11th International Symposium on Measurement and Quality Control 2013, September 11-13, 2013, Cracow-Kielce, Poland

MEASUREMENT PROCEDURES AND EVALUATIONS METHODS FOR THE EXTRACTION AND ASSESSMENT OF FUNCTIONAL FEATURES OF MICROSTRUCTURED SURFACES

Wito HARTMANN[1]*, Andreas LODERER*[2]

1 Institute of Manufacturing Metrology, Universität Erlangen-Nürnberg,
Nägelsbachstraße 25, 91052 Erlangen, Germany, wito.hartmann@fau.de
2 Institute of Manufacturing Metrology, Universität Erlangen-Nürnberg, Germany.

Abstract:

The paper describes an approach how to measure function-oriented with appropriate measurement technology and evaluation methods. At first important features of the surface, which have a large influence on the functional behaviour, are determined based on a physical-mathematical model of the function. Then – adapted to the measuring task – it is described how to measure these features starting with the selection of suitable measurement procedures (optical/tactile, 2D/3D, multi-scale data fusion). Moreover, the evaluation of the measurement values is also crucial. Automated evaluation procedures based on segmentation techniques and autocorrelation methods were presented using examples of microstructures for the improvement of sliding and ink transfer for printing machines. These procedures allow extracting important functional properties of the measured 3D surface and their quantitative evaluation.

Keywords: surface metrology; model-based test technique, microstructure, function-oriented, segmentation techniques

1. INTRODUCTION

Microstructured surfaces contribute to improve functional properties, such as aerodynamical or tribological properties of a component. The geometrical optimisation of these microstructures is usually difficult if only a low correlation between the production parameters, the measured surface parameters and the functional behaviour is known. A possible reason for this is that the measured surface is evaluated insufficiently. Although for example hemisphere cell structures, which are commonly used for functional reasons (e.g. to improve sliding) as well as for manufacturing reasons, have dimensional features like diameters, depths, and pitches, usually only 2D surface parameters like Ra or Rz according to ISO 4287:2009 are calculated, which take only the mean of amplitude values. Furthermore even function-oriented parameters like parameters of the Abbott-Firestone curve have the disadvantage that the manufacturing process cannot be controlled and adjusted with the values directly. Actually if geometrical features are determined, the measurement evaluation is usually done with high user influence manually, so that due to time constraints only a small area with few features are used to evaluate the entire surface, which may lead at a high process variation to erroneous assessments.

2. DEFINING FUNCTION-ORIENTED MEASURANDS

A fundamental requirement to improve the function of a microstructure and to assess its functional ability based on dimensional measurements is to understand its physical behaviour. As described in [1] a general approach is based on a mathematical-physical model of the function, which represents the causal interrelation between surface geometry and surface functionality. With simulations as well as practical experiments ideal geometrical parameters can be defined, which significantly influence the function ability.

From the ideal geometrical specification measurands have to be derived and after that appropriate measurement instruments have to be selected (Fig. 1). Already here it should be considered, which metrological requirements should be prioritised in favour of the assessment of the functional ability. As stated in many reports like [2] or [3] surfaces interact between each other in a 3D way and functional requirements are related to the surface texture strongly. 3D techniques do not only give a reliable description of the surface but also provide more information to establish a relationship between the geometry and its function. Furthermore resolution, measuring angle and optical cooperativeness are essential for the selection of a suitable measuring system. If for example the depth of a microstructure is important, a measurement system with a high vertical resolution such as a white light interferometer should be chosen. If large measuring angles are important to get also measurement data of sharp flanks measurement systems based on focus variation or confocal techniques should be preferred [4].

