Building models for coupled thermo elastic problems in different software architectures using a new model exchange format

Stefan Sauerzapf\textsuperscript{1,*}, Andreas Naumann\textsuperscript{2}, and Michael Beitelschmidt\textsuperscript{1}

\textsuperscript{1} TU Dresden, Institute of Solid Mechanics, Chair of Dynamics and Mechanism Design, Dresden, Germany
\textsuperscript{2} TU Chemnitz, Faculty of Mathematics, Research Group Numerical Mathematics (partial differential equations), Chemnitz, Germany

To reduce the energy consumption of machine tools while preserving the productivity and quality, the deformation caused by thermal loads must be taken into account. Two approaches to reach this goal are the integration of model predictive error correction algorithms into the machine controller and a machine design that mitigates unwanted thermo-elastic behaviour.

Both approaches demand a profound understanding of the machine behaviour under different thermal load scenarios by simulation. The computation of representative distortions requires accurate models of the machine components, relevant physical phenomena and appropriate numerical methods, ranging from adaptive finite element discretization to model order reduction methods. In most cases, these methods and models are developed independently by different scientific groups, whereas the total goal of an improved operation of the machine tool demands the joint knowledge of all teams within the same machine model.

This contribution introduces an open source format for a seamless model exchange between the scientific groups. It bases on the standardized and machine readable JSON format. The JSON scheme comprises of all necessary model information. The main use cases, benefits and drawbacks are outlined. The file structure is briefly described. Design decisions and problems are discussed. After that, a workflow using the new format to calculate the thermal behaviour of a machine tool is shown. Different modelling approaches to calculate the thermal field are compared. Finally, the next development steps and further use cases for the format will be outlined.

© 2021 The Authors. Proceedings in Applied Mathematics & Mechanics published by Wiley-VCH GmbH.

1 Introduction

The Collaborative Research Centre/Transregio 96 (CRC/TR 96) aims to increase the productivity and quality while reducing energy consumption by incorporating thermo-elastic simulations into the machine development and machine application. From the multitude of model developers, users and different scientists backgrounds, a demand for a cross-platform approach to exchange and use models emerges, which is tackled by the use of a custom exchange format. The format, along with a simple use case, will be shown.

2 Exchange Format

The proposed exchange format uses the javascript-object-notation (JSON) as widely used file format in the web. Therefore, libraries for parsing and writing exist for nearly all platforms and programming languages. As it is a plain text format, version control systems can be used to keep track of model changes easily. The model structure is separated into five core sections, shown in Fig. 1.

![Fig. 1: Core structure of the coupled problem exchange format](image-url)

The model comprises of a geometry section, containing parts with their respective meshes and material associations. The movement section describes the movements of the machine parts. In the section boundary Condition - Sources - Constraints, physical information for the model are defined and ordered by there physical domain. At last, so called properties are given, which can be constants, look-up-tables or functions and are used to parametrize boundary-conditions, movements and so on.

The major advantage of a custom structured format is the high flexibility, as additional informations can easily be added and format changes can be incorporated quickly. As the format is used by multiple subprojects of the CRC/TR 96, a common vocabulary for the same entities, despite of different modelling approaches and modeller backgrounds, has been established.

* Corresponding author: e-mail stefan.sauerzapf@tu-dresden.de, phone +49 351 463 37984

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.
3 Example Use-Case

On top of the file format a simulation tool chain, as shown in Fig. 2, was developed. The model definition to generate a JSON-model-instance is realised in ANSYS® Mechanical using a custom extension. The JSON-model-instance is fed into the open source finite element (FE) toolbox DUNE to carry out a transient FE analysis of the problem. Additionally the toolbox can generate a state space system (SSS). The size of those models can be reduced using custom model order reduction (MOR) techniques from the MESS-toolbox. The transient simulation for both SSS can be carried out with the same custom solver.

Fig. 2: Implemented tool chain using the exchange format

The tool chain shows the major advantages of platform and non proprietary exchange formats. Open source and closed source software get interoperable and problem tailored numerical methods can be applied to industrial problems. At the same time the development of the tools remains independent.

In Fig. 3 temperature fields for one simplified demonstrator machine, simulated with three different approaches, are shown.

Fig. 3: Calculated thermal fields of simple test machine a) Finite element model b) State space system c) Reduced order state space system

The results of the FE model in Fig. 3 a) and the SSS b) are identical, because the problem is linear in the temperature and the same coupling method was used. The maximum difference between the reduced order solution c) and the full model a) has a magnitude of 0.25 K, while the reduced model is 1000 times smaller. In turn, the time integration is at least 1000 times faster as the simulation of the full model.

Those numbers show how the use of MOR methods enables the application of complex FE models for the real-time control of machine tools. Further details to the modelling techniques and more results can be found in [1] and [2].

4 Summary and Outlook

This paper gives an overview of a custom model description format for coupled thermo-elastic problems. The tool chain uses the format to exchange models between different tools and realize simulation tasks in the CRC/TR96. Additionally some results for a simplified demonstrator machine were shown.

The next steps include the extension of the format to facilitate the usage for coupled thermo-elastic simulations. Therefore, the tool chain needs some extensions with respect to the boundary conditions for the elasticity. Furthermore it is planned to release the format, along with a reference implementation in C++, which allows the incorporation into other tools.

Acknowledgements Funded by the German Research Foundation – Project-ID 174223256 – CRC 96. Open access funding enabled and organized by Projekt DEAL.

References

[1] S. Sauerzapf, J. Vettermann, A. Naumann, J. Saak, M. Beitelschmidt, and P. Benner, Simulation of the thermal behavior of machine tools for efficient machine development and online correction of the tool center point (tcp)-displacement, in: Conference Proceedings on Thermal Issues, (euspen, Bedford, 2020), pp. 135–138.
[2] J. Vettermann, S. Sauerzapf, A. Naumann, M. Beitelschmidt, R. Herzog, P. Benner, and J. Saak, Model order reduction methods for coupled machine tool models, in: Proceedings of the 2nd International Conference on Thermal Issues in Machine Tools, (CTU, Prague, 2021), pp. 199–206.