MOTION DEVIATIONS OF A ROTATIONAL POSITIONING TABLE INDUCED BY THERMAL EFFECTS

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1. Introduction

When considering the positioning deviations of measurement systems which are equipped with an additional rotational axis, usually only the angle error is compensated during the measurement. Other systematic errors revealed during the machine acceptance test, for instance the wobbling of the axis, can be minimized by respective correction factors in the control. Besides these mechanically induced deviations, environmental effects, such as thermal influences are typically neglected. In order to guarantee high-precision measurements, the exact positioning of the probe is a basic prerequisite and hence requires the consideration and quantification of environmental effects. Especially when looking at optical measurement systems, positioning deviation affects stitching and will strike down as artefacts in merged images. Furthermore a precise and repeatable probe positioning is indispensable for the optimal focussing of the optical unit, in order to produce images with highest possible precision [1]. The accuracy of a measurement particularly depends on the temperature change over time [2]. Previous research revealed that the step motor (Fig.1-a) of a typical rotational unit is the most influential, non-constant heat source in close proximity of the probe if the measurement device is used in a temperature controlled room. Therefore this paper discusses the temperature influence of the step motor on the positioning accuracy.

2. Experimental Setup

In order to evaluate the spatial positioning accuracy of the rotational unit, a particularly designed ball measurement standard (BMS, see Fig.1-b) is fixed in the rotational unit. The BMS consists of two ceramic (Al_2O_3) balls, which are connected by two carbon fibre rods with a thermal expansion coefficient $\alpha=0.3\text{x}10^{-6}\,K^{-1}$, as well as titanium elements $\alpha=8.6\text{x}10^{-6}\,K^{-1}$. The implemented balls have a guaranteed form deviation of less than 40 nm. The position of the BMS is then tactilely evaluated upon reproducibility using a coordinate measuring machine Zeiss Prismo Navigator (MPE 0.7+L/350 µm according to ISO 10360-2:2009). The experiments are carried out in a measuring laboratory with quality class 3 (VDI/VDE 2627-Blatt 1) and cleanroom class ISO 6 (DIN EN ISO 14644-1). However, as shown in Fig. 1-c, two temperature sensors, of which one is attached directly upon the rotational unit and the second is in close proximity of the BMS without a material contact, monitor the temperature profile over time.

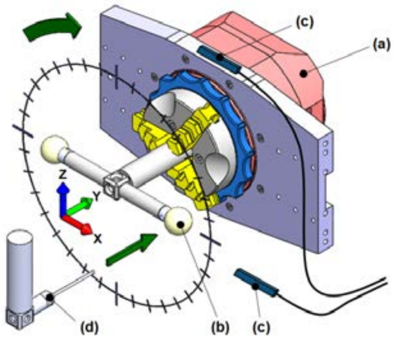

Fig. 1. Experimental setup: (a) step motor; (b) BMS; (c) temperature sensors; (d) +Y-probe

3. Experimental investigation

In order to determine the position of the centre point of the BMS the measuring adaptor will be scanned over several positions on a particular trajectory with over 2000 measuring points in each position. The positions are defined to replicate the nominal diameter of the spherical surface. To ensure the measurement of exactly the same pose in each angular position of the rotational unit, an axially aligned (Y-axis) measuring probe is applied (see Fig.1-d). The experimental testing procedure is divided into four phases. In the first and second experimental phase the centre points of the BMS are determined statically without angular displacement, 80 times in total within 2 hours. The single variable is the state of the step motor. In the first phase the rotational unit undergoes several revolutions before the measurements and is connected to the power in order to replicate a heat state under realistic operating conditions. In phase two, however, the step motor is disconnected from the power supply and hence is passive without any heat emission. In phase 3 the rotational unit undergoes two full revolutions with increments of 10° whereas the determination of the centre points takes place in the breaks in-between, resulting in 72 sphere position datasets. In phase four the incremental rotational displacement is done manually with disconnected power supply and hence in a passive state of the step motor.

4. Results

The results from the static experiments reveal that small changes in ambient temperature of less than 0.15 K produce almost no positional deviations in the radial direction, whereas in the axial direction a divergence of approximately 0.3 µm occurs (see Fig.2). This is slightly higher than the calculated value of 0.25 µm of the total thermal expansion of the measuring setup. As soon as the power supply is connected, a temperature offset of almost 2 K between the two temperature sensors can be observed. The influence of the step motor's heat source seems to have an enhanced impact on the axial position of the BMS. During the experiment a change of the ambient temperature of -0.5 K could be observed resulting in a flatter deviation profile of the positioning accuracy. Even tough disclosing different profiles, both the radial and the axial deviations amount to about 1.8 µm by the end of the experiment. The results from the rotatory table test reveals that the mechanical influence on both axial and radial deviations are quite similar, whereas the axial position reacts more serious on the heat source of the step motor (see Fig.3).

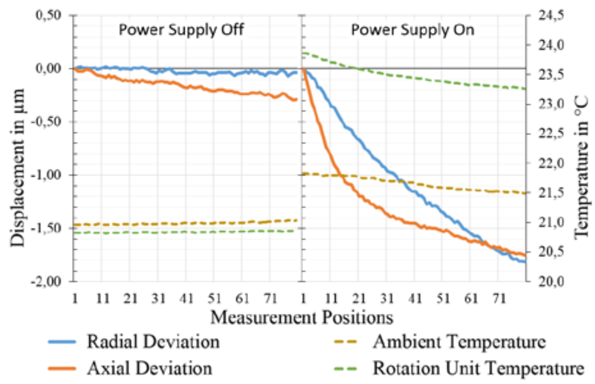

Fig. 2. Profiles of BMS sphere centre point position in axial and radial direction; static experiment phases 1 (power supply on) and 2 (power supply off)

Hence, the profile of the axial deviation shows an ascending trend. The temperature increase, resulting from the active step motor, causes a superimposition of errors, which partly cancel each other solution, leading to less distinct differences between local maxima and minima in the deviation profiles. The maxima are higher in the connected power state whereas the minima are significantly lower compared to the passive, manual angular displacement experiments.

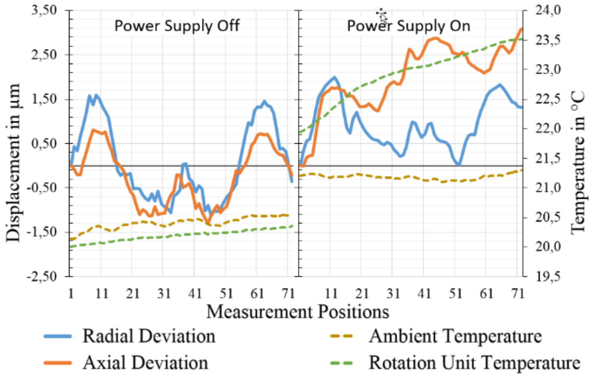

Fig. 3. BMS sphere centre point position profiles in axial and radial direction; rotatory experiment phases 3 (power supply on) and 4 (power supply off).

5. Conclusion

Based on the present study a significant temperature influence of the step motor on the positional accuracy of a rotational table unit could be observed under controlled room temperature conditions. As part of further research an investigation of the superimposition of these heat effects and higher ambient temperature changes will be carried out in order to simulate near-production conditions.

References

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