According to Fig. 1 measurement results should be determined in a way that not only the conformity to the geometric specification can be verified, but also that the manufacturing process can be corrected and that the results can be used as input parameters in the mentioned simulations to assess the functional ability of the measured surface [1]. Since rough-

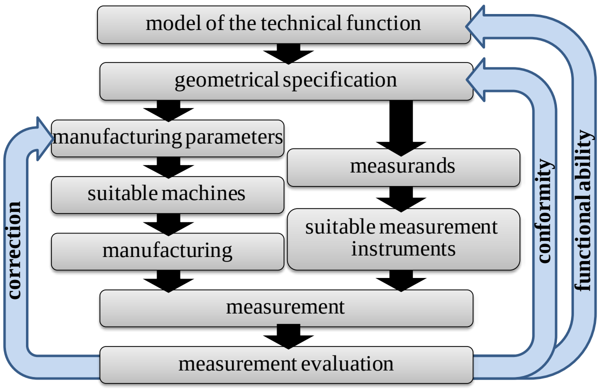

Fig. 1: Dimensional measurements support the conformity decision, the correction of manufacturing parameters and the assessment of the functional ability of the measured surface (based on [1])

ness parameters according to ISO 4287:2009 or ISO 25178-2:2012 are untypical as input parameters for manufacturing microstructures or simulations, it is better to use evaluate dimensional features like diameters, depths, and pitches. Since a microstructured surface consists of several millions of these features with relative large form deviations typically, a robust automatic evaluation method is preferred. In this context segmentation methods provide a good way to extract and assess functional features of microstructured surfaces.

3. EXTRACTION AND EVALUATION OF FEATURES OF MICROSTRUCTURED SURFACES

All surfaces have some features which may or may not be important for a given technical function. In order to separate function related features from the insignificant ones automatically, segmentation methods are used. In ISO 25178-2:2012 and ISO 166610-85:2013 segmentation is defined as a method, which divided a surface into mutually exclusive areas spatially. Although segmentation techniques are developed for 2D image processing problems primarily (pixel-based segmentation by grey values), they could also be applied in surface metrology [4]. Here edge-based segmentation techniques are used, which uses gradient information for segmentation purpose. In the following the main steps for a feature based evaluation are presented.

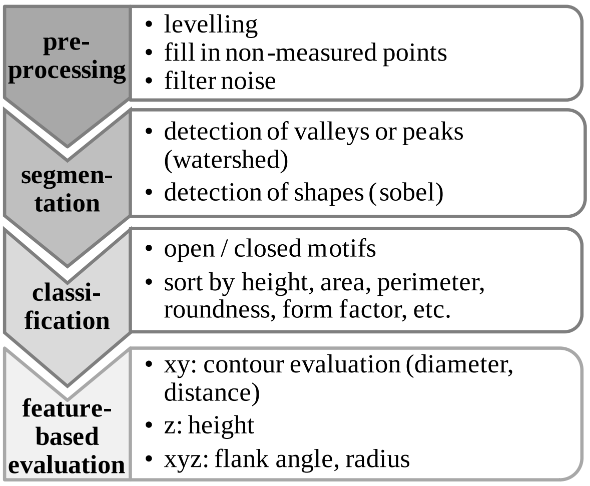

Fig. 2: Main steps for the extraction and evaluation of features of a microstructure

3.1 *Pre-Processing*

Since measurement noise and artefacts of the surface can result in an over-segmentation, the surface measurement data should be pre-processed. If an optical measurement instrument is used, often flanks cannot be detected completely, because the reflected light is scattered on the inclined surface. Thus, areas are in measurement data, which do not have a measured height value. During pre-processing, those non-measured points are filled out under consideration of neighbourhood points artificially. Polynomial interpolations are used for the filling of those points. Furthermore the surface data should be levelled, i.e. the measured surface is rotated in the image plane mathematically by using a least square algorithm. If there is too much noise in data and only form parameters of microstructure are calculated, also smoothing filter like median filter and Gaussian filter can improve the segmentation.

