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Profiler tip characterization using a precision sphere

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Abstract

To achieve high precision form measurements by a tactile profiler, besides a stable coordinate system and a constant velocity of motion the form of the probing tip is a decisive factor. For reliable form measurements the form of the profiler tip has to be removed from the measured profiles. Therefore, the mean tip radius and the 3 d tip shape have to be investigated. As a nearly ideal sample for 3 d tip characterization a calibrated precision sphere is measured by the metrological profiler instrument HRTS at the PTB. The instrument is equipped with a linear moving stylus and an interferometer on the z-axis. The construction of the measurement head allows equivalent profile measurements in x- and y-direction of the instrument. Therefore, mean tip radius values are determined for x- and y-scanning for the full opening angle of the tip. Topographical measurements are used for imaging the tip within a limited opening angle. After characterisation of the tip for both scanning directions a conventional two dimensional tip characteriser sample is investigated by x- and y-scanning. The radii of the test specimen are calibrated with an expanded uncertainty of 0.11 µm with excellent agreement for both scanning directions.

Keywords: Microform measurement, tip characterization, curvature analysis

1. Introduction

The characterisation of cutting edges is a demanding task in mechanical engineering and fabrication. For validation and calibration of radii measured by optical methods, traceable tactile measurements are necessary and also demanded by the producers of optical instruments. In order to achieve comparable results from tactile measurements a metrological profiler as described in [1] should be used. For these instruments the shape of the tip is the limiting factor of uncertainty in microform measurement. Therefore, the radius of the profiler tip has to be characterized as precisely as possible [2, 3]. For tip characterisation in three dimensions as necessary for a topographical instrument, a precision sphere is the first choice because tip characterizers like a sharp edge, work only in two dimensions and are often limited to a small angle depending on mechanical properties. Regarding the fact that we have to realize a tactile calibration independent from optical methods excludes these methods from tip characterisation.

2. Experimental set up

For our investigations we used the tip of the metrological profiler instrument described in [1]. It has a nominal tip radius of 2 µm and an opening angle of 90°. The instrument has a linear moving stylus, on the z-axis, carrying the tip on the lower end and a mirror on the top. A small metal splint inside the stylus and two magnets inside the housing of the measurement head prevent the stylus from rotation. Linear movement of the stylus is measured by an interferometer. The stylus is guided by air bearings and equipped with a real time force control system. The sample under test is mounted on a x-y-table. The table has low-noise vacuum preloaded air bearings and is driven directly by voice coils. The linear movement of the table in x- and y-direction is measured by two optical linear encoders. The resolution of both linear encoders and the interferometer on the z-stylus is 0.1 nm. The z-range of the instrument is 240 µm, x and y ranges are 50 mm. Position data of all linear encoders, air pressure and the current of the force compensation system are registered synchronously in real time by the controller of the instrument during each profile measurement. The main advantage of the instrument is the linear moving stylus carrying the diamond tip. Therefore, it plays no role, if the sample under test is moved in x- or in y-direction. Both these axes of the instrument are applicable for movement in a profile measurement of the sample under test. The instrument is designed for topographical measurements with 24 h duration. It is located in a thermal controlled environment (± 0.1 °C). In case of a 2d single profile measurement the main contribution of uncertainty is 23 nm, caused by the analogue, linear encoder signal of the moving axis. Regarding all components of the instrument including thermal drift during a single profile measurement an expanded uncertainty of 23.3 nm is achieved on a flat sample. For a 3D topographical measurement with hundreds of profiles over 12 h an expanded uncertainty of 33 nm is obtained on a flat sample.

3. Experimental Results

The sample used for tip characterisation is a calibrated ruby sphere with a nominal radius of 500 µm. The radius was calibrated by roundness measurement along the equator line of the sphere at PTB. The radius value is D_SC = 500.393 µm with an expanded uncertainty of 50 nm.

Topographical profile measurements are made along the equator of the sphere. Each profile has a length of 800 µm to cover the full angular range of 90° of the tip. In order to determine the position of the equator 400 parallel profiles are recorded with a distance of 500 nm. Each topography measurement covers a field of (800x200) µm² with the highest point of the sphere nearly in the middle. These measurements are made in forward and backward direction along the x-axis and also along the y-axis with adapted positioning of the sphere. The configurations are sketched out in Fig. 1.

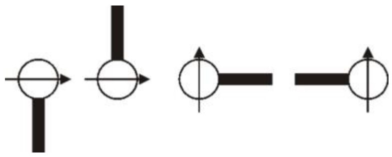

Figure 1. Orientations of the sphere for tip characterisation.

