The INRIM 1D comparator with a new interferometric set-up for measurement of diameter gauges and linear artefacts

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Abstract

The INRIM 1D comparator was updated with a new interferometric set-up providing differential measurements of probe–sample displacements along the x-axis. In the proposed design, the measuring and reference beam paths fulfil the Abbe condition both in lateral and vertical alignment when probing the middle height section of the measuring gauge. Compensation of mechanical and thermal drifts was extended by using a symmetric and differential design of the optic paths. Significant improvements of the repeatability between series were demonstrated by internal comparisons with reference artefacts .

1 Introduction

Diameter gauges and linear artefacts such as step gauges, line scales and length bars/end standards are key artefacts in dimensional metrology. Traceable calibration of these artefacts is often performed by 1D measuring machines equipped with laser interferometers or precise linear encoders for absolute length measurements.
Metrology laboratories have settled their own measuring machines according range, types and sizes of artefacts to be calibrated. Among these labs, a length measuring machine has been equipped with a double-pass plane-mirror interferometer, this last on the x-moving table and the reference mirror on the z-moving axis together with the contact probe/transducer [1]. A double probing system with independent interferometers to detect simultaneously both sides of the artefact and then determine the zero by contacting themselves the two probes was built for external diameter gauges [2]. A comparator with the probing system and interferometer mirror on a stage moving along x- and z-axes was built recently for diameter gauges up to 300 mm [3].

The opto-mechanical arrangement of the on-board metrology system is a crucial aspect to match the best performances of the machine including stability and repeatability together with a friendly use. The adoption of linear arrangements of the interferometer optics has the advantage of a simple opto-mechanical assembly and alignment, at the costs of some larger drifts and mechanical instability. Meanwhile, a multiple-pass differential configurations based on the Abbe principle may have some constraints in terms of more complicated optics and alignment, and of reduced room size for accommodating the sample and the reference gauge block for probe calibration. In addition, the continuous interferometer reading as needed for the full cycle of each measurement run, requires large and flat optics, namely when the probing system has to move significantly along the z-axes to contact both side of end standards or external diameter gauges.

2 The INRIM 1D comparator

The 1D comparator in use at INRIM for measurements of diameter gauges (spheres, rings and plugs), end standards (step gauges up to 420 mm) and linear artefacts is based on a Moore measuring machine, equipped with a laser interferometer and a bi-directional mechanical probe. The probe is used to determine the start and the end point of the interferometric displacement measurement, whereas the mechanical probe diameter is determined with a calibrated gauge block. Measurement runs are fully automated.

The measuring apparatus was modified with a new interferometric set-up based on plane-mirror differential interferometry (Fig. 1). As shown in the sketch, two mirrors, acting as reference mirrors of a double-pass plane-mirror interferometer, are fixed to the z-stage moving up/down the mechanical probe. The supporting structure was designed for mounting the two mirrors symmetrically and in-plane with the mechanical probe, and compensating the overall material thermal drifts along the x-axis. Due to the symmetric design, the measuring and reference beam paths fulfil the Abbe condition in lateral and vertical alignment when probing the middle height section of the gauge.

The size of the two rectangular mirrors (reference path) allows for vertical movements up to about ±45 mm and lateral movements up to about ±17 mm while keeping the interferometer signal to determine the x-displacements. A continuous reading of the x-positions of the contact probe is required along the full cycle of the measurement run, namely when moving the contact probe from one end face to the other face of end standards, from the outer surfaces of external diameter gauges, or when moving laterally the probe for searching the maximum diameter of cylindrical gauges. Large vertical movements are also needed for calibration of the gauge at different height sections and other measurement purposes (straightness, etc.). In the present set-up the measuring machine may accommodate diameter gauges up to 200 mm lateral size, about 100 mm height and linear artefacts up to 420 mm length.

