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Reduction of warm-up period after machine downtime by means of a thermoelectric tempered motorized milling spindle

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Abstract

In the application sectors of optics, metrology, automotive engineering as well as information and communication technologies, there is a need for machined components with shape and positional tolerances in the submicrometer range. During machining, a significant share of geometrical errors is caused by thermally induced shifts of the positional correlation between tool and workpiece. With the intention to improve the thermoelastic behaviour of machine tools, the development of thermoelectric temperature control systems for motorized milling spindles is one research objective of the INSTITUTE FOR MACHINE TOOLS AND FACTORY MANAGEMENT (IWF) and the ALFRED JÄGER GMBH. It is shown that the thermoelectric tempering system can affect the temperature and the axial elongation of the shaft. Thereby, the warm-up period after machine downtime can be reduced by 45 %. This enables the potential for a major reduction of the auxiliary process time in the field of high-precision manufacturing.

Thermoelectricity, thermoelectric temperature control system, machine tool, motorized spindle

1. Introduction

In the application sectors of optics, metrology, automotive engineering as well as information and communication technologies, there is a need for machined components with shape and positional tolerances in the submicrometer range [1]. The manufacturing of high-precision components in large quantities is challenging and demands a sufficient productivity. During machining, thermally induced shifts Δl_{th} of the positional correlation between tool and workpiece have a significant influence on the machining accuracy a of machine tools [2]. This

