Master's Thesis - Master of Science in Engineering

Thermal Stability in Machine Tools

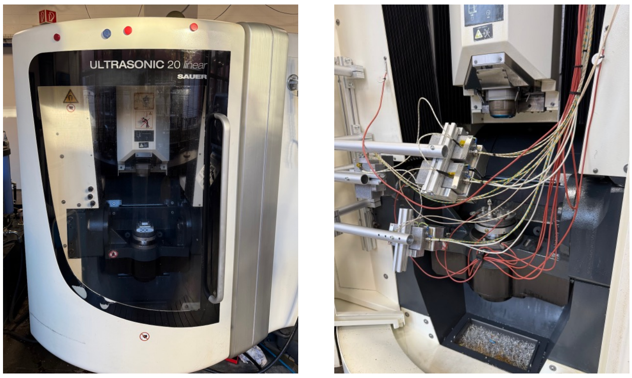

Figure 1: *Machine tool with closed enclosure (left) and experimental setup for the compensatory approach (right).*

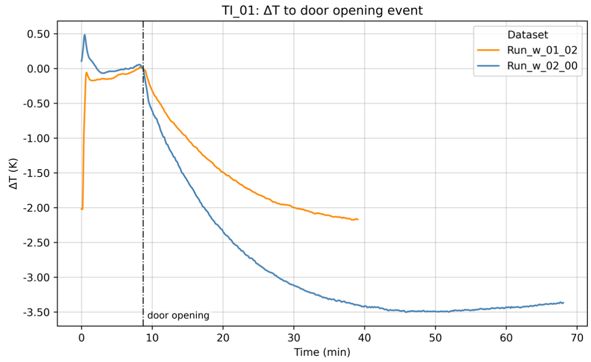

Figure 2: *Measured cooling effect during autumn (orange) and winter (blue).*

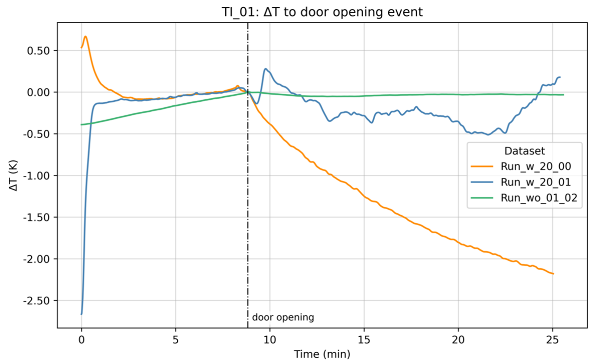

Figure 3: *Measured temperature during preventive experiments: reference cooling with applied cutting fluid (orange), reference without applied cutting fluid (green), and preventive measure (blue).*

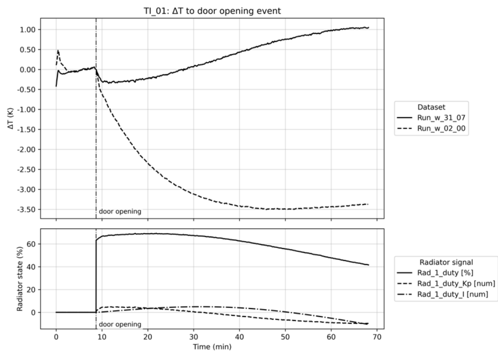

Figure 4: *Top: measured temperature during compensation experiments, including reference cooling with applied cutting fluid (dashed line) and compensated temperature (solid line). Bottom: PI controller output.*

Problem Description

Thermal effects constitute the dominant source of error in machine tools. While thermal errors have been extensively investigated in the literature, thermal deformation caused by evaporation-induced cooling has received little attention.

Evaporation is driven by a concentration gradient between the liquid–air interface and the surrounding ambient air and continues until either air saturation is reached or the liquid phase is depleted. In machine tools, this situation occurs after machining operations when aqueous-based cutting fluids remain on machine components and the machine enclosure is opened to the ambient environment.

The resulting concentration gradient promotes evaporation, during which the latent heat of phase change is extracted from the liquid. This process leads to a local temperature decrease of machine components, causing thermal deformation and potentially impairing the dimensional accuracy of subsequently machined parts, thereby reducing process stability and productivity.

Aim of this Work

In this work, evaporation-induced cooling is experimentally investigated in a real machine tool environment. The machine tool used for the experiments is shown in Figure 1 (left). The effect is quantified based on temperature measurements, and two mitigation strategies are proposed and evaluated: a preventive and a compensatory approach. The preventive approach is based on local steam injection to suppress evaporation by reducing concentration gradients. The compensatory approach employs controlled thermal radiation using infrared radiators to offset evaporation-induced heat losses. The experimental setup for the compensatory approach is shown in Figure 1 (right).

Results

The maximum measured local cooling reached 3.5 K during winter conditions, as shown in Figure 2. The preventive approach proved effective in maintaining temperature stability within ±0.5 K, as depicted in Figure 3. The compensatory approach successfully reduced the residual cooling to a maximum of 0.3 K using controlled infrared thermal radiation, as shown in Figure 4.

These results demonstrate that evaporation-induced cooling represents a relevant and previously underestimated source of thermal error in machine tools and that both preventive and compensatory strategies offer viable means for its mitigation.

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