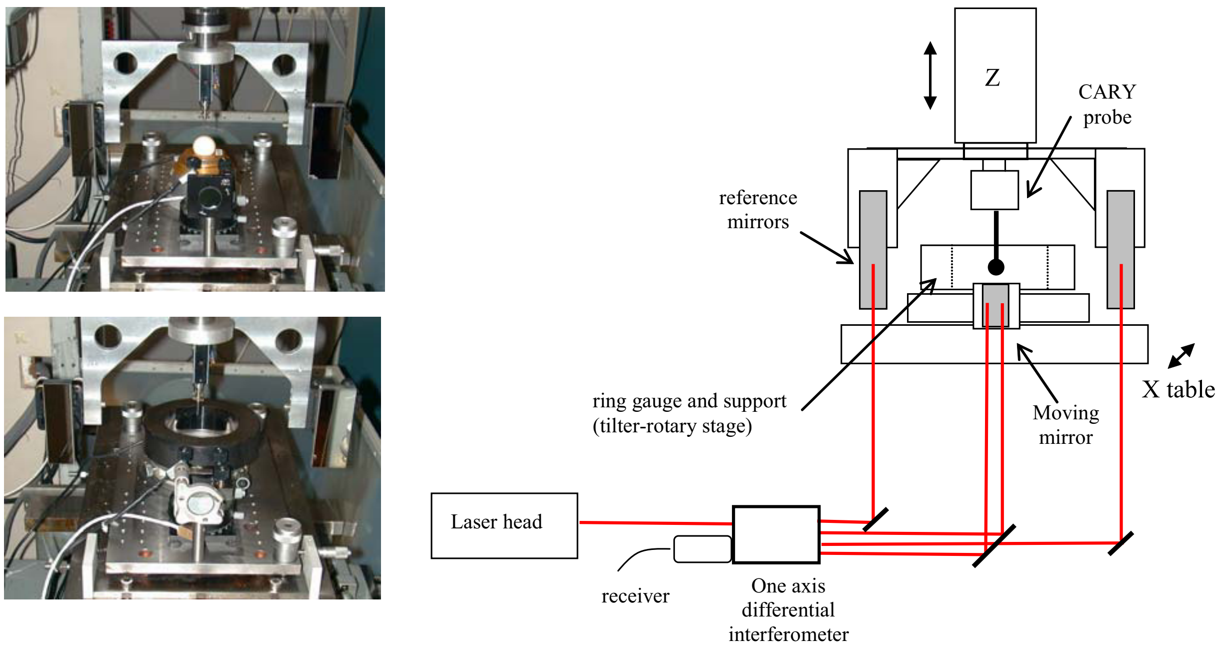

Figure 1: Photos and schematic of the measuring apparatus with the differential interferometric set-up. The x-movements of the machine are perpendicular to the figure; for a better understanding the reference and measuring paths of the interferometer are drawn on the figure plane.

3 Methodology of measurement

The procedure to be used for calibration of diameter gauges is shortly described in the following. It requires an initial setting and alignment of the gauge by the operator, then it is fully automated by the PC-based control of the measuring machine. Main steps are:
- alignment of the diameter gauge and of the reference gauge block;
- setting of the measuring section for cylinder gauges (fully automated; use is made of a small sphere at the top of ring and plug gauges);
- search of maximum diameter (fully automated; search along the y-axis for rings and plugs; along y- and z-axes for spheres; error due to misalignment of the reference mirrors is corrected);
- probe constant calibration;
- measurement of the straightness of cylinder gauges;
- measurements (diameter) of the spherical probe and of the gauge under calibration; repeated at least 9 times for each run.

In addition, other procedures are implemented in the control software for the calibration of step gauges, ball bars and wide range displacement transducers. The machine makes also use of an optical probe for calibration of linescales.

Compensation of the ambient parameters and thermal effects is provided by monitoring temperatures (air, reference and measuring gauges), humidity and pressure during the measurement run. The air refractive index is calculated using the revised Edlen's formula and the ambient parameters are measured by a precision thermometer, a Rosemount barometer and a Mitchell hygrometer. The relative CO_2 content is assumed to be 400 ppm.

4 Results

The new setup was tested by internal comparisons with reference artefacts. Several measurements runs were repeated over a period of months, on a sphere standard from a recent comparison (Fig. 2). First runs were performed in early 2010 by using an initial design, not fully symmetric, of the differential interferometer. The final setup shown in Fig. 1 was developed and tested in early 2011.