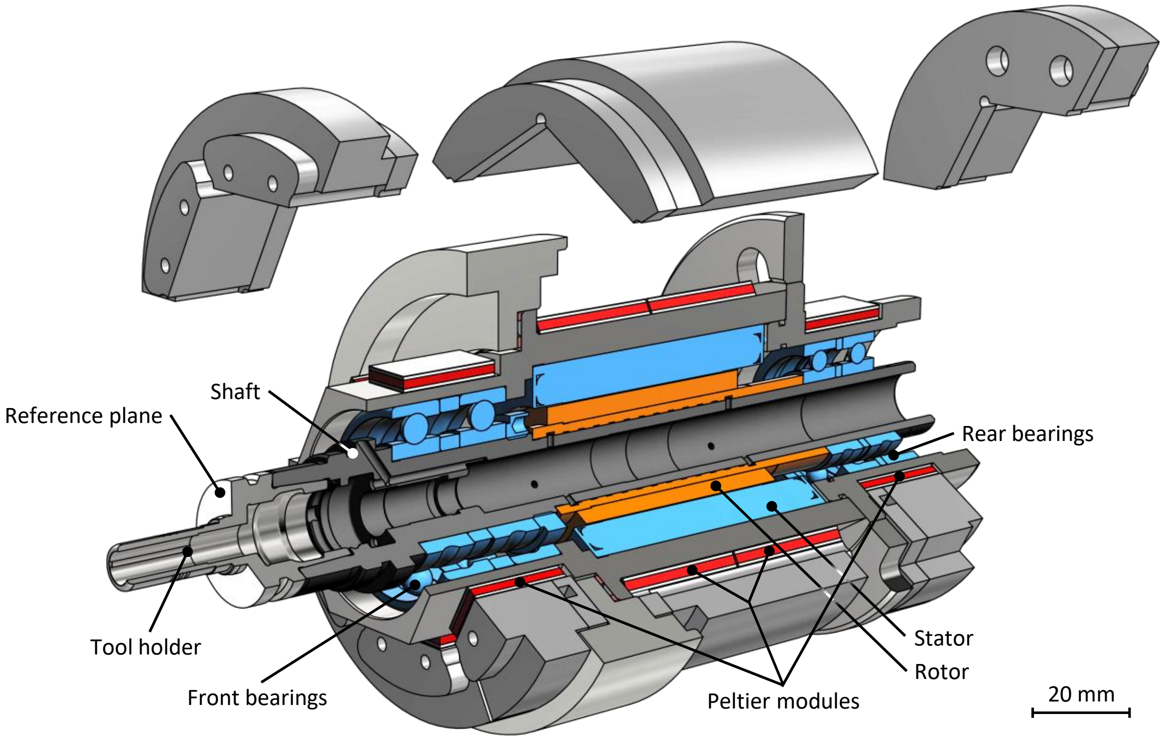

Figure 1. Model of a thermoelectric tempered motorized milling spindle

is due to electrical and mechanical power losses, which induce significant heat flow rates $\dot{Q}_{ind}$ into the adjacent machine tool components [2, 3]. The drives and bearings of motorised milling spindles represent such significant heat sources. Due to their vinicity of the tool-center-point, motorised spindles have a considerable influence on the achievable machining accuracy a of machine tools. To minimize the negative impact on the achievable machining accuracy a, the thermal losses must be dissipated by effective cooling systems. State of the art fluid cooling systems do not react on changes in the induced heat flow rates $\dot{Q}_{ind}$ caused by changes of rotational speed n, load torque M_l or machine downtime in consequence of tool or workpiece change [4]. To meet high-precision accuracy requirements it is necessary to reach a thermal steady state after changes in the induced heat flow rate $\dot{Q}_{ind}$. This process is time consuming and has a negative impact on the productivity. With the intention to overcome the conflict area between machining accuracy a and productivity, the development and testing of thermoelectric temperature control systems for motorized milling spindles is one research objective at the Institute for Machine Tools and Factory Management (IWF) and the Alfred Jäger GmbH [5].

2. Prototypic spindle and measurement procedure

With the aim to improve the thermoelastic behaviour of machine tools, in particular to reduce the warm-up phase after machine downtime, a prototype of a thermoelectric tempered motorized spindle has been manufactured. Figure 1 shows a model of the prototypic spindle with each six Peltier modules around the front and rear bearings and twelve Peltier modules around the stator of the motor. The Peltier modules allow to control the bearing temperature ϑ_b on the outer ring and the stator temperature ϑ_{st} on the outer stator surface. These temperatures are measured by resistance thermometer of type Pt1000-AA made by Therma Thermofühler GmbH, Lindlar, Germany. The spindle is driven by an asynchronous motor. Additional equipment allows to measure the shaft temperature ϑ_s using a pyrometer of type CT-CF22-C3 made by Micro Epsilon Messtechnik GmbH & Co. KG, Ortenburg, Germany, and to measure the axial shaft elongation Δl_s at a reference plane on the tool holder using a capacitive displacement sensor of type CSH05FL-CRm made by Micro Epsilon Messtechnik GmbH & Co. KG, Ortenburg, Germany.

To verify the potential of the thermoelectric temperature control system the prototypic spindle has been compared to a commercially available reference spindle of type Z62-H360.02 made by Alfred Jäger GmbH, Ober-Mörlen, Germany. Both spindles were operated in a test bench with measurement of shaft temperature ϑ_s and axial shaft elongation Δl_s. In the test procedure both spindles were operated at a rotational speed n = 55,000 1/min and stopped two times for a downtime period $\Delta t_0 \approx 300$ s to simulate a change of the tool or workpiece.

3. Results

Figure 2 shows the axial shaft elongation Δl_s and the shaft temperature ϑ_s of the reference spindle. The reference spindle shows an average axial shaft elongation $\overline{\Delta l_s}$ = 20.7 µm at a rotational speed n = 55,000 1/min. When the spindle was stopped, the axial shaft elongation Δl_s as well as the shaft temperature ϑ_s decreases immediately. After setting the rotational speed back to n = 55,000 1/min, the axial shaft elongation Δl_s reaches a steady state within a time period $\Delta t_{ss,1}$ = 439 s and $\Delta t_{ss,2}$ = 343 s.

