“Real mechanical profile” – the new approach for nano-measurements

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Abstract. Different functional meanings, e.g. contacting surfaces or visual effects lead to different real surfaces. For nano-measurements in ISO/DTS 14406:2003 (E) it is stated to distinguish between the mechanical and the electro-magnetic surface. Until today the traced profile has been the only defined surface of a workpiece. It is defined in ISO 3274 as "the locus of the centre of a stylus tip as it traverses the surface within the intersection plane." The new approach for the extraction of the real surface is the correction of the traced profile with the radius of the tip by the morphological operation erosion. The result of the correction is defined in ISO/DTS 14406:2003 (E) as the real mechanical surface. The resulting profile is called the real mechanical profile and it is defined in accordance with the ISO definition. The poster discusses the distortion of the traced profile compared to the new real mechanical profile.

1. Introduction

Stylus instruments are well developed for the measurement of deviations in the range of micrometers. The evaluation of geometrical deviations of a surface within the nanometer range with stylus instruments is limited by calibration uncertainties and insufficient definitions. For the reduction of these limits new methods and theories have to be developed. Besides the development of the stylus instrument and the development of new standards [1], [2] the definition of the real surface should be integrated in the evaluation of geometrical deviations with stylus instruments. The poster discusses the definition of a new profile that is not part of the ISO standards today but fulfills the definition of the real mechanical surface. Distortions of the profiles resulting from the tracing process and the radius of the tracing element will be demonstrated on real and generated profiles.

2. Traced Profile

The development of manufacturing processes and the reduction of the geometrical deviations of the surfaces have forced the development of stylus instruments [3]. The measurement of super smooth surfaces lead to the development of a new characterization of surfaces in the nanometer range [4]. The function of stylus instruments defined with different profiles has constantly been the same. Stylus instruments scan surfaces with a stylus and detect deviations as a surface profile. The surface profile is defined in ISO 4287 as

the profile that results from the intersection of the real surface by a specified plane[5].
The realization of the surface profile with a stylus instrument is the traced profile. The traced profile is defined in ISO 3274 as

the locus of the centre of a stylus tip which features an ideal geometrical form (conical with spherical tip) and nominal dimensions with nominal tracing force, as it traverses the surface within the intersection plane. Note: This is the profile from which all other profiles defined in this International Standard are derived [6].

The tip radius of the stylus of a standard stylus instrument is at least 2 µm with an angle of 90° [6]. For the evaluation of nano-measurements that limits the result of the tracing process. In the following example the tracing of the surface has been simulated with two tip radii. The generated real surface (Figure 1) represents an object with nano-roughness. Different tip radii lead to different traced profiles (Figure 2, Figure 3). With a 2 nm tip radius (Figure 2) the surface can be extracted completely but with the tip radius of 2 µm (Figure 3) most detail of the nano-roughness of the real surface is eliminated.

The profile in Figure 3 does not represent the real surface. The centre line of the stylus tip is not the reproduction of the real surface.

3. The real surface
The real surfaces of workpieces have different functional meanings. The different functional meanings can be e.g. contacting or visual effects. A contacting effect can be the volume of liquid that can be hold by a pocket in the surface of a workpiece. A visual effect is e.g. the shine of a mobile phone
cover. As stated in ISO/DTS 14406 (E) [7] the different functional surfaces depend on the physical interaction in the atomic structures and lead to different real surfaces. For nano-measurements it is therefore more important to differentiate between the different functional surfaces. Today two different functional real surfaces, the **mechanical** and the **electro-magnetic**, are defined [7]. The real mechanical surface (Schema 1) is the mechanical boundary of the erosion, by a spherical ball of the radius \( r \), of the locus of the centre of an ideal tactile sphere, also with the radius \( r \), rolled over the real surface of a workpiece [7].

![Schema 1: definition of the mechanical real surface](image)

Until today the definition of the real surface has not been implemented in the evaluation of geometrical deviations with measurement instruments. For the extraction and definition of the real mechanical surface morphological operations are the bases. Morphological operations and the consequences for the evaluation of surfaces have been investigated for a couple of years [8], [9]. The definition of the mechanical surface introduces the morphological operation erosion. The erosion is like the dilatation a basic morphological operation. Structuring elements are the device for using morphological operations as filter. The stylus tip is an example of a structuring element. Structuring elements can have many shapes and sizes. Most common are balls with different sizes.

The trace of the center of the structuring element is the result of filtering a surface with the morphological operation dilatation. For the extraction of the geometrical deviations with a stylus instrument the dilatation is identical with the traced profile (Schema 2). Therefore the tracing with a stylus instrument can only lead to the real mechanical surface.

