Studies on Multi-Domain Modelling and Thermal Coupling of a Machine Tool

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Abstract

Energy optimization in production plants is at present a very current topic. In this context, the research project INFO[1] deals with a comprehensive simulation of production halls with all micro- and macrostructures, in order to be able to make qualified predictions about the efficiency of different energy saving measures. An important sub-range of this research concerns modelling and simulation of machine tools, two parts of which will be presented in this paper.

The first part focuses on general multi-domain modelling of an actual machine tool (i.e. a lathe from the Institute for Production Engineering and Laser Technology from the Vienna University of Technology). An object-oriented modelling approach allows combining electrical, mechanical as well as thermal aspects in a structural manner. Combined top-down and bottom-up modelling techniques with gradually increasing level of detail identify the degree of modelling effort necessary or sufficient for certain applications and simulating certain scenarios. Future work plans to validate the simulation results against measurement data obtained from machine tests with the lathe.

The second part concentrates on the thermal coupling of the machine tool components with the environment. For that we selected a specific area of a machine tool, i.e. a linear guiding device with drive motor. In a first step the thermal behavior is studied and in a further step we consider the heat transfer and other effects on the environment. For this, the room around these tools is discretised in thermal compartments, which can also affect each other. The object-oriented modelling approach allows refining the discretisation easily, so that effects of a higher resolution can be studied too. Like in the first part, the simulation results will be validated against measurement data from the machine tool.

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[1] http://www.projekt-info.org

1 Introduction

The research project INFO was created out of a need to make qualified predictions about the energy consumption in production halls in order to identify saving potential and optimize production through different energy saving measures. For that, this project attempts to create a comprehensive simulation of production halls with all micro- and macrostructures [1]. One interesting topic in this context is to look at the thermal aspects and heat emission of machine tools [2]. These aspects are studied in more detail by creating a multi-domain simulation model of a machine tool with its thermal environment. This study is split into two parts, which are presented in the following sections.

The new object-oriented modelling approach, which is applied here, is called Physical Modelling, it is designed for modelling and simulation of physical systems in various domains and has proven its worth over the last years. Not only does this approach make the modelling process simpler, faster and more efficient, the models are also more modular, allowing the user to easily refine the structure by adding new components in a structural manner.

Since there are a number of software tools available for Physical Modelling in multi-domain applications, choosing two different tools for our implementations (i.e. MATLAB/Simscape™ [3] and MapleSim [4] in our case) allow comparisons regarding numerical performance, suitability and usage.

2 Multi-Domain Modelling of a Turning Lathe

In our study of modeling and simulation of machine tools, we consider not only electric drive components and mechanical elements, but we are also interested in the waste heat developing in different places. In order to be able to validate the model against actual measurement data, we attempt to recreate an actual turning lathe, which is provided by the Institute for Production Engineering and Laser Technology from the Vienna University of Technology.

Since the characteristic time constants occurring in these three physical domains differ widely, simulation of such coupled models also becomes numerically challenging. Implementing this model step by step with gradually increasing level of detail allow identifying the numerical boundaries of our simulation. On the other hand we can also show what degree of modelling effort is necessary or sufficient for certain applications, where significant changes in the simulation results are to be seen and which simulation scenarios are possible and reasonable.

The first overall model is relatively simple, but already contains all important mechanical and electrical components. This model is afterwards refined and extended by thermal components. As part of this first model, which was implemented in Simscape, Figure 1 shows the modelled main drive of the lathe with asynchronous engine, electrical control, voltage supply and gear belt drive.

The asynchronous engine as well as the servo motors for the remaining drives of the lathe and some of the basic mechanical components like gear belt drive, lead screw and linear bearings are modelled as Simscape components using Simscape Language [3]. For the remaining elements like inertia, friction or thermal mass, we used existing Simscape blocks from the Simscape Foundation Library. Heating of the drive motor as well as the gear belt drive have been factored in by thermal output ports from the blocks and respective thermal masses with specified heat capacity.

The main mechanical loads for the motor are the inertias of the main spindle and the cuck holding the workpiece. During the machining process, the cutting force generates another torque on the motor. This torque is modelled as a simple torque source, where the value of the torque is calculated externally using common formulas and parameters [5].

In further model refinements, additional details like elasticity of the mechanical parts or heating of the workpiece can be taken into account.

