

An Energy Model for the Calculation of Losses and their Effects on Machining Accuracy

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Abstract

In a machine tool, energy is consumed in a variety of forms. The most important consumers of energy are the electric drives, hydraulics and sometimes even pneumatics. In this study models will be derived that show the relation between power consumption and the accuracy of the machine tool.

1 Introduction

Manufacturing uses a lot of energy and as such many measures are taken in order to reduce the energy consumption of machine tools. These measures are not only done in order to gain economic advantages, but are also enforced by governments and standards. Due to these circumstances a lot of research has been done to improve the efficiency of machine tools. This research considers measuring the energy consumption as in [1] or examining the efficiency of a machine tool with different machining parameters [2]. It is also known that the energy consumption can be divided in constant and variable power consumption. The variable power consumption largely depends on the load and the processing time [3] and as such a machine tool consumes most power during manufacturing [4].

Any change in the energy consumption will also affect the thermal behaviour of the machine tool. This in return influences the machining accuracy. The relation between the energy consumption and thermal behaviour of the machine tool is a focus in this work.

2 Power Loss in Drives

In order to calculate the thermal error due to moving linear axes it is also necessary to know the losses of the machine elements. The loads on the electric drives are

calculated, based on the dynamics of the tool path and the friction inside machine elements. The load on the drive and the velocity is then used to compute the mechanical power, which is consumed by the drive, as well as its losses [5]. With all this data the energy consumption of the whole CNC system can be estimated. An example is shown in Fig. 1, which shows the current, which is necessary to perform a pendular movement of an axis.

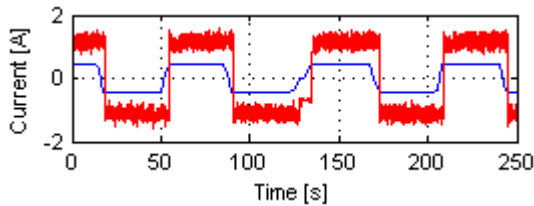


Figure 1: Simulated (blue) and measured (red) current

3 Power Consumption of Cooling Devices

Different coolant temperature control strategies were implemented in a FEM model to get a relationship between the cooling power and the thermal error. These are:

- a) Constant coolant temperature (in this case $T=20^{\circ}\text{C}$)
- b) Coolant controlled according to the actual environmental temperature
- c) Coolant controlled according to a local machine tool structural temperature

The implemented control is a two-point controller with a variable set-point and hysteresis. The concept of the machine tool that was analyzed is shown in Fig. 2. It can be seen that the bed is in contact with the coolant, whilst the linear axes only interact with the environment. Waste heat from the process is generated and transferred to the coolant. The thermal error and coolant energy consumption is analyzed for a change in the environmental temperature according to Fig. 2.

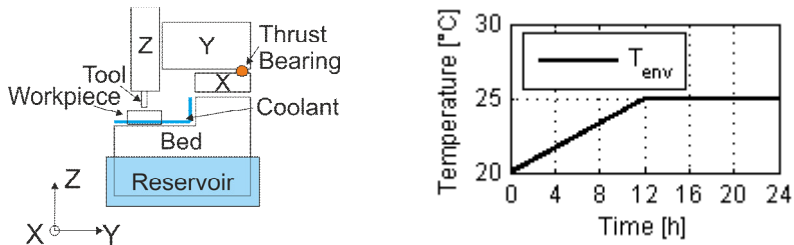


Figure 2: Machine configuration and environmental temperature profile

3.1 Results for the Thermal Error

Simulation results for the TCP displacements are shown in Fig. 3. The normalized displacements are shown for the three control strategies a) to c) described above. Especially the Y-direction is sensitive to changes in the environmental temperature and therefore represents the main focus in this case.

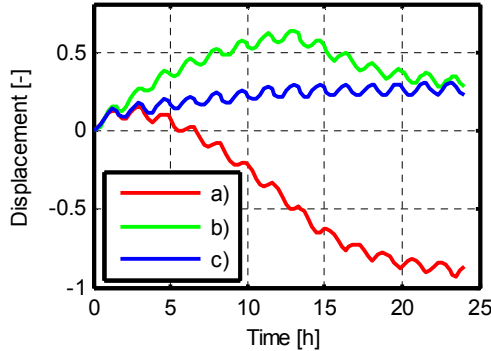


Figure 3: Normalized displacements in Y-direction for the three coolant strategies

For case a) with a coolant temperature kept constant, the bed stays at about 20°C. The structures of the axes follow the environmental temperature and expand in the negative Y-direction, away from the thrust bearing (Fig. 2). In case b) the Y-displacements change significantly. As heat transfer between the machine bed and the coolant is higher than between the axes and the ambient temperature, the machine bed reacts faster to the temperature. The bed causes a fast elongation in the positive Y-direction and then the axes slide moves the tool back in the negative direction. In case c) it can be observed that now the displacements could drastically be reduced by enforcing a homogeneous temperature over the entire machine. Compared to the configuration with constant coolant temperature, the displacements could be reduced to about 30%.

3.2 Results for the Energy Consumption

The average cooling power that has been needed to achieve the desired coolant temperature can be seen in Fig. 4 for the three cases. Most of the cooling power is not needed to achieve a certain coolant temperature, but to remove waste heat, e.g., from the process. Case a) has the largest power consumption, as in that case the

temperature difference between the coolant and environment is the largest. For the other two cases the power consumption was reduced by about 350W, which still corresponds to a reduction of almost 15%.

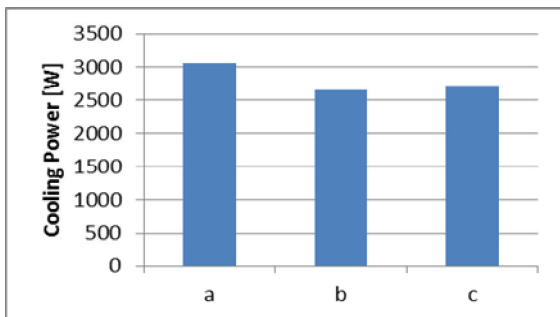


Figure 4: Average cooling power for the three cases a), b) and c)

4 Conclusion

An example of coupling the thermal error to the energy consumption was shown for ancillary units. The cooling strategy has a severe impact not only on the energy consumption, but also on the thermal error. This has to be considered when controlling the ancillary units as needed. A model to calculate the energy consumption in feed drives was also shown. This model can now be coupled to thermo-mechanical FEM in order to calculate the thermal error due to the moving axes.

References:

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