Comparison of Roughness Measurements between a Contact Stylus Instrument and an Optical Measurement Device based on a Colour Focus Sensor

R. Danzl*, F. Helmli* and S. Scherer*

* Alicona Imaging GmbH, Teslastrasse 8, A-8074 Grambach/Graz, Austria

ABSTRACT

The measurement of the roughness of technical surfaces plays an important role in scientific and industrial applications. Traditionally the roughness has been measured using contact stylus instruments. In contrast to this, we present the optical measurement device InfiniteFocus by Alicona Imaging, which is able to reconstruct 3D models of technical surfaces and allows amongst others to measure their roughness. We demonstrate this using a random micro-roughness standard with known calibrated roughness parameters Ra and Rz.

Keywords: measurement, roughness, optical, surface

1 INTRODUCTION

Traceable roughness standards are commonly used in order to evaluate the functionality and accuracy of tactile profile measurement devices. In recent years optical measurement devices have become more and more popular for several reasons. First they operate in a non-contact way and do not damage the surface. Second they are able to reconstruct whole areas at once and not only surface profiles. Third they do not suffer from limitations inherent to contact stylus instruments such as a smoothing of surface profiles due to the radius of the stylus tip.

The roughness measurement using contact stylus instruments is well described in various standards which take care of the special characteristics of these devices [3][4][5]. These standards include for example how to setup the contact stylus instrument or how to filter surface profiles so that small scale vibrations are filtered out that occur during the measurement process [6].

At the moment there is no international EN/ISO norm on optical surface metrology devices. However an ISO draft is currently developed in the ISO/TC 213 WG 15 which tries to describe procedures on how to classify and operate such devices [7].

InfiniteFocus is an optical surface metrology unit that operates on a colour focus sensor and in contrast to most tactile measurement devices it delivers more than "just" roughness values but full 3D models [8]. Since the measurement of profile roughness parameters such as Ra and Rz plays an important role for many industrial applications, a crucial requirement for optical devices is to deliver roughness parameters which are comparable to those obtained by contact stylus instruments.

In this paper we provide a comparison between contact stylus instruments and the optical device InfiniteFocus. Due to the lack of special norms for optical devices the comparison has to be performed with special care as will be outlined in the following sections.

In Section 2 we start with a description of the InfiniteFocus system and its main characteristics. Section 3 contains a description of the materials and methods used for the roughness measurement. This includes a description of the calibrated roughness standard used for comparison and a detailed description of the methods used to calculate the roughness parameters with the contact stylus instrument and the InfiniteFocus system. In Section 4 the results are provided including a comparison of the roughness parameters and several 3D models reconstructed using the InfiniteFocus system.

2 DESCRIPTION OF THE INFINITE FOCUS SYSTEM

InfiniteFocus is an optical device for 3D surface measurement (Fig. 1). Its operating principle combines the small depth of focus of an optical system with vertical scanning to provide topographical and colour information from the variation of focus.

Novel and unique algorithms reconstruct this into a single 3D data set with accurate topographical information. The vertical resolution can be as low as 20nm making the instrument ideal for surface study of both homogeneous and compound materials.

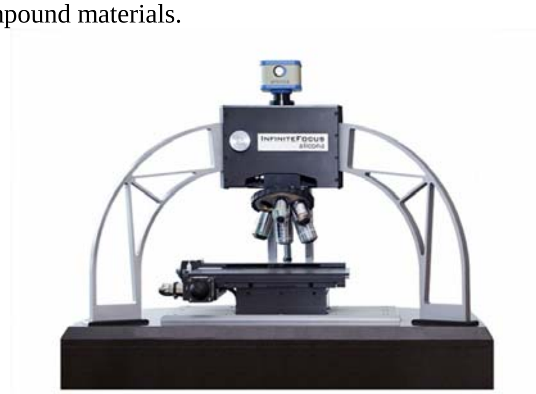

Figure 1: The InfiniteFocus system

The instrument can be used in both the laboratory and near production environment. Automation of functions and analysis can also be added to make the instrument useable for the majority of surface metrology and inspection requirements.