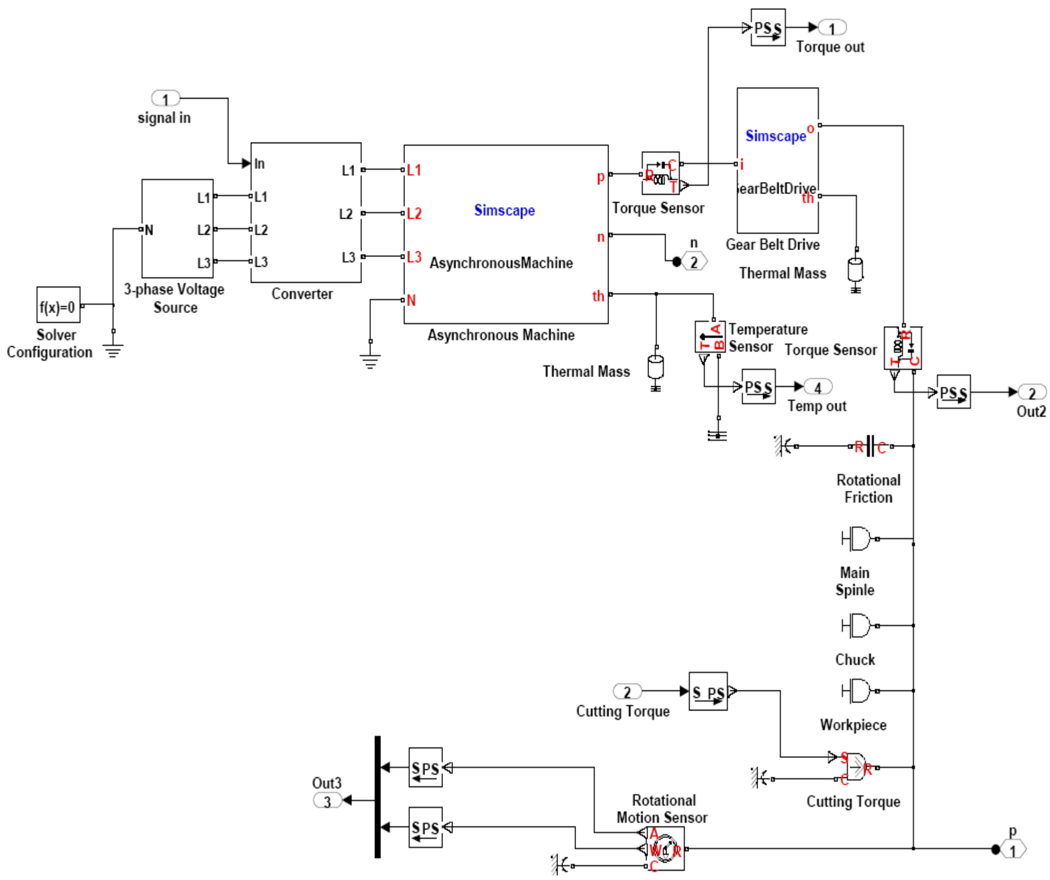

Figure 1: Main drive of the turning lathe model with power supply, electric control, asynchronous motor, gear belt drive, load and cutting force

Further parts of the overall model include a slide for automatic feed and a cross-slide for the infeed. As output of this model, the results of a basic simulation run with the lathe can be seen in Figure 2. This simulation run starts with the run-up of the main spindle and an infeed with the cross-slide. After that, the longitudinal slide moves for about 0.15 m with applied cutting and feed forces, therefore simulating the machining process. Last, the cross-slide returns in its original position and the spindle stops. This procedure is also depicted in Figure 3.

