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Acclimatisation time of precise workpieces for quality inspection

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Abstract

During manufacturing precise parts are machined under shop floor conditions. For quality inspections these parts are brought into a measuring chamber. The research presented is a simulation study investigating the acclimatisation time of a machine tool bed brought from one functional room into another. The work deals with effects of thermal memory from any previous environment as explained in the thermal effects diagram of Bryan [1]. For the study a machine tool bed is either made of cast iron or polymer concrete. The boundary conditions required for the computations, for example the convective heat transfer coefficients, are derived from computational fluid dynamics (CFD) of the conditions in the air conditioned measuring chamber. The air temperature in the measuring chamber is controlled to 20 °C. Finite element method (FEM) is used to compute the temperature distribution over time and the thermally induced deformation of the bed. The deformations due to the temperature distribution of functional surfaces of the bed are evaluated as a function of time. Evaluation criteria are, for example, the flatness deviation of the guideways. The study shows that the time to reach a temperature distribution of the part, appropriate for evaluation of manufacturing errors, strongly depends on the material of the part and the boundary conditions, like the air stream velocity in the measuring chamber. It is shown that a storage time of more than one week in the measuring chamber is necessary to inspect geometrical features with small tolerances. The described combination of several computation methods can be transferred to any type of part.

Simulation, Measurement, Precise Workpieces

1. Introduction

For quality inspections precise parts are brought into conditioned measurement chambers. There, the parts need time to get acclimatised. How long the acclimatisation takes is often unknown. To this end a simulation procedure is performed. It is shown, that the air velocity around the part depends on the chamber's design and that low velocities result in huge acclimatisation times. Furthermore, the acclimatisation time and the verified flatness of the part depend on the workpiece material and its shape.

2. Methodology

The cooling down of a part surrounded by a fluid can be described with the Biot number Bi as a dimensionless quantity.

$$Bi = \frac{h \cdot L}{\lambda_S} \tag{1}$$

In (1) L, the characteristic length, depends on the geometry of the part, what is not varied. The thermal conductivity of the part λ_S depends on the material and is known for the investigated materials. The convective heat transfer coefficient h depends on the local air velocity. CFD is used in a first step to obtain the local values for h.

For studying the measuring chamber is modelled in Ansys CFX, as illustrated in Figure 1. The design of the chamber is performed as recommended in VDI/VDE 2627 [2]. As precise part for evaluation a machine bed is chosen. The flatness of the guidance surfaces is analysed as a function of time and for different materials.

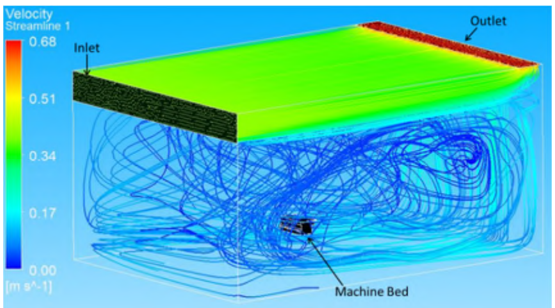

Figure 1. Air velocity in the measuring chamber after 24 h with an inlet velocity of 0.2 m/s and an average pressure on the outlet of 0 Pa.

3. Simulation study

3.1. Measuring chamber

The measuring chamber has a length of 10 m, a width of 7 m and a height of 5 m. The chamber has the quality of 1 according to [2]. The air flow is modelled according to section 6.1.1.2, figure 8a) of [2]. The velocity of the inlet stream is 0.2 m/s. The air temperature is controlled to 20 °C.

3.2. Workpiece under investigation

The evaluated workpiece, a machine bed 1 m × 0.4 m × 0.4 m in size, has a homogeneous temperature of 24 °C at the beginning of the simulation. The bed is either modelled of cast iron or polymer concrete. The material properties are given in table 1. The bed is placed on the left side of the chamber.

Table 1. Material properties for the simulation study

Material property	Cast iron	Polymer concrete
Density	7800 kg/m^3	2300 kg/m^3
Thermal conductivity	46 W/(m×K)	1.7 W/(m×K)
Heat capacity	540 J/(kg×K)	1000 J/(kg×K)
Thermal expansion	11.7 µm/(m×K)	11.7 µm/(m×K)

4. Results

4.1 Influence of workpiece material

To analyse the acclimatisation time, the temperature of the bed is evaluated. Figure 2 shows the average bed temperature over a simulation time of about 7 days. The cast iron bed has a temperature of nearly 21 °C after 7 days storage time, the polymer concrete bed of about 20.3 °C. This difference results from the different thermal conductivity and heat capacity.

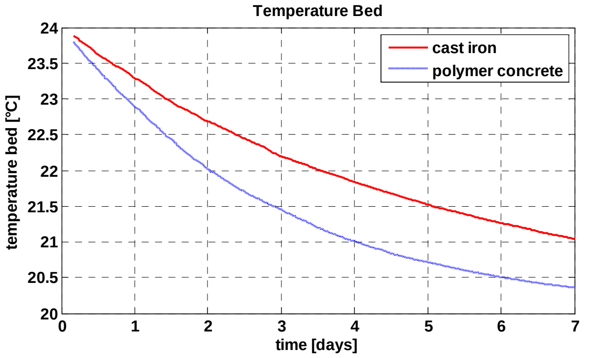

Figure 2. Acclimatisation time of the machine bed. The average temperature of the body is analysed over 7 days.