3.2 *Segmentation*

Most popular for the segmentation of 3D surface data is the watershed algorithm, which is also described in ISO 166610-85:2013. The term “watershed” comes from daily life: Water drops falling on a topography flow along the steepest slopes in the local minima, where a catchment basin arises. Lines, which separate adjacent catchment basin from each other, called watersheds. These watersheds provide a segmentation of the image into different separate regions that represent possible object contours [6]. Every structure is closed with such a watershed line and detection of this line makes it possible to identify the convex pattern. By reversing this process also concave pattern can segmented. So, with the watershed algorithm, all peaks and valleys and their associated zones are identified [7]. By connecting peaks (or valleys) over saddle points the 3D surface is divided into motifs [8].

For the segmentation of microstructures, where the individual structures do not adjoin and therefore real watershed exists, other gradient-based algorithms like the Laplacian or the Sobel algorithm are more appropriate (Fig. 3). The Sobel algorithm calculated the first derivative of z, while it is smoothed in xy-direction by using a 3x3-matrix. If one of the 3×3 neighbouring points does not exist, arithmetic mean is calculated without this point. By this way, boundary effects are compensated and evaluated region should not have to be scaled down. If edges are rounded, this algorithm needs to be extended, because structures are always separated at the point with the greatest slope (2^{nd} derivative = 0). This means, e.g. for cell shapes, that diameter and volume are always calculated to small. By increasing round motifs up to the next saddle point (1^{st} derivative = 0), the problem can solved in this case.

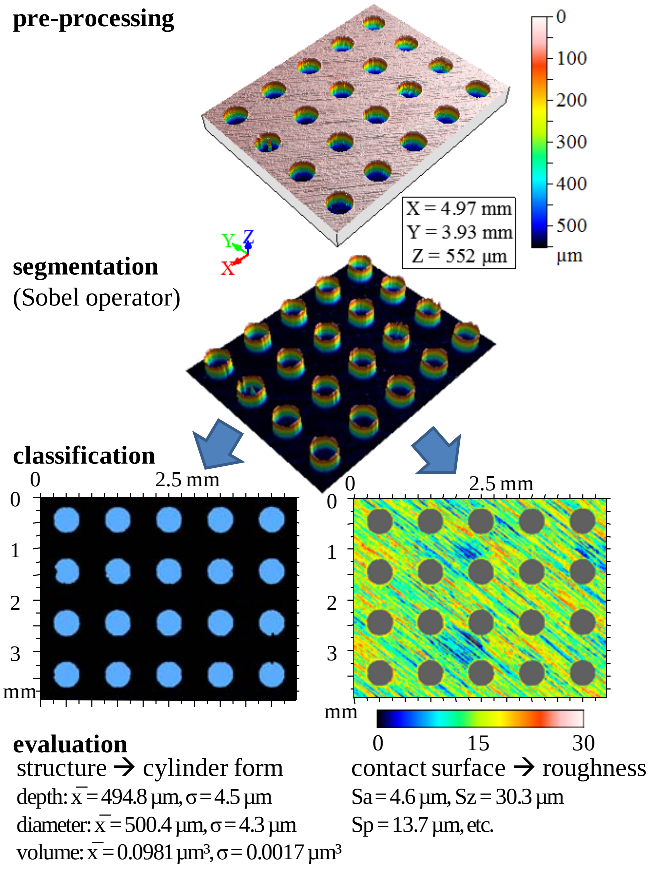

Fig. 3: Segmentation using the Sobel algorithm

3.3 Classification

Since each segmented feature has its own functional effect, it makes sense to classify them in groups according to their geometrical properties. These geometrical properties, which are used as a threshold, can be the area, roundness, height, compactness etc. In Fig. 3 the parameter roundness was used to differentiate stud holes and the background (upper surface). Since motifs are usually incomplete at the border of the lateral measuring range, theses open motifs should also be rejected.

3.4 Evaluation of segmented features

By segmentation and classification of microstructured surfaces the analysis of individual features is facilitated. For features in xy-direction the contour of the segmented can be evaluated using fitting algorithms for circles, ellipsoid or straight lines based on the least square condition. In z-direction step high measurement according to ISO 5436-1:2000 can be applied. For features in xyz-direction the complexity of the evaluation can be reduced by evaluating the profile section in xz- or yz-plane (contour analysis).