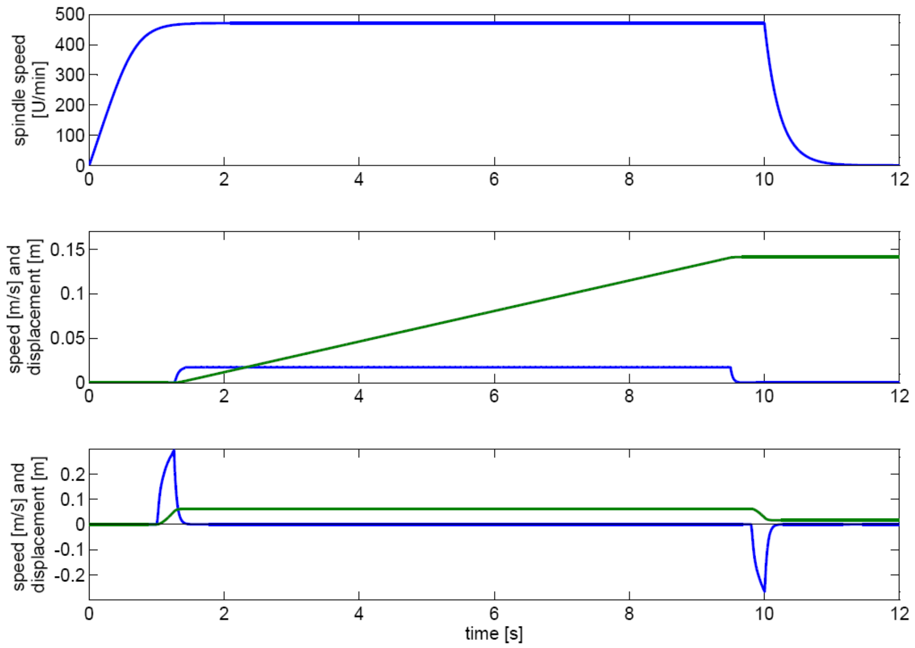

Figure 2: Simulation results of a basic simulation run: Spindle speed (top) and displacements of the slide (middle) and cross-slide (bottom)

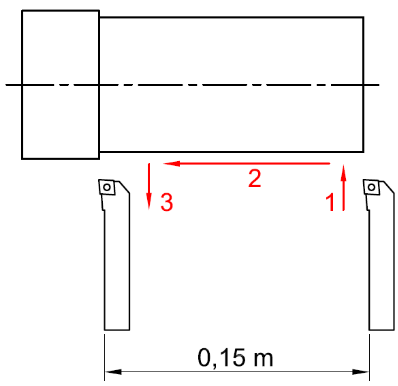

Figure 3: Schematic of the simulation run shown in Figure 2

3 Thermal Coupling with the Environment

For the second part the thermal coupling of a machine tool with its environment shall be analyzed. Therefore a part of a machine tool, namely a linear guiding device with a drive motor, is modelled using the Physical Modelling approach. Figure 4 shows a photograph of the setup and Figure 5 depicts the model of the device implemented in MapleSim.

