

An Effective Approach in Measuring Orthogonal Diameters and Sphericity for CMM Verification

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Abstract

The traceability of the reference sphere is crucial in providing a valid, meaningful and reliable verification of Coordinate Measuring Machine (CMM) and Articulated Arm CMM (AACMM). During the development of the related verification services, the Standards and Calibration Laboratory (SCL) has to determine the sphericity of a reference sphere for probing and scanning tests. These tests are required to determine the form errors, size errors and, in the case of AACMM, articulated location errors. SCL approached national metrology institutes (NMIs) for the sphericity calibration. These NMIs preferred to provide roundness values of some random great circle traces rather than that of 3 orthogonal circle traces. The latter was a suggested approach in determining the sphericity in ISO 10360-5:2020. For that reason, SCL developed its own calibration capability on sphericity, by adopting the error separation technique and establishing her own source of traceability. In the development, SCL identified an effective approach in measuring the orthogonal roundness and diameters by designing a simple fixture. With that fixture and rotating the stem connecting the sphere to a fixed angle two times, three orthogonal great circle traces can be measured using the same setting. It can also be used in measuring 3 orthogonal diameters with minimal change in a two opposite-points setting. In this poster, the difference between the sphericity and roundness is reviewed. The advantages and disadvantages of error separation method are discussed. The fixture design is shown with the technical details explained. The fixture is simple to fabricate and the approach can be adopted by calibration laboratories in providing the sphericity calibration for CMM as well as AACMM verifications.

Roundness and sphericity in CIPM MRA and ISO 10360 standards

In simple words, roundness is a two dimensional parameter that determines how closely an object matches a circle, while sphericity is a three dimensional parameter that compares an object with a perfect sphere.

National Metrology Institutes (NMIs) are responsible in providing the source of traceability to the International System of Units (SI). NMIs participate in inter-laboratory comparisons to demonstrate their competences in fulfilling this task and have their capability recorded in the Calibration and Measurement Capability (CMC) list of the International Committee of Weights and Measures (CIPM) Mutual Recognition Arrangement (MRA). In that list, only roundness was found for form error in roundness standard like hemisphere, sphere and cylinder. Probably due to the three dimensional nature of sphericity, it was not in the CMC list nor in the Consultative Committee for Length (CCL)'s Length Service Classification (DimVIM).

In ISO 10360-5:2020, sphericity can be determined by "a minimum of 3 orthogonal great circle traces, or using 25 or more points well distributed on the sphere". It could be for this repetitive nature of the task and/or the necessity of building a fixture, some NMIs preferred to provide roundness values of some random great circle traces instead for user, which may not be ideal in determining the sphericity for CMM verification.

