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# Application of function-oriented roughness parameters using confocal microscopy

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ABSTRACT

Optical measuring instruments are widely used for the functional characterization of surface topography. However, due to the interaction of the surface with the incident light, effects occur that can influence the measured topography height values and the obtained surface texture parameters. Therefore, we describe a systematic investigation of the influences of optical surface topography measurement on the acquisition of function-oriented roughness parameters. The same evaluation areas of varying cylinder liners which represent a typical application of function-oriented roughness parameters were measured with a confocal microscope and a stylus instrument. Functional surface texture parameters as given in the standards ISO 13565–2, ISO 13565–3 and ISO 25178–2 were evaluated for both measurement methods and compared. The transmission of specific surface features was described and a correlation analysis for the surface topographies obtained with the different measurement methods and their resulting functional roughness parameters was carried out.


## 1. Introduction

For the evaluation of profile and areal surface texture, there is a broad variety of parameters defined in ISO 4287, ISO 13565–2, ISO 13565–3 and ISO 25178–2. Most frequently, amplitude parameters such as *Ra*, *Rq*, *Sa* or *Sq* are applied in an industrial context. However, for many applications that require a functional characterization of surface texture, these parameters are insufficient. For example, when a characterization of round-ridged or sharp-ridged surface textures is required, amplitude-based parameters are not suitable [1]. Based on this shortcoming, for surfaces with stratified functional properties, new parameters were introduced for profile measurements in the standard ISO 13565 [2,3].

With the growing importance of areal surface texture characterization (see [4]), equivalent areal parameters were introduced in the standard ISO 25178–2 [5] as well. However, with optical surface topography measurement, different physical effects occur which are still subject of current research in areal metrology (see e.g. [6,7]). Thus, we aim at a sound description of the relationship between the effects that occur in optical metrology of stratified functional surfaces and the resulting impact on function-oriented roughness parameters. This is examined by comparing the parameter results of tactile and optical measurements of cylinder liners.

Section 2 provides an overview of the state of the art of functional roughness parameters, before the experimental setup is described in Section 3. The results of the study are provided in Section 4, before conclusions regarding the application of function-oriented roughness parameters for optical metrology are drawn in Section 5.

## 2. State of the art

Due to the shortcomings of the amplitude-based surface texture parameters for functional surface characterization, the parameters *Rk*, *Rpk*, *Rvk*, *Mr1*, *Mr2* of ISO 13565–2 [2] *Rpq*, *Rmq*, *Rvq* of ISO 13565–3 [3] and *Sk*, *Spk*, *Svk*, *Smr1*, *Smr2*, *Spq*, *Smq*, *Svq* of ISO 25178–2 [5] were introduced. Functional parameters are commonly applied for the evaluation of e.g. plateau-honed surfaces and thus provide a tool for the evaluation of properties which are associated to the height-dependent material ratio (e.g. oil retention volume) of round-ridged and sharp-ridged surfaces [1].

Different applications and variations of functional parameters have been examined: Pawlus et al. [8] summarized the historical background of the functional surface texture parameters and

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**Nomenclature**

| Nomenclature | Definition |
|---|---|
| *CCF* | Areal cross correlation function |
| *DS* | Difference function |
| $dev_{per}$ | Percentage deviation |
| *M* | Number of discrete points in x-direction |
| *Mr1* | Upper material ratio delimiting core area 1 |
| *Mr2* | Lower material ratio delimiting core area 2 |
| *N* | Number of discrete points in y-direction |
| *P* | Profile roughness parameter |
| *r* | Correlation coefficient |
| *Ra* | Arithmetic mean deviation |
| *Rk* | Core roughness depth |
| *Rmq* | Material ratio at plateau-to-valley intersection |
| *Rpk* | Reduced peak height |
| *Rpq* | Plateau root mean square roughness |
| *Rq* | Root mean square roughness |
| *Rvk* | Reduced valley depth |
| *Rvq* | Valley root mean square roughness |
| *Rz* | Average peak-to-valley profile roughness |
| *s* | Experimental standard deviation |
| *Sa* | Arithmetic mean height |
| *Sk* | Core height |
| *Smq* | Material ratio at plateau-to-valley intersection |
| *Smr1* | Upper material ratio delimiting core area 1 |
| *Smr2* | Lower material ratio delimiting core area 2 |
| *Spk* | Reduced peak height |
| *Sq* | Root mean square height |
| *Svk* | Reduced dale height |
| *Svq* | Dale root mean square deviation |
| *u* | Index in x-direction |
| *v* | Index in y-direction |
| *Z* | Measured topography dataset |
| *z* | Measured topography height value |
| $\alpha$ | Rotation angle |
| $\lambda$ | Filter cutoff wavelength |