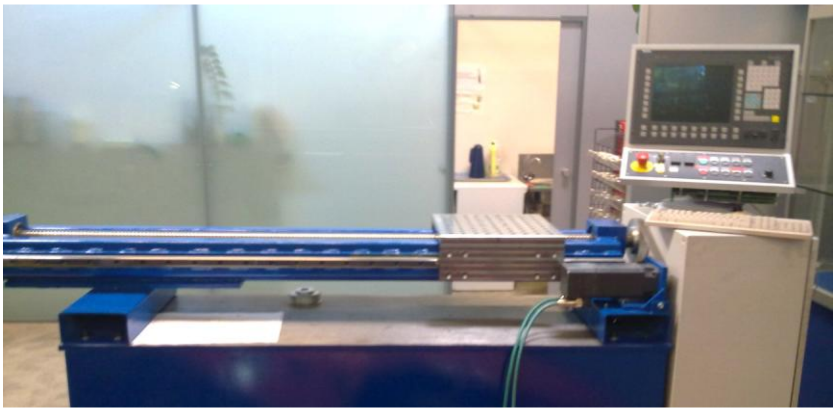

Figure 4: Test setup for the linear guiding device which is to be modelled

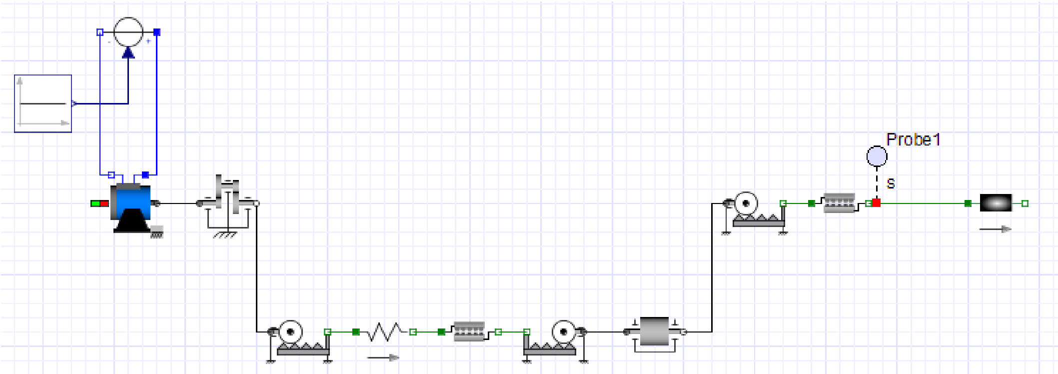

Figure 5: MapleSim model of the linear guiding device with blocks from the Modelica Standard Library

The assembly consists of a permanent magnet DC motor, a gear belt, a thread bar and the cart, where the mass is attached. The motor is represented by a DC Permanent Magnet Motor block. For the gear belt, the gear ratio is modelled by a gear, the elasticity by a linear spring and the friction by a translational friction component. The thread bar is modelled through its inertia and lead. Furthermore, the friction between the cart, the thread bar and the sliding mass are being taken into account. All components are from the Modelica Standard Library and the model is implemented using MapleSim.

For this first model, the source for the motor has a constant voltage, but it is planned that in further implementations it will be regulated by a controller. For the given configuration the results of the simulation depicted in Figure 6 are somewhat realistic in the way that you can see the run-up of the motor and the linear characteristics of the model in steady state.

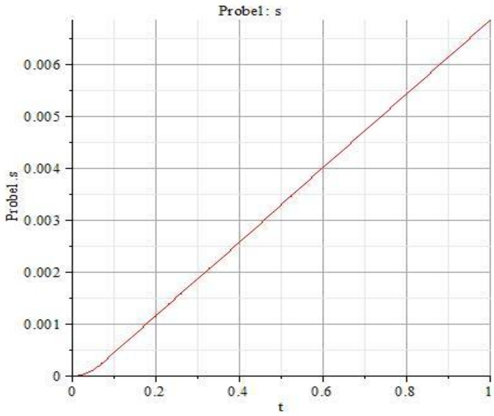

Figure 6: Acceleration and linear translation of the sliding mass over time

For the model of the environment a room with the proportions 20m x 10m x 6m is assumed. In a first step, this room is discretised with eight compartments of equal volume, at first only two-dimensional for reasons of simplicity. A schematic of this situation can be seen in Figure 7, the corresponding model is depicted in Figure 8.

Several assumptions are made for this model. First of all, the walls of the room are perfectly isolated, that means there is no heat exchange between the wall and the air. The only mechanism of heat exchange between the compartments is conductance, so there is no convection. Furthermore, the machine is the only source of heat in the room. For the parameters of the air, namely the density, specific heat capacity and thermal conductivity, we used typical values [6]. All parameters are assumed to be constant with a reference temperature of 20 °C.

As can be seen in Figure 8, there are two heat sources in the model representing two different discretised part of the machine, which emit heat. In our model, this would be the motor and the mechanical friction.

The simulation with results shown in Figure 10 starts with a running machine (i.e. it emits heat) and an initial temperature of 20 °C in all compartments. The machine runs for an hour, where the two different sources constantly emit a certain amount of heat. After that, the machine is turned off and is cooling down during the next four hours, cf. Figure 9.

By looking at Figure 10, one can observe that the biggest increase of temperature is in the compartment with the stronger heat source. The compartments adjacent to it have an observable increase of temperature after a short time and the compartments further away are heating up much slower.

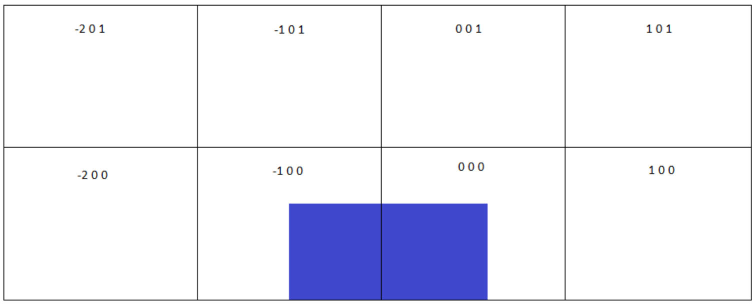

Figure 7: Schematic view of the discretisation and the two heat sources representing different parts of the machine

