The EMRP Project “Thermal design and dimensional drift”

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Abstract

With current trends in precision engineering demand of higher accuracies for industrial high-end production and measurement equipment, temperature effects and time-dependent drift, are a serious limitation for achievable system performance. These limitations can be stretched by a more insensitive design of machine components and active compensation of thermal gradients caused by heat sources.

For insensitive machine design knowledge and control of medium to long-term dimensional drift and thermal properties are required. The study of dimensional drift including aging and thermal expansion using interferometric methods [1] is well known, but will also be utilized here for the investigation of joints, sensors and actors. For the determination of influences of forces, indentation methods will be used with a focus on the creep of materials and the thermal dependence of hardness [2].

The influence of heat sources on precision engineering instruments can be reduced by improved placement as well as by use of appropriate materials, which can be effectively supported by thermal modelling [3]. Even more compensation can be achieved by active thermal control of machine subsystems. Cooling elements with low vibrational and thermal backlash has to be developed and thermal modelling will allow for an improved model based control.

Reliable and low maintenance temperature measurement [4] is a key for active thermal control. Current state of the art temperature measurement equipment needs regular re-calibration, which will be addressed by the development of a miniaturized fixed point cell for use near 20 ºC for in place calibration of platinum thermometers with respect to the temperature scale ITS90 [5]. The use of thermocouples is a promising choice for the measurement and even more for the active control of

temperature gradients. The characteristic of different thermocouple devices in dependence of temperature differences and mounting conditions will be investigated.

1 Project overview

The project is divided in four technical workpackages as shown in fig. 1. The first two workpackages deal with the measurement of thermal behaviour of materials, joints and sensors. WP1 pools the development and optimization of measurement equipment, while WP2 includes the measurement tasks using this equipment. The task of WP4 is the development of methods for designing thermal insensitive equipment by improved material selection and placement as well as by avtive temperature control. This work is supported by thermal modelling and by developing in WP3 a maintenance free high resolution temperature metrology with accuracy in the mK range.

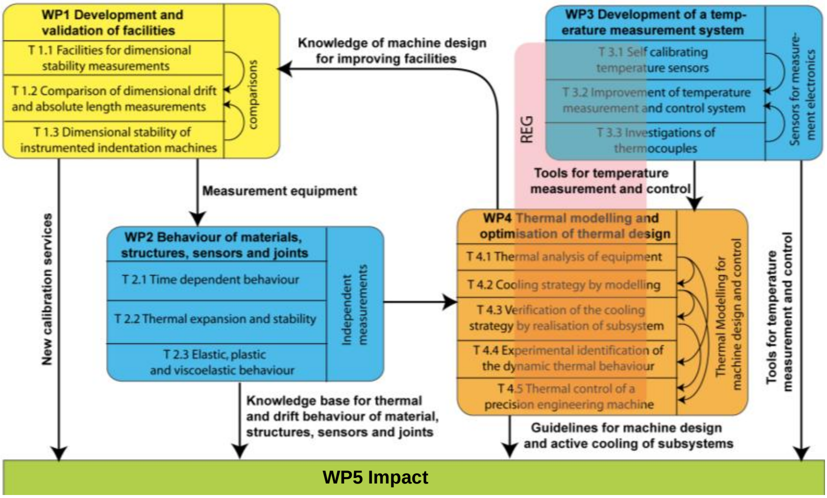

Figure 1: project overview

2 Interferential measurement of drift and thermal expansion

A key part of the project is the ability to measure the stability and thermal behaviour of materials, joints and sensors with sub-nm accuracy. A well established technology for material investigations is the use of end gauge comparators. For samples whose end faces have optical quality and are parallel to each other better than 50 µrad, the length can be measured in the PTB “Precision Interferometer” [1] which is based on a Twyman-Green interferometer, operated within a thermally stabilized vacuum chamber. The sample is wrung to a flat reference plate. Phase stepping interferometry is used at three different wavelengths to obtain phase maps of the sample including the end plate. The center position of the sample front faces with respect to the camera pixels is assigned using a mask. This allows removing the sample and measure later at the same position to get a long time history of the sample length. Parameters like temperature or pressure can be changed in the chamber. The long term stability of several materials, including single crystal silicon, is shown in figure 2.

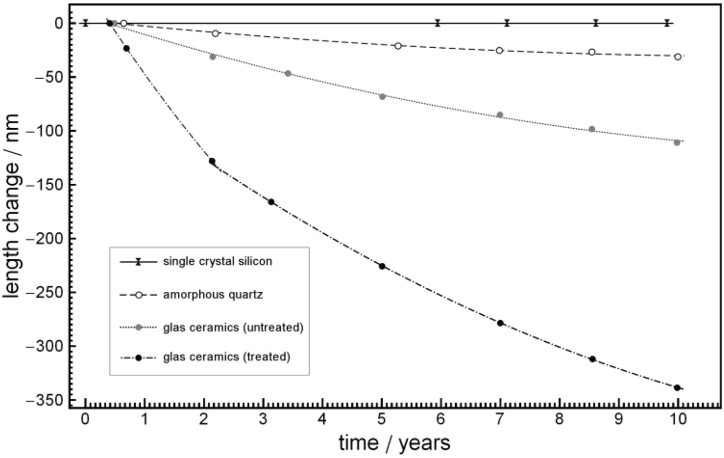

Figure 2: Long time stability of materials measured by PTB's Precision Interferometer

This technique can also be applied to joints, where a sample is mounted (glued, screwed, ...) on a larger back plate as well as sensor or actor systems as long as the surfaces are parallel. The IOF will supply samples soldered [6] or bonded to a reflecting back plate.

It has been shown that using heterodyne interferometry, phase measurement resolution and stability in the 10 pm range is possible [7]. Because it is not possible to repeat a measurement after a sample has been removed, this method addresses shorter time frames. The so called *Picodrift Interferometer* [8] will be established at VSL, aiming for traceable measurements of one-dimensional relative length changes with better than 10 pm and 100 pm uncertainty on a short-term minute timescale and on a medium-term week timescale, respectively.

While these optical concepts probe essentially *bulk* stability of the sample, indentation measurement concepts access mechanical material properties through surface interaction with potential to operate also under harsh conditions, such as high temperatures of hundreds of ºC and will also allow to measure creep effects due to the indentation forces. The indentation measurement equipment of NPL will be improved in the project.

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