The arrows in Fig. 1 indicate the direction of profile measurement in relation to the shaft of the sphere. For every orientation the profile with the largest radius value is selected as the profile along the equator. Beside the radius value the circular fit yields the coordinates of the central point. In the next step a circle with the calibrated radius value is positioned in the central point and subtracted by a vector operation in circular coordinates from the measured data. The difference gives the form of the tip including all errors of the reference sphere. The result of the calculation is shown in Figure 2 for an equatorial profile.

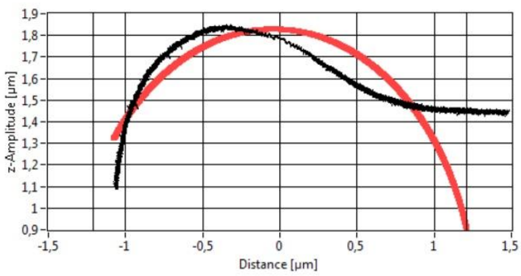

Figure 2. Tip form after spherical vector subtraction (profile: black curve, circular fit: red curve)

The profile in Figure 2 is distorted by the shear angle of the z-axis relative to the moving x-axis. The distortion can be compensated by consideration of the shear angle in between both axes z and x. Figure 3 shows the form of the tip after correction by a shear angle of 0.363°.

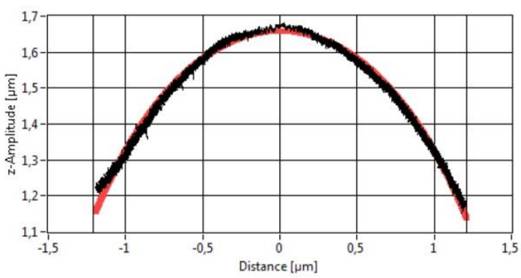

Figure 3. Tip form after subtraction of the reference sphere and shear angle correction (profile: black curve, circular fit: red curve)

The circular fit represented by the red curve in Figure 3 and the profile measured backwards in x-direction results in a mean tip radius of 1.63 µm in x-direction of the instrument. A similar investigation for profile measurement in y-direction results in a shearing angle of 0.063° and a mean tip radius of 1.93 µm. The angular range in x-direction is 88.91° and 89.91° in y-direction. The expanded uncertainty of these values is estimated at U(k=2) = 100 nm.

For 3D tip reconstruction 1000 profiles in x-direction are measured on the reference sphere in the first orientation shown in Fig. 1 over an area of (500x500) µm². For thermal drift correction, one profile is recorded in y-direction close to the equator line. Figure 4 shows the result of this investigation including shear correction. The image of the tip is limited to an angular range of 26°.

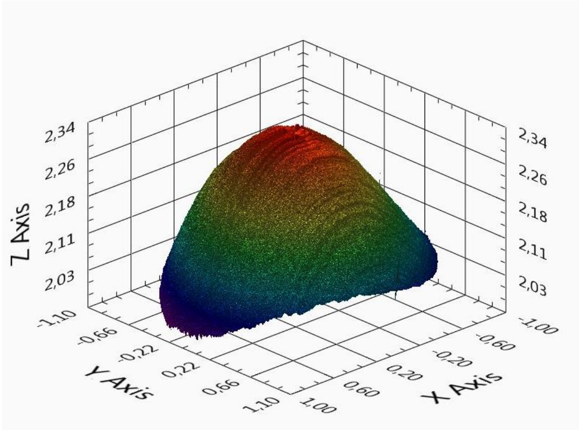

Figure 4. 3D-tip reconstruction (shear correction in x-direction)

The mean tip radius calculated by a spherical fit to the 3D data in Figure 4 is 1.75 µm.

Looking on the value of the expanded uncertainty of the instrument for a 3D topographical measurement on a flat sample, given in section 2 now we can calculate the uncertainty of a 3D measurement on a microform standard regarding the uncertainty of the mean tip radius value given in this section. Therefore, the expanded uncertainty of tactile microform measurement by the metrological profiler instrument is 110 nm.

As a test of the tip radius data, a radius standard sample with a nominal radius of 20 µm is measured in x- and y-scanning directions of the instrument. The mean radius value in x-direction is R_x = 19.78 µm. Measurement in y-direction, for the same sample gives a radius value of R_y = 19.80 µm. The good agreement of the two values documents the quality of the tip radii in both directions measured by x- and y-scanning.

3. Summary and outlook

The goal is to reduce the uncertainty in tactile tip characterisation, because it provides the largest contribution to the budget of uncertainty of the instrument. For that reason, a new reference sphere with lower uncertainty of the calibrated radius value is also on the way.

The tip radius for scanning in x- and y-direction and the 3D tip shape of a metrological profiler instrument were measured using a high precision reference sphere. In order to reduce the uncertainty of the instrument, the quality of positioning will be enhanced. Also the z-range of the instrument will be extended and a new tip with an opening angle of 60° will be installed.

3. References

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