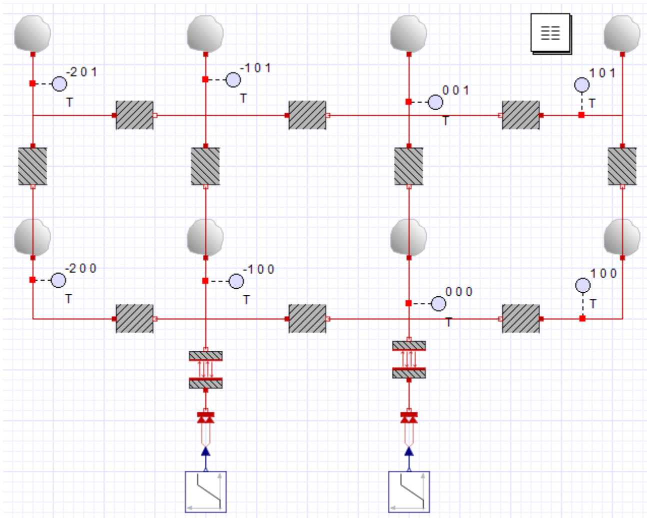

Figure 8: Thermal model of the discretised environment with eight compartments, two heat sources and conductive heat transfer

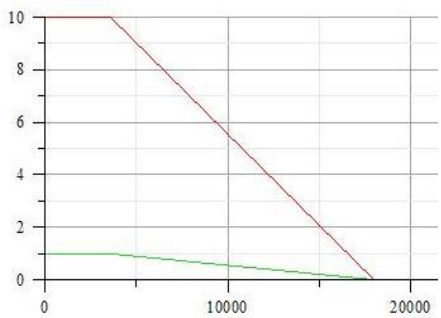

Figure 9: Heat emission of the two different sources over time

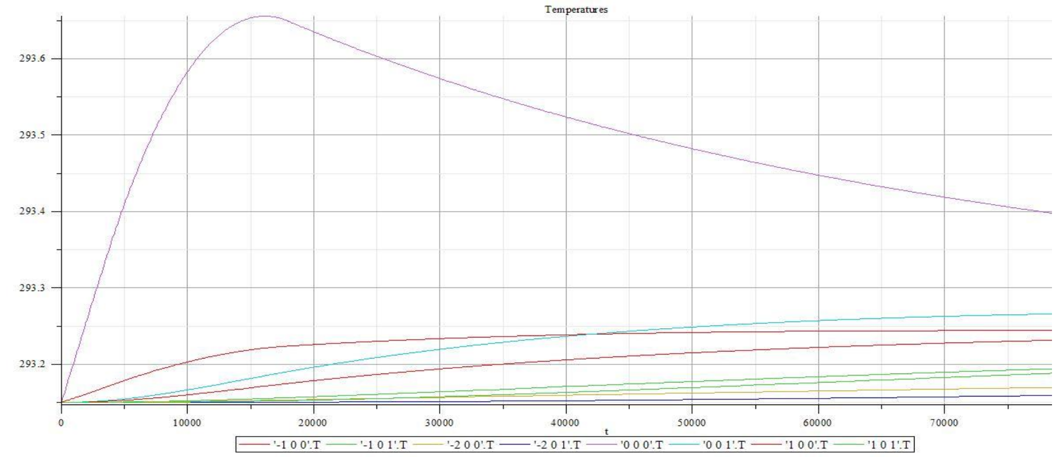

Figure 10: Temperatures in the different compartments over time

4 Summary and Conclusion

So far, the Physical Modelling approach seems to be a suitable tool for multi-domain modelling and thermal considerations of machine tools. The big advantage of creating modular models, which can easily be modified and refined, has been proven.

The exact parameterization of the components turns out however as somewhat difficult, since for the modelling many parameters are needed, which are not shown in data sheets, like friction coefficients or control parameters.

5 Outlook

Future work regarding the studies shown in this paper will focus on refinement of the models and parameterization of the remaining components. For model validation it is planned to obtain measurement data from the turning lathe as well as the linear guiding device and compare these measurements with corresponding results from the simulation.

6 References

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