euspen's 16th International Conference & Exhibition, Nottingham, UK, May 2016
www.euspen.eu

Metrology on micro-spheres with engineered surface texture

Alain Küng [1], Anaïs Nicolet [1], Felix Meli [1], Rudolf Thalmann [1], Christoph Battaglia [2], Michael Marxer [2], Thomas Jordi [3]

[1] Federal Institute of Metrology METAS, 3003 Bern-Wabern, Switzerland
[2] NTB Interstaatliche Hochschule für Technik Buchs, Institut PWO, 9471 Buchs, Switzerland
[3] Saphirwerk AG, 2555 Brügg, Switzerland

Email: rudolf.thalmann@metas.ch

Abstract
Spherical standards with polished surfaces are commonly available in excellent quality. They are widely used in metrology as calibration standards for coordinate measuring instruments. Micro-spheres with sub-millimetre diameter and optically cooperative surfaces suitable for metrology applications were so far not available. By changing process parameters, a manufacturer of ceramic products is now able to produce micro-spheres with an engineered surface texture. The paper describes the metrological characterisation of rough micro-spheres in terms of diameter, form deviation, surface texture and surface roughness parameters. Ceramic micro-spheres are made available as standards for instrument verification of optical microscopes with 3D measurement capability and will be compatible with future standardized procedures.

Keywords: µCMM, 3D optical microscope, micro-sphere, calibration standard, surface texture

1. Introduction

Spherical standards are widely used for the calibration and verification of coordinate measuring machines (CMM). Whereas for tactile sensors, polished ceramic spheres are commonly available in excellent quality and in a large range of diameters, most optical sensors require "cooperative" surfaces, i.e. diffusely reflecting, but avoiding specular reflections. Recently ceramic spheres with a diameter around 10 mm and a rough surface, but sufficiently small form deviation, were made available and investigated for their use as reference standards for multi-sensor coordinate measuring machines [1]. For optical micro-CMMs or optical microscopes with 3D measurement capability, there was so far a lack of suitable spherical standards. Micro-spheres with polished surfaces are commercially available in good quality with diameters down to around 100 µm. By extending their manufacturing process, the company Saphirwerk was able to produce Si_3N_4 ceramic micro-spheres with an engineered surface texture and diameters in the submillimetre range. The challenge was to get cooperative surfaces suitable for most optical sensor principles, but still keeping the form deviation small enough. To obtain optimum process parameters the relevant characteristics were measured for several production lots of micro-spheres.

The paper describes the metrological characterisation of rough micro-spheres in terms of diameter, form deviation, surface texture and surface roughness parameters. The suitability of the micro-spheres as standards for optical micro-CMMs was investigated involving different sensor principles: focus variation, confocal microscope, fringe projection and scanning white light interference. Of particular interest is the maximum detectable slope angle.

2. Metrological characterization of micro-spheres

The characterization of the micro-spheres involved the measurement of the diameter, the form deviation (sphericity), ISO surface roughness parameters *Ra* and *Rz*, and areal surface texture. For the measurements, five arbitrarily selected micro-spheres of each production lot were glued on a flat surface (gauge block) with Cyanoacrylate adhesive such that the upper hemisphere was freely accessible for all instruments (Fig.1).

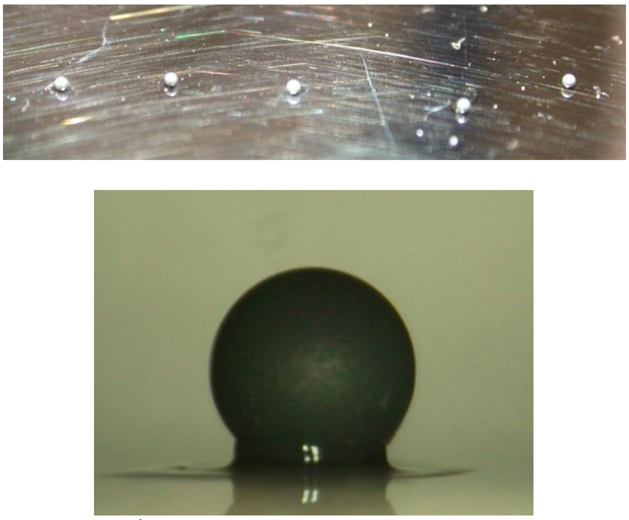

Figure 1. Five Ø 0.4 mm ceramic spheres glued on a gauge block (top) and close up of a single sphere (bottom).