4.2 Temperature distribution within the workpiece

Figure 3 shows the temperature distribution within the cast iron bed after 7 days. The maximum difference after one week storage time is about 0.01 °C. Because of the low thermal conductivity for the same analyses for a bed made of polymer concrete results in a temperature difference of about 0.06 °C.

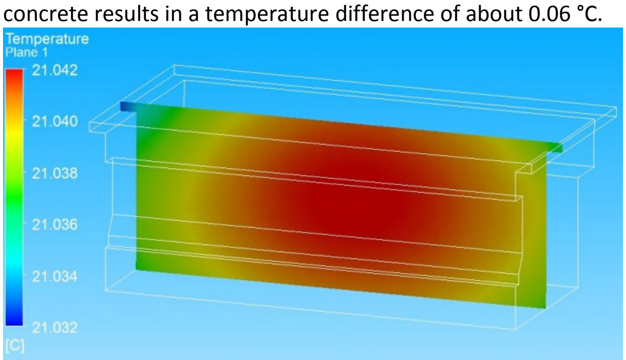

Figure 3. Temperature distribution within a machine tool bed (made out of cast iron) after being 7 days in a measuring chamber with 20 °C air temperature. The bed temperature was 24 °C, when it was brought into the chamber.

4.3 Heat flux depending on the air flow within the chamber

The simulation study shows that it takes more than one week to get the bed mostly acclimatised. This is also influenced by the heat flux between the bed and the environmental air, as it can be seen in figure 4. Moreover, the heat flux is influenced by the air velocity around the bed. The influence of increased velocities is not regarded here.

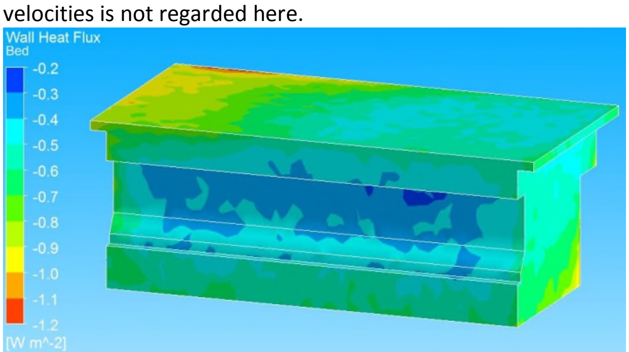

Figure 4. Heat flux distribution on the surface of the machine bed after being 7 days in a measuring chamber with 20 °C air temperature. The bed temperature was 24 °C, when it was brought into the chamber.

Figure 5 shows a cut through the modelled chamber with the bed inside. The air velocity on the back left side of the bed is higher than on the right side. This explains the differences of the heat flux in figure 4. In addition, figure 5 illustrates that either placing the bed somewhere else in the chamber or changing the chamber's air stream design would also result in a modified heat flux.

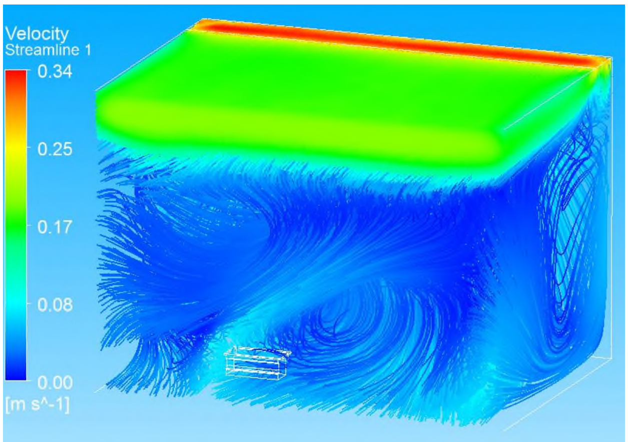

Figure 5. Velocity distribution of the air in the chamber.

4.4 Flatness of the guideway surfaces

Figure 6 presents the flatness of the guideway surfaces as a function of time. Overall, the variations are very small because of the ratio between heat flux and thermal conductivity. Although the effects are small, the influence of different materials can be clearly seen.

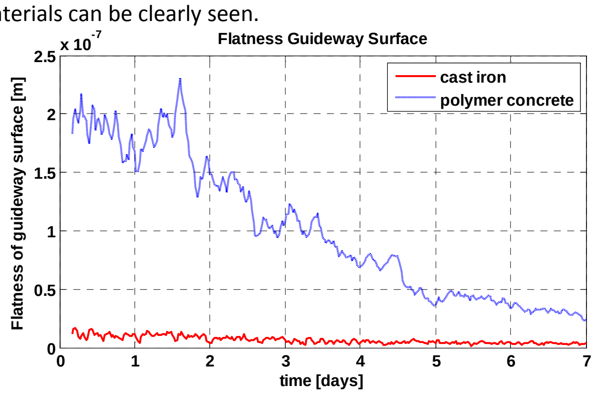

Figure 6. Flatness of the guideway surfaces.

5. Summary, conclusion and future work

The simulation study shows that acclimatisation process in a standard measuring chamber can take very long. The acclimatisation depends most on the part's material and on the design of the chamber. Furthermore, geometrical inspection errors of features, like the surface flatness, on a part that does not depend on its dimension are influenced by the ratio between heat flux and heat conductivity, in combination called temperature conductivity. In the next steps measurements in an air-conditioned chamber are performed to validate the computations and an in-depth simulation study of the machine bed is planned to derive guidelines for storage time.

References

[1] Bryan J 1990 International status of thermal error research. *CIRP-Annals-Manufacturing Technology,* **39** (2) pp 645-656

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