3D-characterization method and morphological filtering for the assessment and the design of friction optimized surfaces

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Abstract. For a specific manipulation of friction surfaces it is important to measure and calculate geometrical parameters to derive the tribological behavior. The new functional approach presented in this paper is the calculation of the characteristic lateral extension of the real contact surface as well as the representative contact radius by applying morphological filters to a 3D-set of data. All surface characteristics, including form, waviness, roughness as well as defined microstructures, are extracted holistically with a 3D Coordinate Measuring Instrument or a Form Measuring Instrument, but with the smallest available tip radius. The paper presents the benefit of this holistic extraction method and the application of morphological filtering for the description of the contact form (plateau or sphere), the real contact surface, number of contacts, the typical contact radius and the typical lateral extension of the micro contact plateaus.

1. Introduction
The control of friction is very important for an energy-efficient function of mechanical motion. The focus of current research is set on the optimization of modern lubricants as well as on the design of friction optimized surface structures. One approach is the development of geometric determined microstructures with equally spaced microcavities. The other way is the improvement of surfaces by defining the contacting area. The intention of the following explanation is therefore not only to define friction optimized surfaces with microstructures but also to assess common friction surfaces without microstructures.

Microstructures are preferably manufactured with erosive or cutting technologies. The application specific design and dimensioning of such microstructures are still empirical. For a better understanding of the mechanisms of a certain surface quality or a defined, determined surface structure for tribological behavior, a detailed interpretation of the effects and mechanisms in and on microstructures is needed. Two types of microstructures are discussed: Microstructured surfaces Type 1 and microstructured surfaces Type 2 [1].

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Microstructured surfaces Type 1 are characterized by cavities with defined geometries equally spaced on the surface. The friction mechanisms primarily occur on the remaining plateau. Within these microcavities, lubricants or particles, which could cause more friction or abrasion, can be stored (figure 1). The bottom part of this figure zooms in on the dependency of the lubrication film thickness and the geometrical characteristics compared to a zoomed in explanation for a surface without microstructures (Figure 1 bottom) over the friction length. Without microstructures the lubrication film thickness decreases over the friction length. With microstructures (figure 1) a periodical regeneration of the lubrication film can be achieved by phases of contact (contact length) and non contact (length without contact). For these secondary mechanisms, the lateral dimension and the volume of the microcavities as well as the surface related part of the nominal surface become important. Besides the lateral dimensions of the microcavities, the dimensioning of its depth structure, depending on the sliding speed and lubricant viscosity, is also important to create hydrostatic pressure.

![Figure 1](image1.png)

**Figure 1.** Mechanisms of surfaces without microstructure; and mechanisms of microstructured surfaces Type 1.

Microstructured surfaces Type 2 are three dimensional geometries without cavities. A simple example is the surface presented in figure 2.

![Figure 2](image2.png)

**Figure 2.** Geometrical characteristics of Type 2 [1].
It can be shown that material stress $p_0$, caused by an applied nominal contact pressure $p_N$, only depends on the quadratic ratio of the structure depth $Z = 2a$ and the period length $L$.

$$p_0 = \sqrt[3]{3\pi \frac{Z^2 p_N v^2}{L^2 (1-v^2)}}$$  \hspace{1cm} (6)

Looking at the single contacts as „Hertzian Contacts,“ the lateral dimension of adhesion related contact areas, the material stress and hydrodynamic friction behaviour can be optimized application specifically with the parameters $Z$ and $L$. These simplified mechanisms are long known but not implemented in production processes. This might be caused by missing measuring methods as well as manufacturing processes. Today there is no general strategy to derivate the parameters under practice conditions.

2. Assessment and design of friction optimized surfaces

Today the geometrical properties are separated into form, waviness and roughness [2]. Different measuring instruments and measuring methods are used to extract these properties independently. A correlation of the geometrical properties and the functional characteristics is not possible with the separated information of the surface. The real contact surface of a workpiece interacts with the counterpart and is influenced by the combined effects of the contact form, number of contacts, the typical contact radius and the typical lateral extension. The understanding of this interaction needs a holistic view of the surface and its properties. Holistic means that all geometrical properties are assessed from one measurement to maintain their connection.

2.1. 3D characterization method

There are different ways to extract a workpiece in a holistic way. The easiest way is to use computer tomography. The problems with that are still the limited resolution and the definition of the electromagnetic surface. Therefore other methods have been developed at the Chemnitz University of Technology. They especially consider the mechanical surface as the functional surface for tribological functions. In ISO standards the mechanical surface is defined for the tactile measuring method and is one functional approximation of the real surface.