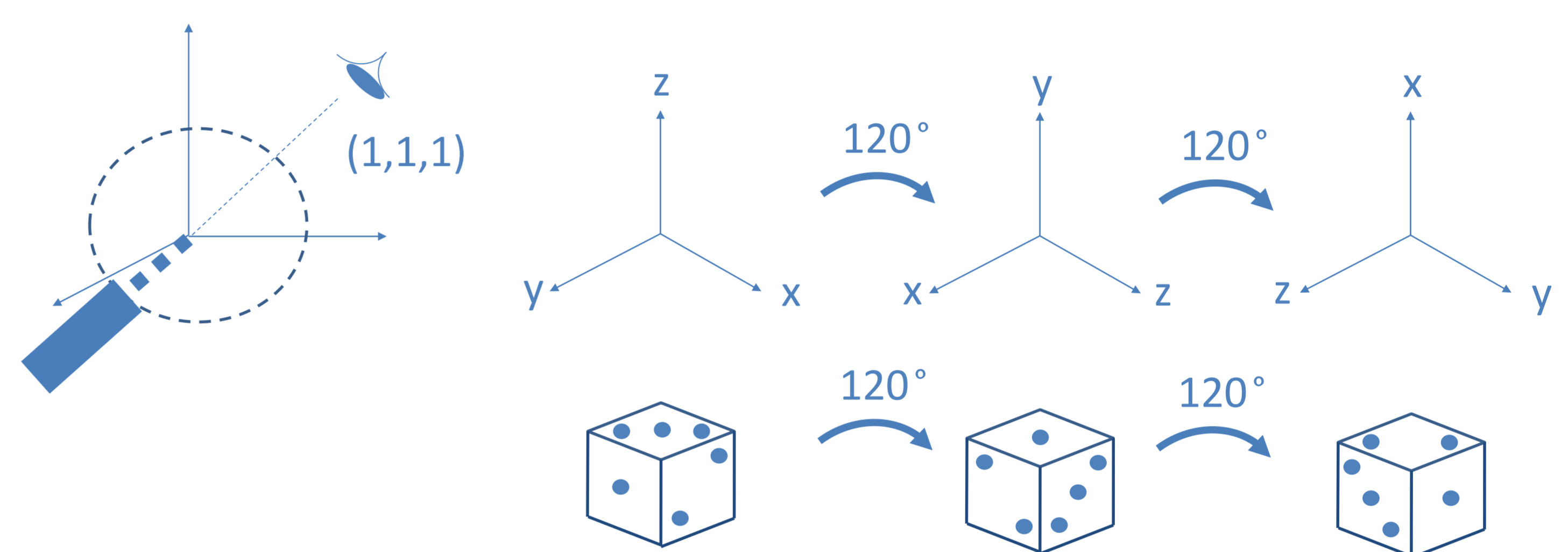
Error Separation – Pros and Cons

Error separation is a common technique for NMIs to determine the form of roundness standards. By forming different angles between the probe and the UUT through a multi-step method, a matrix is formed to analyze the form error of spindle axis and the unit under test (UUT). The advantages of the technique is that it separates the form errors between the spindle axis of the measuring equipment and the UUT such as sphere. This improves the accuracy of the measurement results and reduce the measurement uncertainty to 20 nm or lower. The disadvantages of this technique are the prolonged time requirement for measurement and the harmonic suppression problem which further requires a higher number of measurement step to avoid missing of the dominant harmonic. It also requires a very stable environment throughout these measurements.