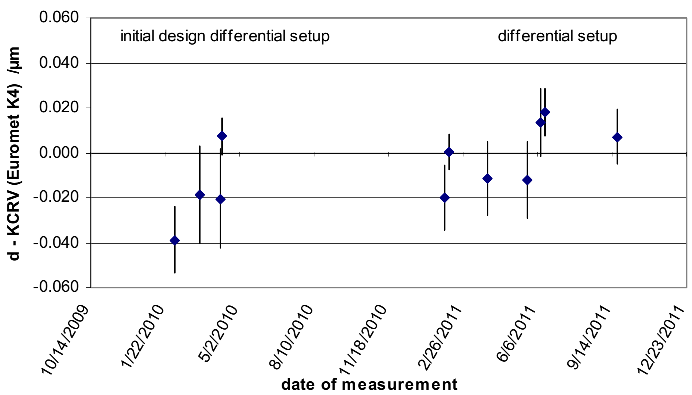

Figure 2. Diameter measurements of a reference sphere. Diameter and st. dev. of each run.

Besides measurements of reference artefacts, the overall stability and sensitivity to thermal drifts of the opto-mechanical arrangement have been characterized by dedicated measurement runs. A long term sensitivity to thermal drifts of up to 1 µm/°C has been observed with variations of about ± 1 °C of the lab ambient temperature and over a period of several hours of settling time. During each of these runs the mechanical probe was kept in contact with the back side of the moving mirror.

This situation is largely far from the measurement conditions where the ambient temperature is usually within ± 0.1 °C variations and the single diameter measurement is taken over a few minutes time period.

The stability of the opto-mechanical arrangement has been tested by driving forth and back up to the full range the x-table of the 1D comparator. In these runs the reference and moving mirrors were fixed to the z-stage supporting the mechanical probe. Readings of the interferometer up to about ± 50 nm have been observed over 440 mm displacements of the table.

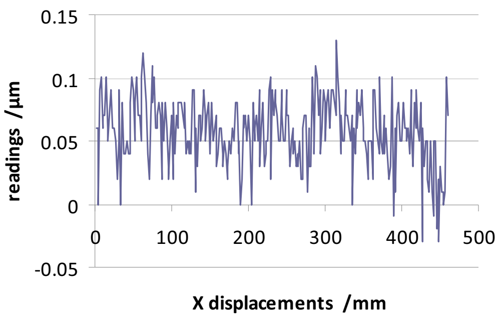

Figure 3. Interferometer readings (zero drift) over full range displacements of the x-table.

5 Uncertainty

The measurement uncertainty was estimated from several components including measurement repeatability, resolution, wavelength in air of the laser interferometer, dead-path, uncertainty of probe constant and reference gage block, thermal and geometrical (cosine and Abbe) effects, measuring axis (searching for max diameter), elastic deformations at the probe-surface contact and gauge's form deviation.

A combined standard uncertainty of 35 nm (ν_{eff} >100) was estimated for diameter measurement of a reference sphere performed with the new set-up. Main contributions (1s) resulted from probe calibration (22 nm), thermal effects (15 nm), form errors (15 nm) and geometrical/misalignment errors (12 nm).

6 Conclusion

A novel interfometer set-up has been developed and tested for the 1D comparator in use at INRIM for diameter gauges and linear artefacts. With the proposed design, the measuring and reference beam paths fulfil the Abbe condition both in lateral and vertical alignment. Compensation of mechanical and thermal drifts has been extended by a symmetric and differential design of the optical paths. Significant improvements of the repeatability between series have been demonstrated by internal comparisons with reference artefacts. Several measurement runs, repeated over a period of months, on a ceramic sphere used in a recent comparison, showed differences up to 40 nm from the reference value (KCRV) determined in the comparison.

References

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[3] Kim J A, Kim J W, Kang C S and Eom T B (2010) An interferometric Abbe-type comparator for the calibration of internal and external diameter standards, Meas. Sci. Technol. 21 075109 (8pp)