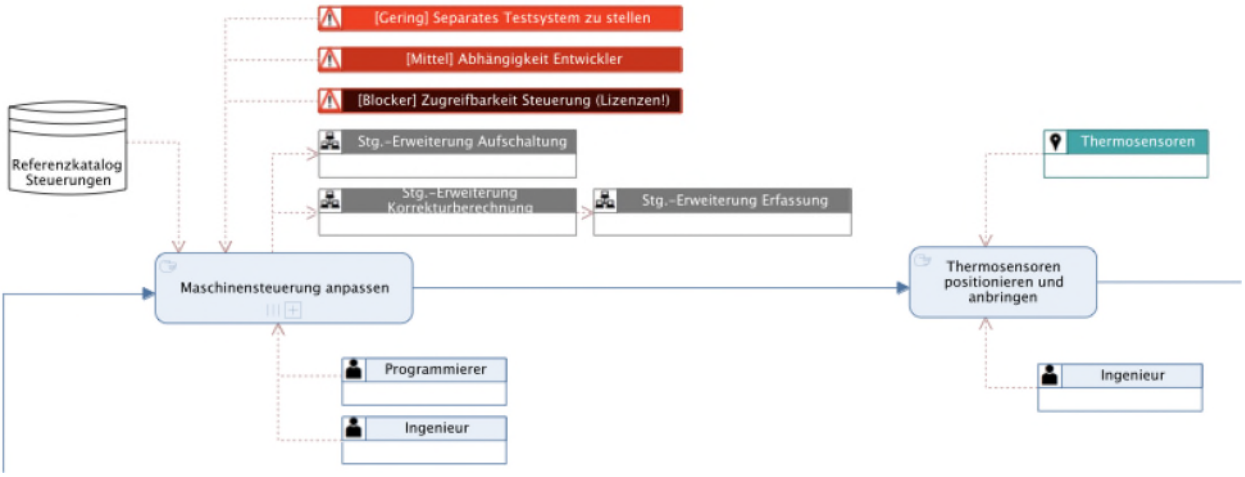

Figure 1. Extract of a modelled solution procedures

project which is still running, they are still in the research process and not fully developed, yet. Therefore, the estimated effort may change as the research goes on. In order to address this within the valuation metric, the concept of the technology readiness level (TRL) [4] will be utilized and included in the evaluation by considering the potential for improvement a higher level of technological readiness can entail.

3. Assessment of the efficiency

In addition to the experts' assessments from the interviews, an exemplary comparative measurement is necessary to prove the effectiveness and the evaluation of the working accuracy.
As described in [5], the relevant drives are loaded by cyclically executed traversing regimes without cutting process.
The regimes are designed in such a way that they represent the already defined technological applications as well as possible.
The thermally induced displacement of the TCP is determined with the developed test piece. With this method, the time course of the thermally induced displacement of the TCP in x, y and z direction relative to the initial state can be measured [6].
The test is carried out and the measurement results evaluated in accordance with the specifications of ISO 230-3 [7].
By comparing the results for the machine with and without the implemented solution method, the improvement of the accuracy in x, y and z direction can be evaluated.
The process stability is determined by multiple repetitions of these measurements.

4. Conception of a recommender tool

The results of the effort analysis and the measurements for the suitability assessment will now be used to carry out a comparative evaluation of the solution procedures. This will be done by using a multiple-criteria decision analysis method (MCDA). The rules of decision logic on which the method is based are to be implemented in a software-based tool. The evaluation is implemented on a case by case basis. That means that the available solution procedures are compared with an initial scenario defined by the user and examined for their solution potential. As a result, a selection of the procedures is issued that are suitable to address the initial problem, stating the expected effort and benefit. This may also include a combination of procedures. So, in the end the user can choose between a set of procedures, that are all suitable to solve the defined problem and build the decision according to personal preferences upon the expected efforts displayed.

5. Conclusion and outlook

This paper describes a method to evaluate and characterize different correction and compensation procedures for thermally induced defects on machine tools.
In addition to solely technical aspects, such as positioning accuracy and process stability, economic aspects are also considered in order to estimate the implementation and maintenance effort. Expert interviews and comparative measurements build the basis for this.
Based on these findings, a recommender tool will be developed. Potential users will be able to select a correction or compensation procedure that optimally suits their capabilities and needs. The characterization provides a better overview of the effort and benefits of a solution and thus, helps to reduce the inhibition threshold for its implementation.
The methods and procedures presented are still in the development stage and therefore, no definite results can be presented at this point.
In the future, it will be necessary to extend the recommender tool by further correction and compensation methods and to make them available to potential users. In this way, weak points and missing aspects will be revealed in the evaluation, which will have to be corrected and added.

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