With segmentation techniques also roughness parameters of individual segmented areas can be calculated. This is useful for peaks or plateaus as mentioned in Fig. 3 (right), which are in direct contact with another surface (e.g. by friction).

The individual results are analysed statistically (calculating of mean $\bar{x}$, median $\tilde{x}$ or standard deviation σ). Thus, statements about the process capability and reliable information about the conformity with the geometric specification can be made. Furthermore, as mentioned in section 2, statistical robust values can be used as input parameters in simulations to estimate the functional behaviour of the measured surface.

4. EXAMPLES

4.1 Microstructure of a Sliding Surface

As described in [9] microstructures can reduce the friction coefficient of a surface. Dimples in the surface are used as lubricant pockets, in which a hydrostatic pressure at high sliding speed can be building up. The simplified CFD simulation in Fig. 4 shows that cell structures with a low aspect ratio cause higher hydrostatic pressure.

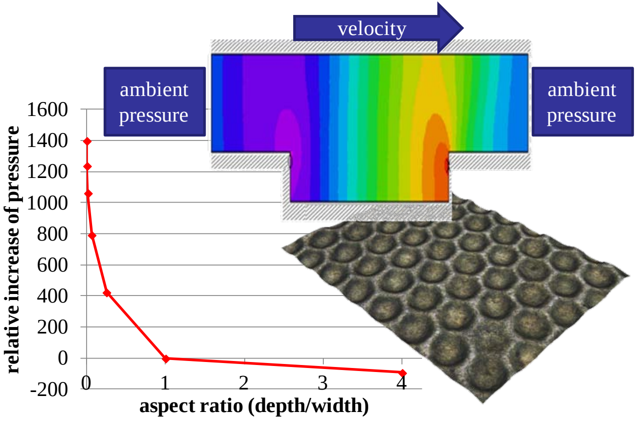

Fig. 4: Relationship between aspect ratio and pressure increase for cell shaped sliding surfaces

In this case, the evaluation of depths and diameters of the cells is required for the feedback of measurement result in the simulation and the assessment of the manufacturing process. For a manual evaluation, the number of evaluable cells is limited due to time constraints and thus the validity of the measurement result statistical uncertain. By means of the watershed algorithm, it is possible to segment an unlimited number of cells automatically. As shown in Fig. 5 441 closed cells could be identified by this method. After that simple evaluation methods are applied like the least square condition for determining the diameter of the Gaussian circle or step high measurement procedures according to ISO 5436-1:2000. Even the volume of each cell could be calculated individually. With these results, the ability of the manufacturing process can be assessed and sliding properties of the measured surface can be predicted using a CFD simulation.

