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The design of a new comparator for form and diameter measurements (KOLD)

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Abstract
High precision form and diameter metrology techniques at the top of the traceability pyramid are of major importance for many industrial production and fundamental metrology related applications [1].
Therefore, PTB has decided to develop a new measurement instrument in close cooperation with the company Mahr GmbH. It shall become the new national standard instrument for tactile form and length measurement of cylinders, rings and spheres. The "KOLD" is destined to replace the comparator for dimension and form (KOMF)[2]. The new system consists of 2 cylinder form measuring machines with a shared rotary table, which includes a centering and tilting unit. Each side can move its tactile probe system on its own in x-y-z direction. In order to reduce the measurement uncertainties down to the 20 nm range and below for diameter measurement a new approach was developed, which uses 8 laser interferometers in pseudo-Abbe configuration with a metrological frame of Zerodur. Also a new method was developed for the system calibration. The final goal is to reduce the 1D and 3D measurement uncertainties for cylinders and pistons, as well as other common workpieces and standards like rings, gauge blocks and spheres.

Form and length measurement, precision measurement

1. Introduction

For the realisation of the traceability chain in coordinate metrology it is mandatory, that reliable length and form embodiments like cylinders, rings, spheres and gauge blocks are available with low measurement uncertainties. Whereas direct optical interferometry can be used for gauge blocks and in special cases also spheres to calibrate them with low uncertainties, there is still a need of tactile based calibration of cylinders and spheres with uncertainties U < 50 nm. Therefore, PTB applies a two-step procedure, using a cylinder form measuring machine with internal interferometry [3] and for lower uncertainties a specialized Abbe-comparator with two tactile probes, called KOMF [2, 4]. Also the realization of the traceability chain of pressure metrology is a further important application [1, 5]. However, the realized measurement uncertainties of fusioned 3D data sets was limited by small inconsistencies of the measured raw input data sets. Furthermore, the KOMF comparator, which was set into operation more than 20 years ago, did not work properly anymore. Therefore, the decision was made to design a new device which should meet these challenges.

2. Concept of the new comparator

The new system shall have the same advantages like the old KOMF system and less disadvantages. Therefore, the design includes two tactile probes which are assisted by 4 double interferometers [6]. The tactile probes can touch each other to define a reference position. For outer diameter measurement this eliminates the need for a calibration of the sphere diameter of the probes. Due to the new construction where the tactile probes are tilted to each other it is now also possible to take this advantage further to inner diameter measurements. However, the comparator shall also improve the form measurement. It turned out, that the concept of an Abbe-comparator competes with this wish. Therefore, the approach of a pseudo-Abbe measurement was made by implementing a symmetric multi-double interferometer concept. The virtual Abbe line has to be measurable in a special construction which will be explained later in this abstract. The name of the concept was called KOLD (German abbreviation for Comparator for Length and Diameter) and was designed in close cooperation with the company Mahr.

2.1. Set-up of KOLD

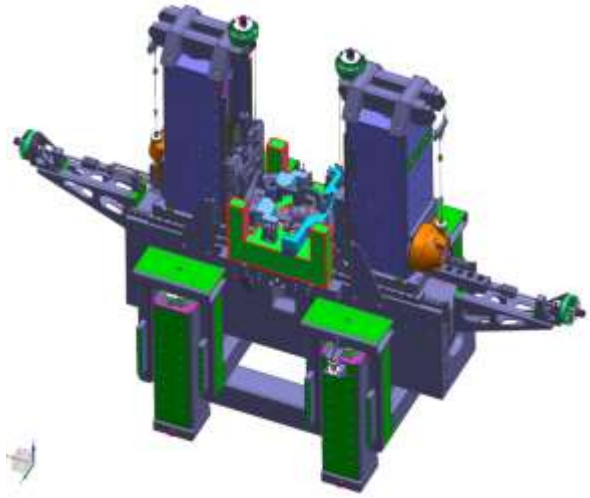

Figure 1. Comparator for Length and Diameter (KOLD)