In the prototypic spindle the thermoelectric tempering system allows to control the bearing temperature ϑ_b of the front bearing and the stator temperature ϑ_{st}. According to Figure 3 a) both temperatures are set to $\vartheta_b = \vartheta_{st}$ = 25°C while the spindle is operating. During the first downtime period $\Delta t_{0,1}$ the temperature of the front bearing is set to ϑ_b = 50°C and during the second downtime period $\Delta t_{0,2}$ to ϑ_b = 40°C. Figure 3 b) shows shaft temperature ϑ_s and axial shaft elongation Δl_s of the prototypic spindle. The average axial shaft elongation is $\overline{\Delta l_s}$ = 11.5 µm at a rotational speed n = 55,000 1/min. When stopped, the axial shaft elongation Δl_s also decreases immediately, whereas the shaft temperature ϑ_s rises. Setting the rotational speed back to n = 55,000 1/min after the first downtime period $\Delta t_{0,1}$, the axial shaft elongation Δl_s reaches a steady state within a time period $\Delta t_{ss,1}$ = 206 s and after the second downtime period $\Delta t_{0,2}$ within a time period $\Delta t_{ss,2}$ = 187 s.

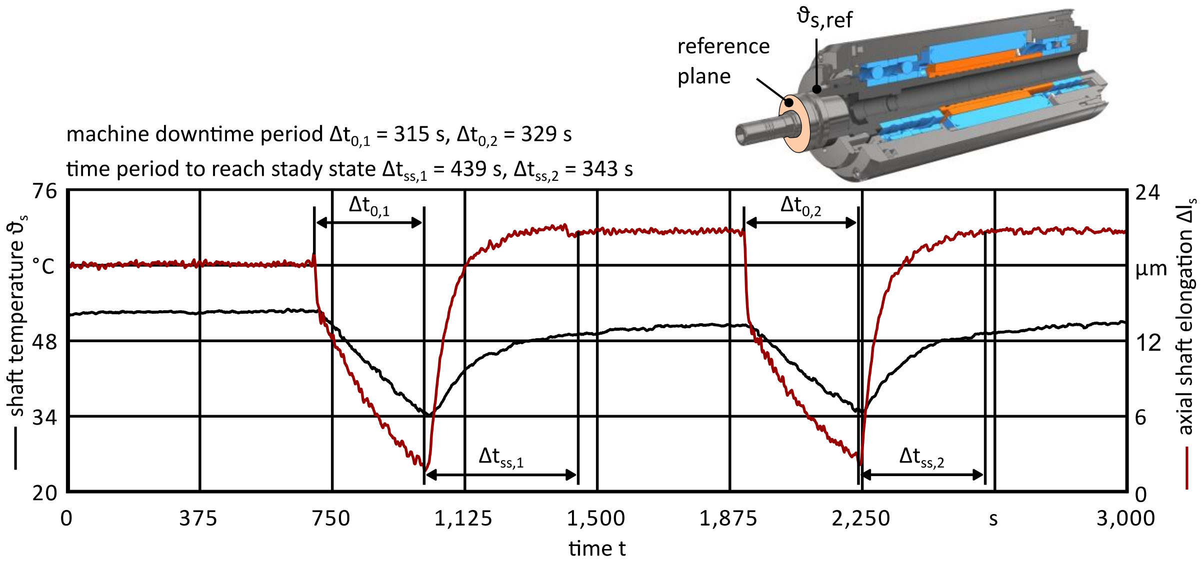

Figure 2. Measurement results for shaft temperature ϑ_s and axial shaft elongation Δl_s of the reference spindle

