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Topographical profiler investigations on a sphere

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Abstract

A ruby sphere with a nominal radius of 500 µm is investigated by topographical measurements on a profiler instrument. The surface of the sphere is gathered by parallel profiles within an area of 500 µm * 500 µm with a resolution of 10 nm within a profile and a distance of 500 nm from profile to profile. The z-axis of the measurement head is a linear moving stylus equipped with an interferometer. Z-data are recorded with a resolution of 0,1 nm within a range of 200 µm. The tip radius of the stylus instrument is nominally 2 µm with an angle of 90°. The contact force is controlled on a constant value below 0,3 mN. The radius of the sphere is estimated at first from single profiles by a circular fit. As an alternative method after filtering curvature data are regarded for radius estimation. Another approach for the determination of the radius is the calculation of the surface function of the segment under test depending on the height of the segment. For the determination of the surface integration process all data are filtered by a cubic-spline function basing on DIN EN ISO 16610-22. Results of each method are compared with the radius value basing on conventional roundness measurement of the circumference of the sphere.

Keywords: Topographical Profiler Instrument, Radius estimation, Surface function

1. **Introduction**

The topographical profiler instrument HRTS (High Resolution Topo Scan) developed at PTB [1-2] is dedicated to the three dimensional metrological characterization of surface texture and form. The requirement of such a machine is underlined by numerous publications in different fields [3–7]. The goal of the measurement on the sphere is to assess the agreement of profiler data with the value based on roundness measurement. From the geometrical point of view especially the shape of the tip and its removal from measured data is a serious problem in the analysis of topographical measurements by stylus instruments. An example dedicated to this problem is given by Schuler et al. in [6]. The measurement on a sphere will also offer the chance to test mean radius evaluation by curvature data in comparison to the circular fit method.

2. Experimental details and results

The topographical representation of the surface of an object by a profiler instrument is a set of parallel profiles. Therefore the radius of a sphere can be estimated by a single profile. The sphere under investigation is attached to a shaft. For our measurements we have fixed the shaft perpendicular to the z-axis of our instrument. In this configuration the x-axis of the instrument is parallel to the equator of the sphere. For radius calculation the profile with the minimum mean value of curvature is chosen. Figure 1 shows the curvature of this profile vs. the x-axis of the profile. There are two positions close to 25 and 475 µm on the x-axis that will limit the relevant area of curvature. For curvature calculation the profile is filtered by a cubic-spline function described in DIN EN ISO 16610-22 with L_s = 2 µm and L_c = 25 µm. In figure 2 the profile is shown by a black line within the limits indicated in figure 1. The red curve in the background of the profile represents the circular fit to the profile. The mean radius given by the fit is about 500.187 µm. The mean value of curvature between the limits depicted in figure 1 yields a mean radius of 500.231 µm. The variation of the radius values within this area can be estimated by the standard deviation of the curvature. Regarding this, radius values are varying between 489.252 µm and 511.714 µm. These values are in good agreement with the calibrated radius from roundness measurement D_SC = 500.392 µm within the segment under test.

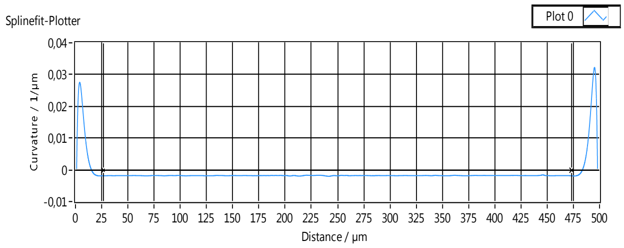

Figure 1. Curvature of the equatorial profile.

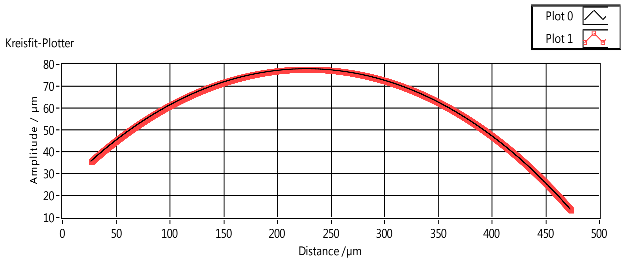

Figure 2. Profile of the curvature from fig. 1 with circular-fit.

An important point for the radius calculation is the knowledge of the mean radius of the tip of the profiler instrument. One method to find the radius value for example is to measure a profile on a so called tip characterizer KNT 4050/01 [8]. But for a topographical instrument we need a three dimensional description of the tip. Therefore we have chosen a confocal laser scanning microscope (Olympus LEXT OLS4100) for tip characterization. The uncertainty of measurement in z-direction of the microscope is smaller than 12 nm. Figure 3 shows the top of the tip in a region of 3 µm * 3 µm. There are 94 profiles within this area with 91 points each. The resolution in x-direction is about 31.65 nm in y-direction 31.48 nm. The topography looks roughly like a sphere with some distinctive deviations. A spherical fit to the data shown in figure 3 yields a mean radius of 2.06 µm.

