ISO compliant reference artefacts for the verification of focus varation-based optical micro-co-ordinate measuring machines

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Abstract

Demand for micro-co-ordinate measuring machines (micro-CMMs) within industry is increasing due to the need for accurate measurement of the geometry of small-scale objects. Optical micro-CMMs have the advantage over traditional stylus-based CMMs of being non-contact instruments, and have the potential to acquire large amounts of data, with high resolution, in a relatively short period of time. The focus variation (FV) technique is typically used for surface topography measurement, but has the potential to be implemented as a sensor technology for optical micro-CMMs. Exploring the possibility of the FV technique as part of an optical micro-CMM requires a robust performance verification of the instrument and measuring procedure, using material measures that are traceable to the definition of the metre. This paper proposes a design for a calibration artefact that is suited to volumetric verification for micro-CMMs based on the FV technique and recognizes recent developments of ISO 10360.

1 Introduction

The ISO 10360 specification standard for acceptance testing and verification of CMMs has several parts, all specific to different groups of instruments and configurations. Each section of ISO 10360 identifies methods and artefacts best suited for the acceptance testing and verification of each group and configuration. ISO/DIS 10360-8.2 [1] (due for ISO/FDIS publication in 2013), is a verification standard written for CMMs with optical distance sensors. There are four main parts to the acceptance and re-verification tests: length measurement error, probing form error measurement, probing size error measurement and flat form error measurement. The probing form and size error tests require a calibrated reference sphere that has a diameter of at least 10 mm. Existing FV surface topography measuring instruments, when used as micro-CMMs, are potentially covered by this standard but the recommended minimum size of the calibration sphere is too large to fully fit within one field of view of a typical system. Most surface topography measuring instruments similar in operation to FV systems, such as confocal microscopes and coherent scanning interferometers are, therefore, also currently excluded from the application of this standard by default, unless the user, and the instrument manufacturer, can agree to use a smaller calibrated reference sphere for the assessment of the probing size and form error. A prototype FV-based optical micro-CMM should, therefore, be verified with calibrated reference spheres of similar size to objects for which the technique has been designed to measure.

Numerous calibration artefacts exist for micro-CMMs (a review is being written by NPL); however, most do not fulfil all the criteria required for a FV instrument. For instance, artefact surfaces are often too smooth to be measured by the FV technique, and the dimensional layout of the artefact is not suitable for an optical instrument with a short stand-off distance. Calibration artefacts have to be designed taking into consideration the conditions for which the instrument performs best, specific requirements for the technology used, whilst also maintaining a traceability chain to the definition of the metre.

2 Novel verification artefact

A novel verification artefact developed for the prototype FV-based optical micro-CMM is composed of multiple small-scale spheres mounted in tiered equally-spaced conical holes. The artefact is specifically designed to evaluate: probing size error, probe form error, and system dimensional accuracy, compliant to ISO/DIS 10360-8.2. A photograph of the artefact is shown in Figure 1.

Reference spheres are suitable components for this verification artefact because they do not have sharp edges (which may cause object illumination problems) and are geometrically ideal in terms of data fitting and modelling. The considerations for FV include rough surface specifications (minimum $Ra \approx 30$ nm), surface slope, and accessibility for high magnification lenses (which generally have smaller standoff distances, in the order of several millimetres).

The spheres are aligned on body diagonals and face diagonals that always include the *z* direction. The sphere diameter chosen for the artefact is 1 mm, although 0.5 mm and 2 mm diameter spheres have also been considered [2]. Four materials have been tested for their suitability for the reference spheres and of these, stainless steel has been chosen for the prototype artefact, but silicon nitride has also been found suitable. [2]

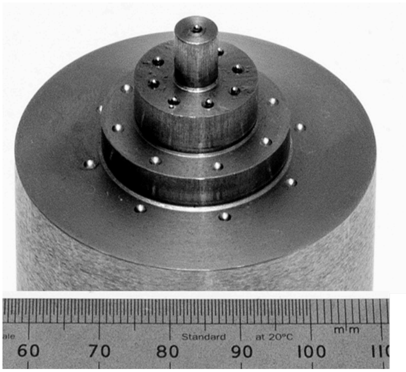

Figure 1: Verification artefact for an optical micro-CMM based on FV.

3 Distance measurement between two spheres

The distance between two consecutive spheres (on the same plane) was measured with a FV instrument using a 50× magnification objective lens, two separate (unstitched) fields of view and the same co-ordinate system. In order to be able to measure as much of the spheres as possible, a ring light and polarizer were used. These serve to increase the illumination aperture of the system, and help improve the detection of scattered light from high angle surfaces. Low lateral and vertical resolutions, 2.93 µm and 0.68 µm respectively, were chosen to minimise the measurement duration. Applying a robust sphere fitting algorithm [3] to the measurement results gives the 3D co-ordinates for the centres of the spheres. From these, the distance between the sphere centres can be calculated. This measurement procedure was repeated three times.

In order to have a comparison to the performance of the FV instrument, the same two spheres have been measured on a high accuracy traditional contact CMM (MPE = $(0.7+L/600)$ µm where L is the nominal distance measured in millimetres), measuring and fitting to each sphere using five data points.

4 Experimental results and conclusions

An example of the result for the separation between two sphere centres measured three times using the FV instrument was 7.122 mm (standard error 0.001 mm), whilst the repeated measurement result for the same spheres using the CMM was 7.112 mm (standard error 0.000 06 mm). The measurement of the FV instrument tends to have higher linear distance values and larger standard deviation values, potentially because the instrument is primarily designed to rely on post process image-stitching. Further sphere combinations have been, and are being, evaluated.

Experimental work is showing the potential of a FV-based instrument to function as an optical micro-CMM. The initial results suggest that the elements of the procedures detailed in ISO/DIS 10360-8.2 can be applied to optical micro-CMMs, thereby providing a traceable verification route to the metre.

The calibration artefact, as shown in Figure 1, will undergo minor dimensional changes in order to optimise the calibration of the artefact using an established contact micro-CMM. Further work will investigate the effect of lateral and vertical resolution for dimensional measurements in the context of the novel calibration artefact presented here, with cross comparison to traditional CMM data also being completed. Consideration will also be given to issues and the merit of short term health checking procedures of a FV-based optical micro-CMM, versus full reverification. Health checking options with artefacts such as this will provide fast estimation and monitoring of optical micro-CMM health. This recognizes similar strategies identified in other parts of ISO 10360.

References

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