Adaptive Cooling Control of a Ball Screw Feed Drive System

J. Hornych, O. Horejš

Research Center of Manufacturing Technology, Czech Technical University, Czech Republic
j.hornych@rcmt.cvut.cz

Abstract

The thermo-elastic behaviour of machine tool structures is regarded as the dominant influence affecting the final accuracy of manufacturing. Not only have the demands on machining accuracy increased, machine tool users also insist on increased manufacturing flexibility, and for this reason, it is not possible to fully rely on a quasi-stable thermal state which a machine can achieve after a certain period of operation. It is necessary to deal with transient thermal states as they occur. Moreover, the majority of published studies deal with the thermal influence of spindle units, but all internal heat sources have to be taken into account; this paper therefore focuses on problems with thermal drifts of the machine axis in non-stationary thermal stress.

1 Thermally affected positioning accuracy and simple cooling

Ball screws are widely used for their rapid translation of precise motion as well as high efficiency and long lifetime. On the other hand, high-speed ball screw drive systems naturally produce heat through friction in contact areas and through electric losses of drive motors, which cause thermal expansion and negatively influence the structure of the machine tool including linear encoders, resulting in the general thermal drift of machine axes (for an example, see fig. 1). Solutions implementing only a cooling circuit, however, are incomplete; the comparison of fig. 1 and fig. 2 shows that in this case the feed drive system was overcooled. Reconfiguration of the coolant temperature regulation would serve no purpose; because of above mentioned requirement of operational flexibility, it's impossible to determine a universal level of cooling intensity. For this reason, a tool for measuring the amount of generated heat is required; a feasible solution could be the utilization of thermal transfer functions.

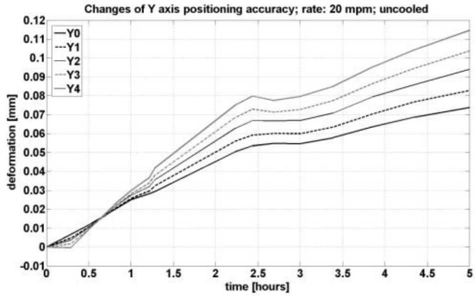

Figure 1: Thermal drift of an uncooled Y-axis of a C-frame machine tool at a rate of 20 meters per minute (i.e. 50% of the maximal rate)

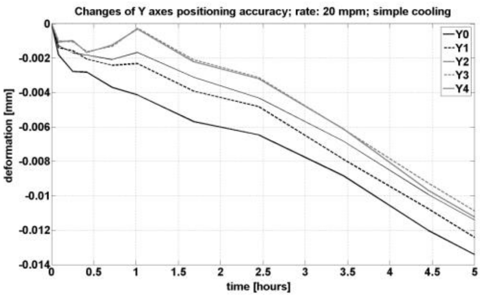

Figure 2: Thermal drift of a cooled Y-axis of a C-frame machine tool at a rate of 20 meters per minute; cooling was performed using a simple double-state model

2 Utilization of thermal transfer functions

A thermal transfer function, member of the frequency transfer function group, describes the link between the output (response) and the input (excitation) of a thermo-mechanical dynamic system in the frequency domain [1]. Various models based on temperature transfer functions were introduced to the public in the past few years. Those models, used for compensatory enumeration of thermal errors (caused for example by the run of spindles), presumed a linearity of the system, at least within the specific range. In the case of cooled axes, however, this presumption is incorrect.

2.1 Identification of the required intensity of cooling

The main radial-axial bearing was chosen as a characteristic heat source for representing the total heat influence of the Y-axis. Identification of the required cooling intensity was based on the inverse form of its temperature transfer function (ITTF). The ITTF was identified via a defined electric heater which had been placed in the bearing shell before the bearing was mounted. As input of the ITTF, temperature difference measured by two probes situated near the bearing in the shell was used. The output of the model is the simulated heat rate of the bearing. The closeness of the cooling meander, however, turned out to be problematic in combination with the simple ITTF model. Cooling changes the shape of the bearing shell thermal field, and therefore the simulated heat rate, or more precisely the requested cooling load, was lower than actually required (see the appropriate curve in fig. 3).

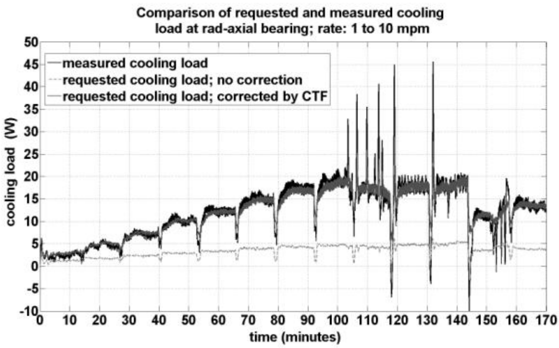

Figure 3: The comparison of the requested and measured cooling load

The influence of the cooling on the shape of the thermal field was simulated by an appropriate correction transfer function (CTF), with current cooling load as its input. The output of the model was the simulated contrast between the temperature difference created when the bearing was not cooled and the temperature difference created when it was. This simulated difference was added to the measured temperature difference, and the result of this sum was used as the corrected input of the ITTF model. The final part presents the application of the ITTF-CTF model.

2.1 Thermal drift of uncooled and adaptively cooled Y-axis

The ITTF-CTF model (Adaptive Cooling Control – ACC) was successfully tested in fluctuating rate mode. The rate started at 1 mpm, and the speed was increased every

14 minutes up to a maximum of 10 mpm. Finally, the rate was decreased to 6 mpm. The comparison of fig. 4 and fig. 5 shows that the thermal drift of the Y-axis was almost eliminated and the ACC system was prevented from overcooling.

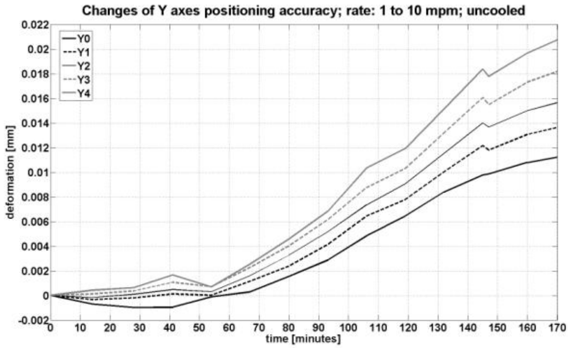

Figure 4: Thermal drift of the uncooled Y-axis of a C-frame machine tool at a fluctuating rate

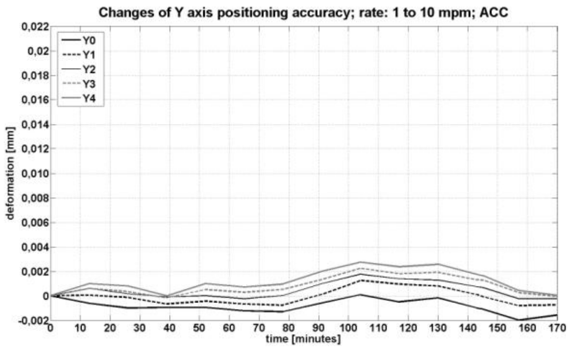

Figure 5: Thermal drift of the cooled Y-axis of a C-frame machine tool at a fluctuating rate; the cooling was applied in adaptive control mode

References:

[1] J. HORNYCH, P. BARTA, M. MARES: Issues in Identification of Thermal Transfer Functions of Machine Tools. In *Proceedings of the euspen International Conference*, San Sebastian, June 2009

[2] J. HORNYCH: Thermal Behaviour and Adaptive Cooling Control of Machine Tools, *PhD Thesis*, Prague, September 2011