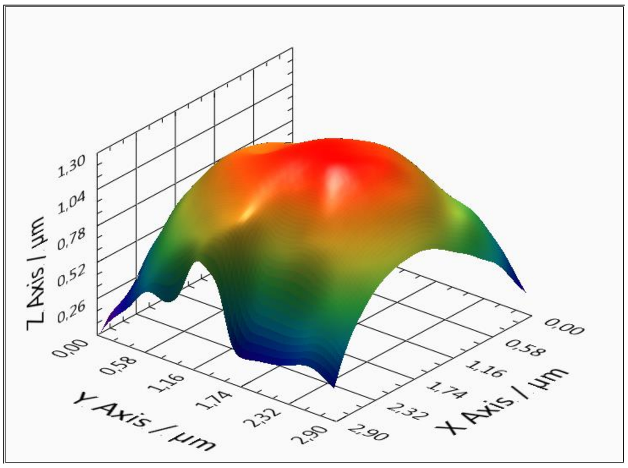

Figure 4. Relevant top area of the diamond tip.

Figure 4 shows the surface of the 500 µm sphere which is measured by 1000 profiles and 5000 points each. The area of the surface topography can be calculated by integration as a function of the height of the segment. In this case the segment has a circular shape and not the quadratic appearance as in figure 4. Beside the area this method delivers the radius of the sphere. As an example we have done such a calculation for a height of 50 µm. During the integration process the surface is filtered with a wavelength of 2 µm and the tip is corrected by an idealized probing sphere with the mean radius given above.

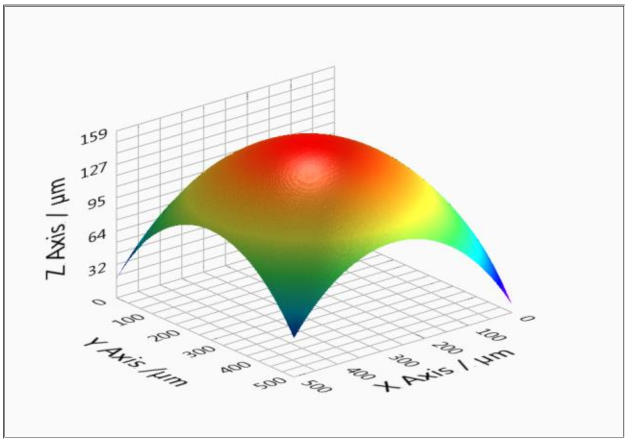

Figure 4. Surface segment of the ruby sphere (raw data).

The calculation yields a radius of 501.43 µm for a height value of 49.9 µm. The deviation to the calibrated value is around 0.21 %.

3. Discussion

A detailed analysis of error budget of our instrument shows, that the main contribution to uncertainty is caused by the uncertainty of the shape of the tip. In the case of the HRTS the uncertainty over all axes in a topographical measurement is around 33 nm. The uncertainty of the shape of the tip is estimated to be around 50 nm or more. In a calculation we have folded the tip area from figure 3 with an ideal sphere with a radius of 500 µm. The sphere is calculated by 1000 profiles each 5000 points in an area of 500 µm * 500 µm. Within the tip area the dilatation process is made by a bicubic spline interpolation. The result of the calculation is a radius value of 501.70 µm. It delivers a tip radius of 1.70 µm. This result differs clearly from the mean radius derived of the data in figure 3. If we take a look on the shape of the tip in figure 3 we see a surface with a fine structure. If this surface is folded with the homogenous surface of an ideal 500 µm sphere it seems to be clear that not all points of the tip will touch the surface of the sphere in a measurement. But this means there occurs a filtering process and only some prominent points of the probing tip with higher negative curvature values (see figure 1) will touch the surface of the 500 µm sphere. Furthermore the areal data, which were taken within a field of 500 µm * 500 µm on the sphere are comparable to data of roundness measurement over the whole sphere, verifying the result of the estimated tip radius of 2.06 µm ± 0.18 µm.

5. Summary

We have demonstrated different methods of data evaluation and radius calculation from single profile and topographical profiler measurements. The paper shows that the form of the tip of the profiler instrument plays a dominant role within the uncertainty budget of a metrological profiler instrument. In future we will concentrate on the characterization of surface functions of different indenters for hardness measurement. Tip characterization will also be a main topic of our work.

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