

## **Thermal Behaviour Improvement of Linear Axis**

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### **Abstract**

In the world of manufacturing technology especially with focus on machine tools a change took place: Until today the manufacturers of machine tools burden the responsibility of the control of thermally induced displacements on machine tools on the users, which means the user has to control the ambient temperature in the shop floor according to the manufacturer specifications. The user's task is also, if required, to warm-up the machine tool and he has to accept the corresponding reduction in productivity.

Nowadays more frequently the machine tool manufacturers take over the responsibility for the control of thermally induced displacements on the equipment from their customer.

In the presented study the linear axes of a lathe was improved. Measurements have shown that the major heat sources on the analyzed machine tool are the ball screws and the heat flow from the Z-axis motor to the bed. In the focus of the research work therefore investigations are analyzed by simulation to improve the thermal behaviour of the machine tool.

The results of cooling the ball screw nut and improving the mountings of the Z- axis motor are presented in this paper.

### **1 Ball screw system**

In Figure 1 the thermal equivalent circuit diagram of the ball screw system is shown. The equivalent circuit diagram has three main elements: the rolling bodies [1], the spindle and the nut.

The model is used to determine the heat flux in the ball screw system [2]. One part of the heat generated during operation flows into the spindle which leads to a temperature increase in this element. The temperature increase induces heat flow to

the ambient air via convection. The other part of the heat generated in the ball screw system flows into the nut and from there to the ambient air.

The spindle is subdivided into 2 regions: On the one hand the area which is passed by the nut during operation (shown in Figure 1 highlighted in gray) and on the other hand the area which is just in contact with the ambient air (shown in Figure 1 highlighted in white).

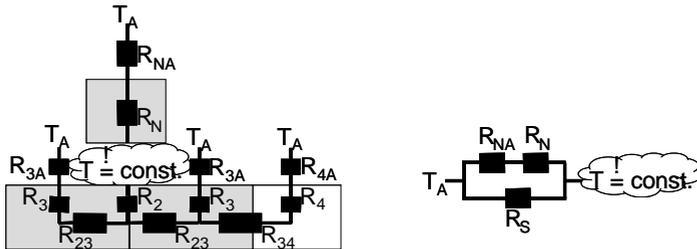


Figure 1: Left: thermal equivalent circuit diagram of the ball screw system, right: simplified thermal equivalent circuit diagram of the ball screw system,  $R_{ij}$ : thermal resistance between bodies  $i$  and  $j$ ,  $T_A$ : ambient temperature,  $T$ : rolling body temperature,  $R_S$ : thermal resistance spindle side,  $R_N$ : thermal resistance of the nut,  $R_{NA}$ : convective thermal resistance of the nut to the ambient air

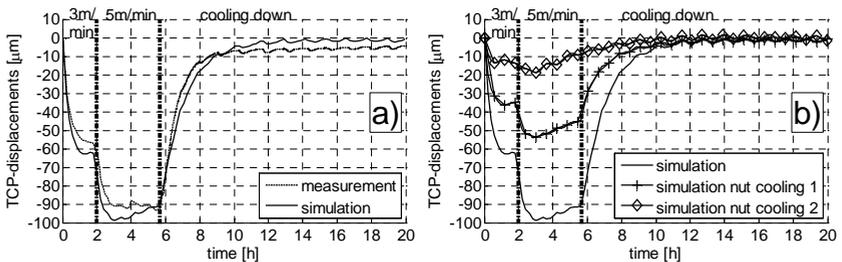


Figure 2: a: measurement and computation results of tool centre point (TCP) displacements in direction of the ball screw of a machine tool without linear encoders, b: computation results of TCP-displacements without nut cooling and with two different types of nut cooling: “nut cooling 1” and “nut cooling 2”

It is assumed that due to the rotation of the rolling bodies the temperature on all contact points is equalized.

Thermal effects on machine tools usually are long-term effects. Therefore having the same temperature at all contact points, the ratio of the heat flux into the spindle and into the nut can be assumed as being the same as in steady state.

With these assumptions the thermal equivalent circuit diagram, shown in Figure 1 left can be simplified to the equivalent resistance diagram shown in Figure 1 right, using Kirchhoff's laws.

Based on the ball screw model shown in Figure 1 the heat flow into the nut can be influenced by modifying the boundary conditions. The convective resistance  $R_{NA}$  can be reduced with a fluid cooled nut. In such a case more heat flows into the nut while the thermo-elastic deformation of the spindle is reduced. The computations have shown that over 97% of the friction heat generated in the ball screw can be conducted through the nut into the coolant. Nevertheless a limit in reducing thermo-elastic deformations of the spindle is reached earlier because other heat sources like the friction heat generated in the bearings become more prominent.

In Figure 2 a) the measured and computed TCP-displacements [3] of a machine tool without linear encoders in direction of the ball screw are shown. During the measurement cycle the analyzed axis is oscillating with 3m/min and 5m/min. Afterwards the axis is measured at standstill for another 14 hours. The ball screw manufacturer offers two types of water cooled ball screw nuts called “nut cooling 1” for a moderate cooling and “nut cooling 2” for heavily loaded ball screws. Figure 2 b) shows that the overall TCP-displacements in axial direction can be reduced by a ratio of five when using the more intensive nut cooling.

## **2 Motor assembly**

As a secondary heat source the measurement and computation results have shown the heat flux from the axis motor into the bed. Therefore different motor mountings are discussed. In Figure 3 examples of possible modified motor mountings with cooling fins and water cooling to separate the heat source from the bed are given. In Figure 3b it can be seen that both mountings reduce the bed temperature. Nevertheless in Figure 3a it can be seen that the motor temperature is rising when using cooling fins as motor mounting while with a water cooled mounting the motor and bed temperature is reduced. Therefore cooling fins are not recommended for motor mounting because the danger of reaching the demagnetization temperature is rising.

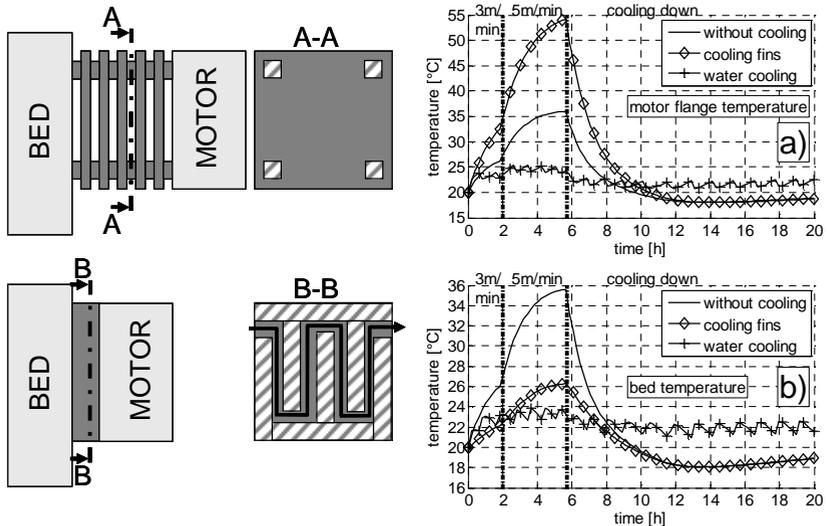


Figure 3: Left: different motor mountings with cooling fins (top) and water cooling (bottom). Right: a) computation results of temperatures at the motor flange without and with two different cooling concepts b) computed temperatures at the machine tool bed where the motor is mounted

### Acknowledgement:

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### References:

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