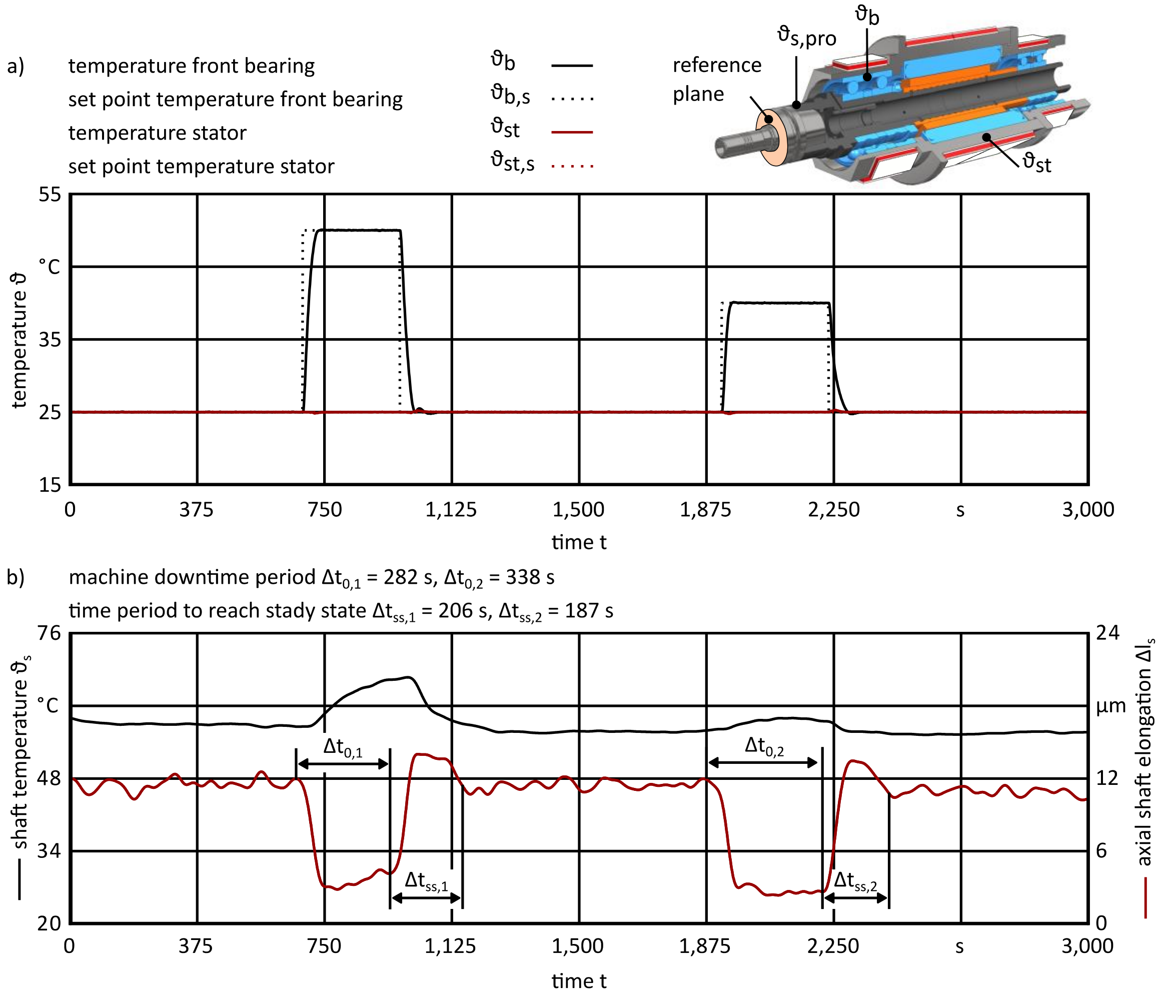

Figure 3. Measurement results of the prototypic thermoelectric tempered spindle; a) controlled front bearing temperature ϑ_b and stator temperature ϑ_{st}; b) shaft temperature ϑ_s and axial shaft elongation Δl_s

4. Conclusion and Outlook

The results presented in Figure 2 and Figure 3 demonstrate, that the thermoelectric tempering system can affect the shaft temperature ϑ_s and the axial shaft elongation Δl_s of the spindle. It is shown that the time period Δt_{ss} to reach a thermal steady state of the axial shaft elongation Δls after a machine downtime period $\Delta t_0 \approx 300$ s can be reduced by 45 %. Therefore, the thermoelectric tempering system has the potential for a major reduction of the auxiliary process time in the field of high-precision manufacturing.

Further investigations will focus on the thermoelectric compensation of changed induced heat flow rates $\dot{Q}_{ind}$ caused by different rotational speeds n. Furthermore, investigations on a thermoelectric tempered spindle driven by a synchronous motor are planned.

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