A stitching approach for the interferometric determination of absolute topographies of spherical surfaces

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A method has been implemented that allows the determination of absolute radii based on interferometric measurements instead of the relative shape deviations which result from conventional roundness measurements. This method extends the applicability of the sphere interferometer of the Physikalisch-Technische Bundesanstalt (PTB) to the reconstruction of the absolute topography of spherical surfaces. It could be shown that it is possible to determine the absolute shape of a spherical object taking into account the two-sided measuring principle of the sphere interferometer of PTB in combination with the implemented stitching procedure. The described approach is a non-contact method with an accuracy of 5 nm or better and a higher lateral resolution compared to conventional tactile roundness measurements.

1. Introduction

The sphere interferometer of PTB was developed for the volume determination of spherical material measures - in particular the spheres of the Avogadro Project [1] - by precise diameter measurements with an uncertainty of 1 nm or less [2]. Up to now only the volume and the diameter instead of direction-dependent radii were of interest, and usually a diameter topography was obtained, which is symmetric to the center of the sphere. To extend the applicability of the interferometer, a method has been implemented that allows the determination of absolute radii instead of the relative shape deviations which result from conventional roundness measurements [3]. The algorithm realizes a stitching technique and enables the reconstruction of the absolute topography of spherical surfaces. Thus, topographic characteristics can be allocated unambiguously and the actual and absolute shape of the sphere under test can be revealed with an accuracy in the nanometer range. As one of the extensions to the approach described in [4] also the systematic errors are included in the model of the reconstruction. The functionality was proven and validated on the basis of simulated and real measurement data.

2. Principle of the measurements

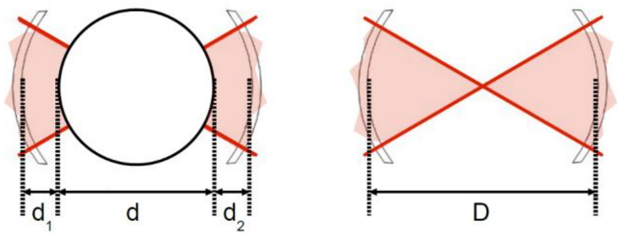

Fig. 1 Sketch of the principle of the diameter measurements.

The principle of the diameter determination is sketched in Fig. 1. As a first step the sphere under test is placed between the spherical reference faces of the two Fizeau objectives and removed out of the cavity in a second step. The diameter d of the sphere then results from the difference of the measurement of the distance D and the measurements of the distances d_1 and d_2: $d = D - d_1 - d_2$. As the field of view has an opening angle of 60°, a segment of the surface of the sphere can be measured at once yielding 10,000 diameter values given by the pixels of the cameras. By rotating the sphere to different positions, the entire surface can be covered with measuring values [5]. Taking the difference of the measured distances, the topographic information from both sides of the sphere is mixed up and the graphical representation of the results is a diameter topography which is point-symmetric to the center of the sphere. To determine the real form of the sphere and, therefore, to obtain the radius topography, which is most likely not point-symmetric, the data should be evaluated so that the topographic information of both sides of the sphere is treated separately.

3. The stitching procedure

The basic idea of the stitching approach is to concatenate the measured segments of the surface ("to stitch them together") and to extract the information about the local topographic shape. The implemented stitching algorithm [3] is based on a mathematical model in which the topography of the sphere and the systematic errors are parameterized by spherical harmonics and by Zernike polynomials, respectively. The systematic errors comprise wavefront deformations, for example, due to the shape deviations of the reference faces. And the geometric corrections take into account a residual misalignment of the objectives. Related to this model, an overdetermined system of linear equations is set up with about 10^5 to 10^6 rows and 10^3 to 10^4 columns depending on the amount of measurement values and the number of parameters in the model. A least squares solution yields the values of the parameters which represent the topography of the sphere, the shape deviations of the reference faces and the geometric corrections. In Fig. 2 an exemplary result of a reconstructed topography is shown together with the related diameter topography. In the reconstruction the distinct features of the topography are located unambiguously, while this is not the case in the diameter topography. Taking additionally into account the absolute diameter value, which results from the usual evaluation of the data, the real shape of the sphere is available.

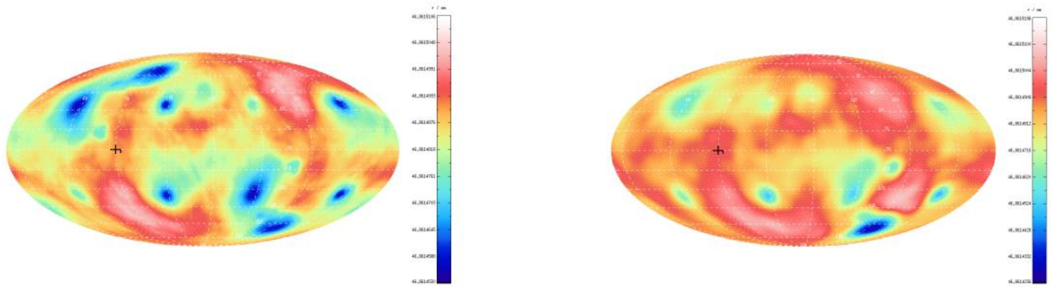

Fig. 2 Exemplary diameter topography (left) and the related reconstructed radius topography (right). The maps are plotted as Mollweide projections and the color scales span approximately 48 nm and 86 nm, respectively.

4. Conclusion

The non-contact interferometric measuring technique offers a high accuracy and a high lateral resolution due to the chosen experimental design. Preliminary estimations provide a standard uncertainty of at least 5 nm. These estimations are limited by the uncertainty of independent results for radii variations from high precision roundness measurements [3].

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