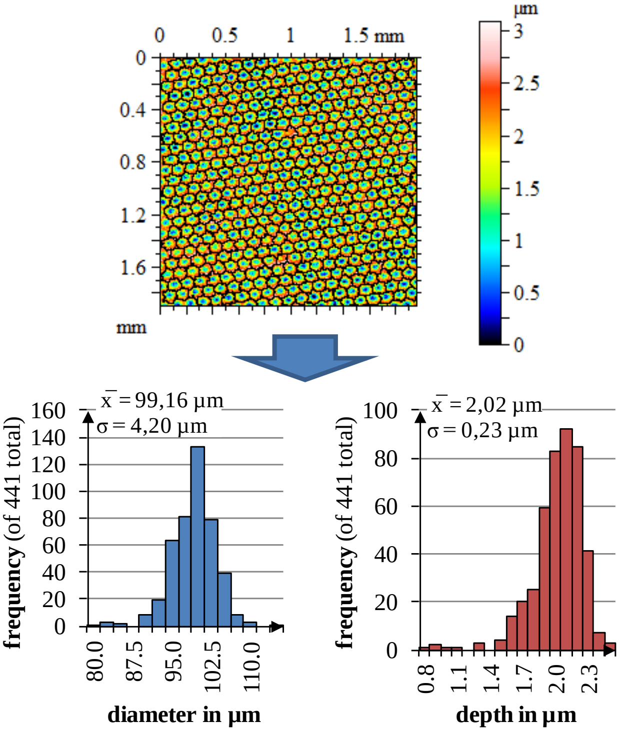

Fig. 5: Automatic evaluation of diameter and depth of the 441 identified closed cells by using a watershed algorithm (manufacturing process: electro chemical machining; measurement instrument: white light interferometer 20x)

4.2 Microstructure of a Printing Roll

Another example is the microstructure of rolls in flexographic printing machines, which influenced the ink transfer behaviour. The basic principles of ink transfer from a flexographic printing machine are based on the fact that initially the microstructure of an anilox roll is filled with ink in a chamber blade system and then a portion of the absorbed ink is transferred to a rubber roll. The rubber roll, on which the printing form is applied, then brings the ink to a printing substrate (paper, foil, etc.). The function of the anilox roll is to dye the printing form uniformly. As described in [1], with a model-based approach, which considers ink splitting models, it could be identified that pick-up volume and transfer ratio are the most important factors for the transferred ink volume. While the pick-up volume is depending on geometrical parameters of the microstructure directly (like bridge width, depth and flank angle), the transfer ratio is also depending on non geometrical parameters like adhesion forces and capillary forces.

Simulations and experimental results show that the transferred ink volume is very sensitive at low (<25 µm) deviations in depth, while variations in width have a 4-5 times smaller influence [1]. At greater depth (>30 µm) the impact of differences in depth has less influence on the ink transfer function, because more ink will not be transferred due to the capillary effect. So structures with low depth have to be toleranced closer to keep a homogeneous colour application.

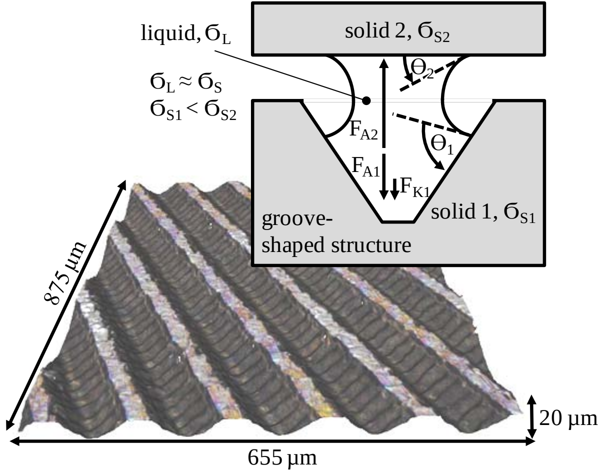

Fig. 7: Microstructure of an anilox roll (manufacturing machine: nanosecond laser; measurement instrument: white light interferometer 20x) and the used model for simulating the transferred ink volume (with wetting angle Θ, adhesion force F_A, capillary force F_K, surface tension of the liquid σ_L, the solid σ_S and between liquid and solid σ_{LS})

To monitor the production process of anilox rolls, geometrical features of the measured microstructure are determined. Since the described structure has in one direction approximately the same shape, a 2D analysis of several hundred profile sections is sufficient in this case. The main angle of the texture is determined by autocorrelation using the parameter Std according to ISO 25178-2:2012 whereby profile sections can be oriented vertically. The structure is segmented by differentiating falling and rising slopes. Then, the depth can be evaluated according to ISO 5436-1:2000. The bridge widths are defined by the intersection points of fitted lines of the upper flanks and of the height of the bridge.