2.1. Diameter and form deviation measurement

The diameter and sphericity deviations were measured with the METAS µCMM [2], using a Ø 125 µm ruby probe and scanning the equator and two perpendicular profiles over the pole of the micro-spheres with a point density of 300 pts/mm (Fig.2). The expanded uncertainty for the measured form deviation is estimated to be below 70 nm, as this results from the ISO 10360-4 [3] scanning probe verification test performed on the METAS µCMM, where a similar probing strategy is used.

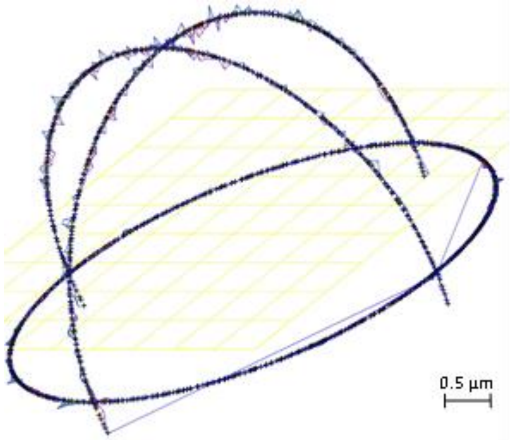

Figure 2. Scanning measurement profiles of the µCMM on a Ø 0.4 mm ceramic microsphere for the determination of the sphere diameter and sphericity deviation.

2.2. Roughness measurement

The roughness measurement on the micro-spheres was carried out using a long range AFM profiler [4] along two central scans of 80 µm length over the apex of the sphere. *Ra* and *Rz* roughness parameters were evaluated over a cutoff length of 40 µm, after convolution of the profile by a standardized tip radius of 0.1 µm or 2 µm, in order to be as closely as possible to the relevant ISO standards [5]. Figure 3 shows a measured roughness profile evaluated with a 2 µm tip radius, resulting in *Ra* = 27 nm and *Rz* = 214 nm.

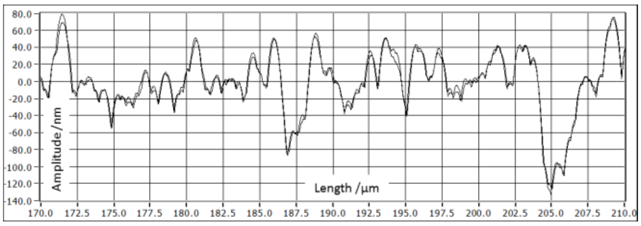

Figure 3. AFM roughness measurement profile evaluated on a cutoff wavelength of 40 µm and convoluted for 2 µm tip radius.

2.3. Areal surface texture measurement

Areal surface texture measurements were useful to analyse and document the manufacturing process of the engineered micro-spheres. The measurements were carried out with the metrology AFM [4] using its 2D scanner over a central range of 20 µm x 20 µm on the sphere's apex. Figure 4 illustrates one of these measurements.

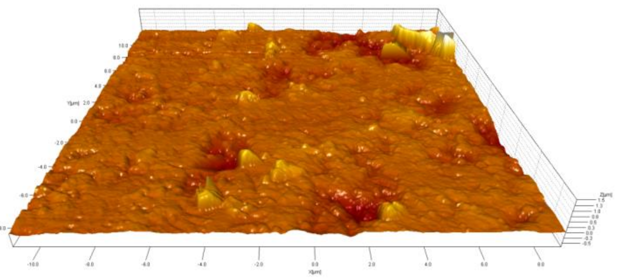

Figure 4. AFM surface texture measurement on a rough micro-sphere within an area of 20 µm x 20 µm.