applied four successive honing processes for the manufacturing of cylinder liners. The manufacturing results were characterized based on a truncation model [8]. Additional studies of honing processes came to the conclusion that the roughness parameters according to ISO 13565–3 are most suitable to describe the influence of the honing parameters – in particular grit size and plateau honing time [9].

Besides the described functional parameters, also a volume-based analysis of the Abbott-curve was introduced, which Franco and Sinatora described as a favored way for the evaluation of peak and valley properties compared to the application of *Spk* and *Svk* [10]. Also in recent studies the characterization of cylinder liners is addressed: Arantes et al. investigated functional parameters as well as feature-based and volume-based parameters and concluded that the latter ones also provide a suitable alternative for the characterization of cylinder liner honing processes [11]. This study included both tactile and optical assessment of functional surface topographies [11].

Artificial neural networks (ANN) can be applied for the characterization of manufacturing parameters [12] and the classification of manufacturing methods [13]. An application of neural networks for the characterization of honing processes of cylinder liners based on the ISO 13565 parameters was suggested by Feng et al. [14]. They developed an empirical model for honing processes and were able to predict roughness parameters according to ISO 13565 based on features of the manufacturing process [14]. Other studies in this field showed that the predictability of the Abbott-curve parameters can be achieved with gray-scale images and an artificial neural network [15]. They indicated that the Abbott-curve can as well be calculated based on gray-scale images and that the resulting parameters featured a high correlation to the topography values [15]. Another image-based evaluation analysis method which can for example be used for the evaluation of groove parameters was introduced by Puente Leon [16].

## 3. Experimental setup

The aim of these experimental studies was to identify challenges when measuring function-oriented roughness parameters with optical topography measuring instruments, in particular measuring honed surfaces with confocal microscopy. The arising effects caused by the interaction of the incident light and the measured surface were investigated qualitatively with the description of visible changes in roughness profiles and quantitatively with standardized roughness parameters. Function-oriented roughness parameters are commonly measured by using stylus instruments. In the present studies, a comparison of measured topography datasets of a confocal microscope with datasets obtained from the same surface with a reference stylus instrument was performed.

**Table 1**
Parameters of stylus instrument and confocal microscope.

| | Parameter | Parameter value |
|---|---|---|
| Stylus instrument | Tip radius | 5 μm |
| | Scanning arm length | 90.25 mm |
| | Scanning speed | 0.5 mm/s |
| | Sampling distance | 0.5 μm |
| | Stylus force | 1.0 mN |
| Confocal microscope | Magnification | 20x |
| | Numerical aperture | 0.45 |
| | Sampling distance | 1.56 μm |

### 3.1. Selected measuring instruments and parameters

As stylus instrument a Hommel-Etamic Nanoscan 855[1] was used. Additionally, a confocal microscope Nanofocus $\mu$ surf[1] with an object lens type Olympus MPlan FL/N[1] was chosen. The parameters for both measuring instruments are listed in Table 1.

### 3.2. Selected surfaces

Six different cylinder liners were selected as samples. Three of them were surfaces provided by an automotive manufacturer (OEM) and the other three were provided by an automotive supplier. All of the cylinder liners were manufactured via a honing process. They were chosen as samples for this investigation because honed cylinder liners are one of the most typical applications for function-oriented roughness parameters (see [9,14,17]). While the surfaces of the samples from the OEM appeared irregular, the samples from the automotive supplier exhibited a dominant honing structure at their surfaces. The distinctive dales turned up as

[1] Naming of specific manufacturers is done solely for the sake of completeness and does not necessarily imply an endorsement of the named companies nor that the products are necessarily the best for the purpose.