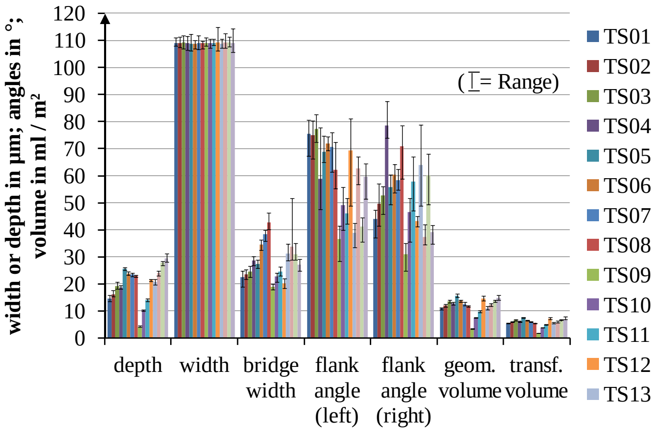

Fig. 8: Example of the statistical shape analysis of 16 different test structures (TS). For each test structure, 25-35 rills were evaluated individually.

The advantage of the mathematical-physical model and the automatic evaluation is, that the also the parameter "transferred ink volume" can be calculated based on measurements (Fig. 8.). This parameter does not evaluate only one feature of the microstructure, but the combination of geometrical and non-geometrical parameters, taking into account their mutual interactions. Thus it is possible to make a priori statements about the amount and the fluctuation of the ink, which is transferred to the printing form.

5. CONCLUSION

To be able to derive correction values from measurements for the manufacturing process and to understand as well as to optimize the function of microstructured surfaces by means of simulations better, the determination of dimensional measurands is necessary. Segmentation techniques facilitate the evaluation of measured microstructures and increase the statistical reliability of the analysis by a greater number of evaluable features and an user-independent evaluation. Furthermore, it is possible to separate functional relevant and irrelevant geometrical properties due a classification. Nevertheless, it was shown that depending on geometric properties (open/closed peaks/valleys, widespread motifs, rounded edges) suitable segmentation techniques have to be selected.

ACKNOWLEDGEMENTS

This article is based on works within the project FunkProMikro, which was funded by the German Federal Ministry of Education and Research (BMBF), and the Transregional Collaborative Research Centre (Transregio) 73, which is funded by the German Research Foundation (DFG). The authors thank for support.

REFERENCES

[1] A. Weckenmann, W. Hartmann, "Function-Oriented Method for the Definition and Verification of Microstructured Surfaces" *Precision Engineering*, 37 (32), pp. 684-693, 2013.

[2] P. M. Lonardo, H. Trumpold, L. de Chiffre, "Progress in 3D Surface Microtopography Characterization" *Annals of the CIRP*, 45 (2), pp. 589-598, 1996.

[3] A. Weckenmann, Ö. Tan, W. Hartmann, "Function-Oriented Characterization for Surface Metrology" *International Journal of Nanomanufacturing*, 7 (5/6), pp. 517-527, 2011.

[4] W. Hartmann, T. Hausotte, F. Kühnlein, D. Drummer, "Incremental In-line Measurement Technique for Additive Manufacturing." *Proc. DDMC*, Berlin, Germany, March 2012.

[5] B. Jähne, "Digital Image Processing", Springer, Berlin/Heidelberg, Germany, 2005.

[6] Ö. Tan, "Characterization of Micro- and Nanometer Resolved Technical Surfaces with Function-Oriented Parameters", Shaker, 2013.

[7] P. J. Scott, "Foundations of Topological Characterization of Surface Texture", *Int. J. Mach. Tools and Manufact.*, Vol. 38 (5-6), pp. 559-566, 1998.

[8] G. W. Wolf, "A Fortran Subroutine For Cartographic Generalization", *Computer & Geoscience*, Vol. 17 (10), pp. 1359-1381, 1991

[9] W. Zimmermann, e. a., „Funktionsorientierte Bewertung und deren Nutzung für die Kurbelwellenfertigung – Ergebnisbericht FunkProMikro", *Apprimus*, pp. 17-38, 2012.