![Schema 2: traced profile identical to the result of the morphological operation dilatation](image)

The process of simulating a rolling of the structuring element underneath the line of the dilatation is the morphological operation called erosion. As mentioned above the erosion after the dilatation is the
definition of the real mechanical surface. The structuring element has to be the same in shape and size for dilatation and erosion if these operations are used to reconstruct the real mechanical surface as the real surface of a workpiece for contacting problems.

Until today the traced profile is the only defined surface of a workpiece but the traced profile is not the real mechanical surface as defined in ISO/DTS 14406 (E) [7]. The best approximation of the real mechanical surface for stylus instruments is a profile as it describes the intersection of the surface in the intersection plane. A new profile that represents the real mechanical surface of a workpiece has to be found.

4. Real mechanical profile
A new approach in nano-measurements is the determination of the real mechanical profile. The real mechanical profile is the intersection in an intersection plane of the real mechanical surface. The new real mechanical profile can be defined in accordance to the definition of the real mechanical surface as

the profile after the application of the morphological operation erosion to the traced profile, with a circular disk of the same radius as the radius of the tip.

Schema 3 is the demonstration of the operation erosion to the traced profile. Today the real mechanical profile is the best approximation of the real mechanical surface.
The following figures are the result of applying the morphological operations dilatation and erosion to a generated profile. The tracing of a surface with nano-roughness with a large tip radius (2 µm) has been chosen to visualize the problems with the traced profile. All profiles are in the same dimension. The traced profile in Figure 3 is identical to Figure 4. The mechanical profile in Figure 6 is the traced profile after the erosion with the radius of the structuring element of 2 µm.

The mechanical profile (Figure 6) of the traced profile in Figure 4 is reduced in height compared to the real surface but has the same height as the traced profile. Lost information about the height can not be corrected with the real mechanical profile.

The comparison of the real surface (Figure 5), the traced profile (Figure 4) and the real mechanical profile (Figure 6) also point out the distortions in the traced profile. Peaks of the real surface (Figure 5) are traced as arches (Figure 4). The distortions caused by the tracing process and the radius of the stylus tip falsify the profile in vertical and horizontal dimension.

5. Distortions of the traced profile
Mechanical filtering and the expanding of structures are the distortions discussed in this section. Distortions of the traced profile due to the shape and size of the stylus are the reduction of the total height of the profile (Schema 4). This filter effect is often called the mechanical filtering [7].

For the extraction of the real surface without the reduction of the height the size of the structuring element circular disk has to be smaller than the local radius of curvature of the surface [7]. For nano-measurements this leads to radii of the stylus tip of a few nanometers.
A motivation for the reconstruction to the real mechanical profile is that part of the surface can be corrected with the morphological operation erosion. For example the peaks resulting from the mechanical filtering are reconstructed as radii.

These radii are the reproduction of the radius of the probe tip and they are also an indicator that the surface has not been extracted correctly because the reproduction of the radius of the probe tip only happens if there is an apex due to the mechanical filtering. Both reconstructions of real surfaces (sinus and trapezoid) are also examples for the horizontal distortions.

The tracing and reconstruction process have been simulated on a trapezoid.

The horizontal distortions are the result of the tracing process. For the correct extraction perpendicular to the surface the texture and form of the surface have to be known. Since that is unrealistic every tracing process leads to expanding structures. With the real mechanical profile the expanding can be corrected. The results of the tracing process and the reconstruction are Figure 10 and
Figure 11. Figure 12 is the superposition of the real surface and the real mechanical profile. The real mechanical profile is a close reproduction of the real surface since the extracting of the surface took place without mechanical filtering. A smaller radius of the tip would lead to the real mechanical profile identical to the real surface.

6. Summary and outlook
The traced profile is not the best approximation of the real surface for stylus instruments. The size of the radius of the stylus tip has a major impact on the uncertainty of the nano-measurements. Distortions of the traced profile resulting from the tracing process and the influence of the radius of the tip can be reduced with the reconstruction of the real mechanical profile. According to the definition of the real mechanical surface the new real mechanical profile is defined. Only the application of the morphological operation erosion is necessary to reconstruct the real mechanical profile form the traced profile. Functional meanings of nano-roughness and nano-structures can be evaluated with less distortion by nano-measurements if the real mechanical profile is used. In the future the real electro-magnetic surface should be investigated for the comparison of nano-measurements with optical and stylus instruments.

The correction of the radius of the probe tip should be done similar to the measurements of form. Today the deviations of form are measured by form- or coordinate measurement instruments. The radius of the probe tip is corrected after the association of an ideal element with the dimension of the radius of the probe tip. The correction after the association is critical for the shape of the profile but less harmful for the peak to valley parameters [9].

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