Figure 1 shows a schematic set-up of the KOLD machine. The KOLD consists of two form measuring machines with a common rotary table for roundness measurements in their center. The two Z-axes towers based on a common machine bed are guided by 6 bearing carriages on each side to reduce guidance deviations in the X-axis. The central component is the rotary table which has a centering and tilting unit to hold the workpiece. This rotary table is embedded into but not connected to a metrological frame made of Zerodur. This frame has reflective planes for the interferometers. All the motors for moving the machine parts where positioned as far as possible from the measuring volume to reduce the thermal influence to the machine. Therefore, the measuring volume as well as the machine will be encased with a housing (not shown). Figure 2 shows the measuring volume with the metrological frame made of Zerodur, the rotary table and the tilted probes with the 4 double interferometers. The mounts of the probe systems and the interferometers are also made of Zerodur to decrease the thermal influence. The metrological loop closes around the probe – the probe mount – the mount of the interferometer – the interferometer – the metrological frame.

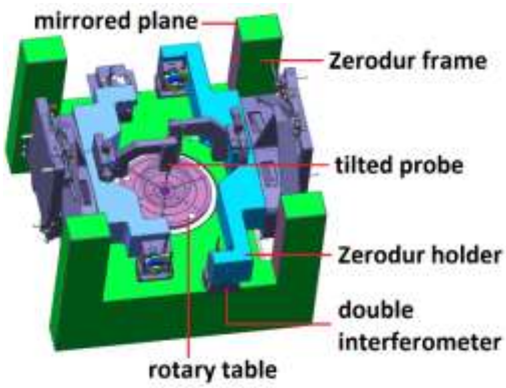

Figure 2. Measuring volume with probe system and interferometers

2.2. Interferometer concept

To measure the pseudo-Abbe position of the interferometers to the probes, we will use a reference cylinder which will be positioned parallel to the Y-direction at the rotary table [6].

The reference position of the length measuring system is defined by touching both probes together in Z-position slightly above the workpiece, as shown in figure 3. The 8 interferometer values are zeroed.

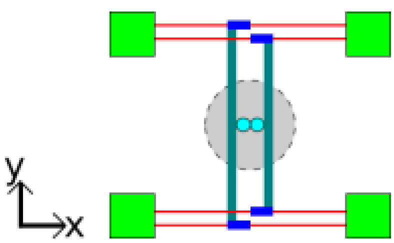

Figure 3. Set reference position to zero above the workpiece

Then the probes contact the workpiece, as shown in figure 4. With the 8 interferometers it is now possible to calculate the influence of the angular deviation of the X-axis guidance. Therefore, the 8 interferometer values can be used to correct the actual position. Due to the fact, that the interferometer beams are moving in Z-axis direction on the mirrors, a lookup-table of the mirror waviness will be used to correct the interferometer values in the X-axis.

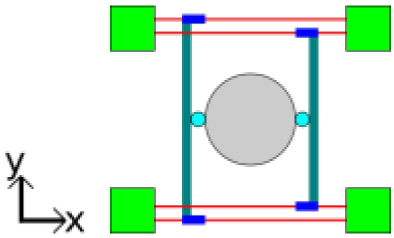

Figure 4. Outer diameter measurement in every height

3. Summary and Outlook

The comparator will be put into operation at the end of February 2017 and first measurement results will be available just before the EUSPEN conference.

The next steps are to characterize the behaviour of the system and the influence of typical fluctuation in environment, laser frequency and drift. With the new comparator it will be possible to decrease the measurement uncertainties in form and length measurement. This improves the traceability chain in pressure measurement and coordinate metrology with lower measurement uncertainties. In the future an additional interferometer system for the Z-axis will be added to further improve some error corrections and to enable high precision angle and squareness calibrations.

4. Acknowledgements

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