2.4. Overview on the measurement results

Five different lots of ceramic micro-spheres were measured so far, with polished spheres in lot 1 and roughened surfaces following different procedures in the other lots (Table 1). All roughened lots show form errors larger than 0.5 µm, which is at the upper tolerable limit in view of an application as reference standard for optical micro-CMMs. The next step will be to correlate the process parameters with the results and hence to optimize the roughening process as to get a small and uniform surface roughness still keeping the form deviation as small as possible.

Table 1 Metrological characteristics of five lots of micro-spheres with engineered surface, lot 1 being polished and the other lots being purposely roughened in the manufacturing process. Values together with standard deviations measured within each lot.

Lot	Ø / µm	Form / µm	*Ra* / nm	*Rz* / nm
1	402.0 ± 0.1	0.15 ± 0.05	5 ± 1	49 ± 1
2	381.0 ± 1.0	0.57 ± 0.13	102 ± 15	640 ± 79
3	366.4 ± 4.6	0.59 ± 0.10	76 ± 16	604 ± 183
4	402.0 ± 0.1	0.58 ± 0.21	37 ± 8	333 ± 100
5	386.6 ± 0.8	0.87 ± 0.04	122 ± 15	676 ± 102

3. Application for optical micro-CMMs

The purpose of these micro-spheres with engineered surface roughness is their application as a reference standard for optical microscopes with 3D measurement capability. First promising results have been obtained with a focus variation microscope Alicona G4. Figure 5 shows an image taken with the 50x objective on a Ø 0.3 mm ceramic sphere. Displayed are the deviations from a best fit sphere with ± 1 µm for the full false colour range. The useful measured surface on the sphere has a diameter of about 0.2 mm, which corresponds to a surface slope at the border of the measurement field of about 45°.

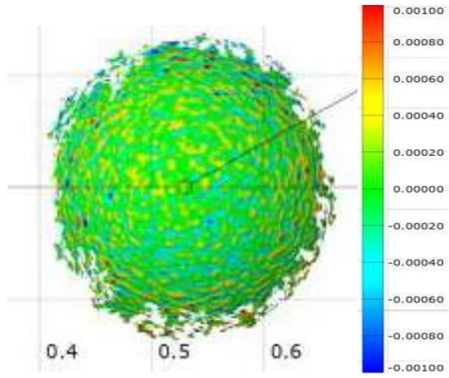

Figure 5. Ceramic micro-sphere measured with a focus variation microscope, all scale values in mm.

4. Outlook

Actual research is going on towards ceramic micro-spheres with somewhat smoother surface and smaller form deviation to be used as standards for performance verification of optical micro-coordinate measuring instruments, compatible with future standardized procedures.

References

[1] Keferstein C, Marxer M, Götti R, Thalmann R, Jordi T, Andräs M, Becker J, "Universal High Precision Reference Spheres for Multisensor Coordinate Measuring Machines", *CIRP Annals - Manufacturing Technology* (2012), 10.1016/j.cirp.2012.03.018.

[2] Meli F, Küng A, Thalmann R, "Ultraprecision micro-CMM using a low force 3D touch probe", *Meas. Sci. Technol*. **18**, 319-327 (2007).

[3] ISO 10360-4, Geometrical product specifications (GPS) - Acceptance and reverification tests for coordinate measuring machines (CMM) - Part 4: CMMs used in scanning measurement mode.

[4] Meli F and Thalmann R, "Long range AFM-profiler used for accurate pitch measurements", *Meas. Sci. Technol*. **9**, 1087-1092 (1998).

[5] Meli F, "Roughness measurements according to existing standards with a metrology AFM profiler", *Proceedings of the 3rd euspen conference,* **V2**, Eindhoven, The Netherlands, 533-536 (2002).