![Figure 3](image.png)

**Figure 3.** (a) 3D-CMM F25; (b) CMM-probe with tip radius 2 µm; (c) stylus tip mounted on the probing shaft.

Mechanical surfaces can be extracted holistically with a 3D Coordinate Measuring Instrument (3D-CMM) or a Form Measuring Instrument, but with the smallest available tip radius. The tip radii used are 2 µm and 5 µm. Common 3D-CMMs do not have tip radii like that. Figure 3 (b) therefore shows a new developed probe for the 3D-CMM F25 by Zeiss (figure 3 (a)). The stylus tip with a radius of
2 µm (figure 3 (c)) is mounted on the special probing system for the F25. The low tracing force of this probing system allows this new development. This approach is still in the testing period. Measuring results will be published in the near future.

A second approach is the holistic extraction with a Form Measuring Instrument MFU 100 by Mahr. Flat and cylindrical surfaces can be measured holistically in one setting with a tip radius of 5µm. For example circular profiles are extracted by rotating the table and shifting the stylus after one measurement to the next position (figure 4 (a)) over the complete flat ring surface of about 12 mm. Figure 4 (b) shows the extraction result. The real contacting surface is limited by the form deviation if the counterpart is perfectly flat. The zoomed detail of the surface plot (figure 4 (c)) reveals the applied microstructure. The extracted profile above figure 4 (c) (position marked with the dotted line) reveals the sinus type surface. Sampling distance and length depend on the characteristic and the dimension of the microstructure and the workpiece.

There needs to be further research to develop these approaches into a general method. The bases for this method and the connection of the functional geometry of the workpiece to the probing conditions are surface parameters to describe the functional behaviour.

2.2. Design of friction optimized surfaces and the development of new parameters

In the past couple of years a set of 3D parameters for roughness has been developed. It is defined in ISO/DIS 25178 part 2 [3]. The parameters are separated in height, spacial, hybrid, function and related parameters as well as feature characterization. These parameters are not sufficient for the design of friction optimized surfaces. The mean line filtering to separate the form and the statistical character limits the holistic description of the surface.

For a couple of years the descriptions of surfaces, with the application of morphological filters, have been qualified at the Chemnitz University of Technology [4]. Figure 5 describes the basic morphological filtering operations. The calculated mean line of a structuring element represents a dilatation. This is the same as extracting the surface with a stylus with a spherical tip and calculating the line of the centre points. The reversal of this is the erosion. Erosion applied after dilatation leads to the reconstructed mechanical surface and is also defined as closing. Algorithms are available to simulate different structuring elements on a surface to derive different closing surfaces. The other possibility is to simulate erosion before dilatation as an opening operation. This is possible for 2D and 3D surface data [5]. Closing and opening surfaces describe the resulting surface after applying the morphological filter operation.
With these closing operations the extracted surface can be separated in form, waviness and roughness portions but in connection to each other by a common datum system. This datum represents the counterpart and is, in the first approach, an ideal flat or cylindrical feature. Furthermore distances and amplitude parameters as well as void and material volume can be calculated as 3D parameters to associate geometrical surface characteristics to tribological parameters (figure 6). Supporting points are a set of points that have the same x- and y-coordinate for different closing surfaces. These new parameters based on the common datum system will be implemented in evaluation software soon.

With morphological opening operations the real radius of a surface can be calculated (figure 7). A more or less good approximation of the simulated surface to the mechanical surface can be achieved by simulating closing surfaces with different radii for the structuring element. No difference between the mechanical surface and the simulated surface is an indicator for the best possible approximation.

Algorithms have to be developed to calculate the distribution of contacting radiiuses as one influencing value to characterize the tribological behaviour. The distribution of volume parameters, number of contacts and the lateral extension of the micro contact plateaus have to be visualized.
3. Summary and outlook
For a specific manipulation of friction surfaces it is important to measure and calculate geometrical parameters to derive the tribological behavior. All surface characteristics, including form, waviness, roughness as well as defined microstructures have to be extracted holistically with a 3D Coordinate Measuring Instrument or a Form Measuring Instrument, but with the smallest available tip radius. A common datum system has been developed to describe the real contact surface, number of contacts, the typical contact radius and the typical lateral extension of the micro contact plateaus. With morphological operation a segmentation of the surface based on this common datum system is possible.

The future intention of the presented research is the development of a design guide for friction optimized surfaces with microstructures and an optimization tool for common friction surfaces to support designers and application engineers. For an improved description of the tribological behaviour the new characterization method and the newly developed surface parameters will be applied to different workpieces not only with microstructured surfaces. The designer will be assisted with tolerance principles, 3D-notation rules, parameter tables, and so on.

4. References
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