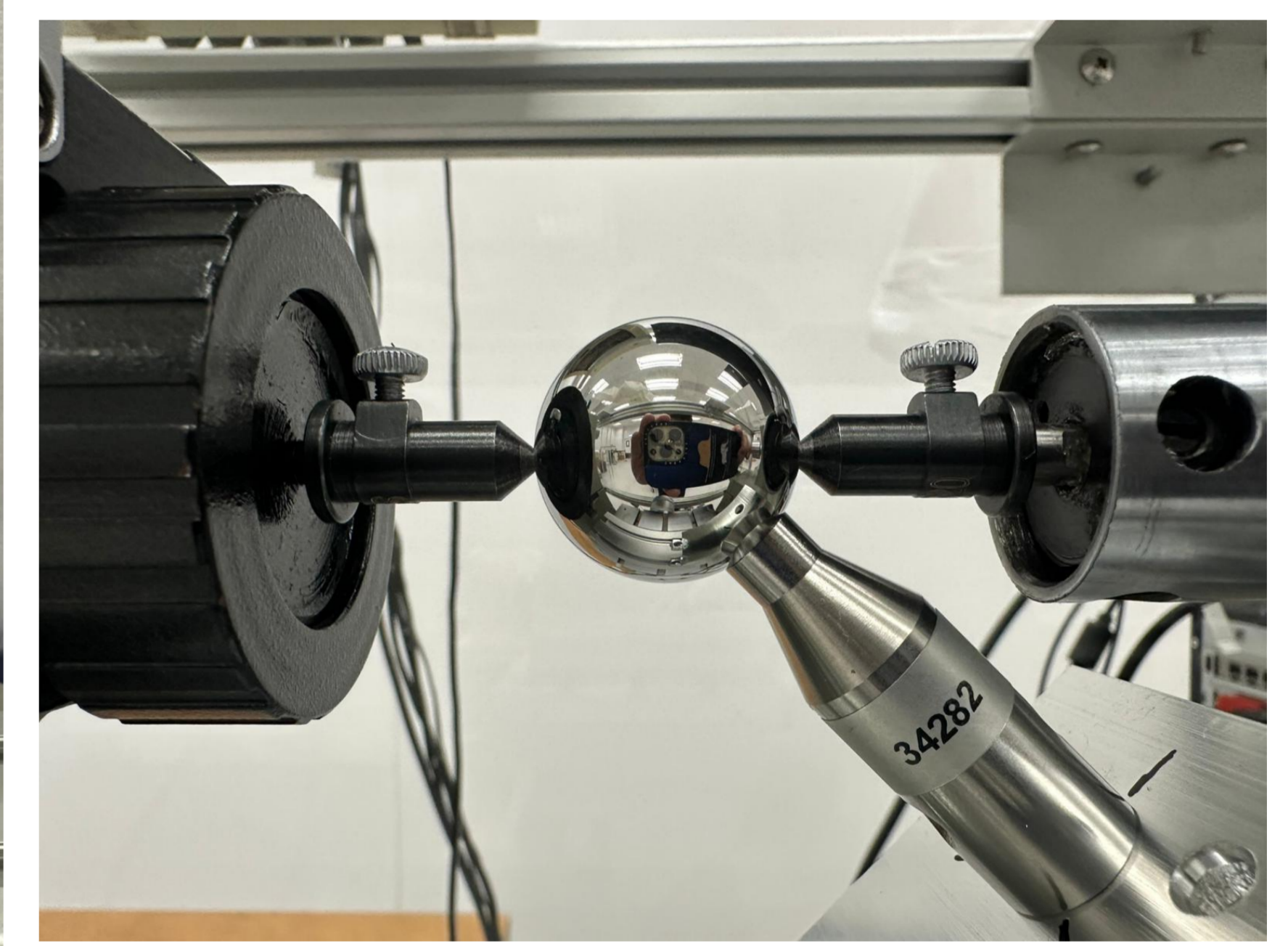
Fixture Design

After developed her error separation technique on sphere, SCL designed a prototype fixture to support the sphericity measurement, by measuring 3 orthogonal roundness. The fixture is simply an angle plate forming a 45° to the horizontal plane. The stem of the sphere to be measured is mounted perpendicularly on the angled plate, which has marks at 0° and $\pm 120^\circ$ near the rod, as in the figures below. After measuring a great circle horizontally, the rod is rotated to $\pm 120^\circ$ for the other two great circles. The roundness of these great circles would automatically be the orthogonal roundness values.

The phenomenon is intuitive and can be explained using the figures below. Assuming the center of the sphere is the origin. When viewing the sphere from the location (1, 1, 1), which is on the axis of the stem of the sphere, the three axes will be replaced by one another at each 120° . This phenomenon can also be demonstrated by replacing the sphere with a dice. Each great circle measured is parallel to the top surface of the dice.



Fixture forming a 45° to the horizontal plane. After measurement of a horizontal great circle, the stem of the sphere is rotated $\pm 120^\circ$. The three great circles obtained in this way are orthogonal to each other.



The fixture can also be used in measuring the diameter of the sphere. If the fixture is supported by a turn-table, diameters of a great circle can be obtained by rotating the turn-table after measurement. Repeat the measurement after rotating the stem by $\pm 120^\circ$, diameters of three orthogonal great circles can be obtained.

Application to ISO 17865:2016

If the sphericity is not used as a rated operating condition, ISO 17865:2016 is referred to determine the form and its uncertainty. For sphericity determined using 3 orthogonal great circle traces, the above arrangement can directly be used. If a five great circle traces orthogonal to directions (0,0,1), (1,0,1), (0,1,1), (-1,0,1) and (0,-1,1) is preferred, the fixture can also support these measurements, by measured at 0° and then rotated the stem to 60° , 180° and 240° . These 4 orientations plus one without using the 45° plate could provide the required great circles' orientations.

Conclusion

SCL has developed calibration service on sphericity of sphere to support CMM and AACMM verification. A fixture that can allow measurement of 3 orthogonal roundness by rotating a rod was developed. Its design and application are discussed.