A key characteristic of the system is that it does not only deliver topographical information but also an optical colour image of the surface which is perfectly registered to the height data. The technology on which the system is based is just about to be included into ISO standards classifying different methods for surface texture extraction [7].

3 ROUGHNESS MEASUREMENT

The roughness measurement comparison is done using a traceable micro roughness standard (Section 3.1). The contact stylus instrument and the conditions under which the roughness calibration is carried out are outlined in Section 3.2. The procedure for the roughness measurement by the InfiniteFocus system is summarized in Section 3.3.

3.1 Description of the Calibrated Roughness Standard

The roughness standard used to demonstrate the roughness measurements with InfiniteFocus is a roughness standard of the company Halle Präzisions - Kalibriernormale GmbH (Germany) (Fig. 2) [10]. It is a random roughness standard from the line of products KNT 2058/03 with serial number 2873.

The normal is made from hardened stainless steel and has the dimensions 40x20x10mm. The measurement area has a diameter of 12mm and consists of an irregular profile which has a period length of 4mm along the measurement direction. The quality grade of the normal is A, the nominal Ra value at Lc = 0.8mm is 1.5µm. For this standard a calibration certificate has been made by the company Halle which is certified for roughness measurements.

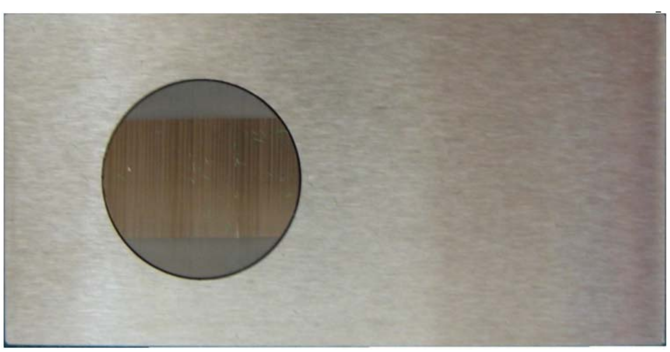

Figure 2: The random micro roughness standard used for the roughness measurement comparison between the InfiniteFocus system and a contact stylus instrument.

3.2 Roughness Measurement using the Contact Stylus Instrument by Halle

The micro-roughness standard (Section 3.1) has been calibrated by the company Halle Präzisions - Kalibriernormale GmbH using a contact stylus instrument approved by the PTB (Physikalisch Technische Bundesanstalt, Germany) [11]. They use a perthometer, model: S6P, No. 21386. The stylus radius is 4µm, the static measuring force F = 1 mN.

With this instrument the roughness parameters Ra and Rz were determined from the micro-roughness standard according to [1][2]. A profile filter with cutoff of 0,8mm was used. The total evaluation length of the profile was 4,0mm. The reference temperature was 20°C.

In total 7 profiles have been extracted and used for the roughness measurement. The calibration values for Ra and Rz are the mean values of these 7 measurements. According to Halle the uncertainty of the measurements is valid for a confidence level of at least 95%

3.3 Roughness Measurement using the InfiniteFocus System

Roughness measurements using the InfiniteFocus system are performed in two steps. In a first step a 3D model of the standard is reconstructed using the InfiniteFocus technology. In a second step a surface profile is extracted from the 3D model and the roughness parameters are calculated from this profile according to ISO standards [4][5][6].

The InfiniteFocus system can be equipped with objectives of different magnification ranging from 2.5x to 100x. Higher magnifications lead to better axial and lateral resolutions but have the disadvantage of smaller field of views that can be reconstructed in a single step. In order to obtain 3D models that are large enough for ISO conform measurements (e.g. length of 4mm) the InfiniteFocus system provides the ImageField functionality. Using this operation mode, the system reconstructs several single 3D models with slight overlap that are consecutively stitched together based on colour and on topographical information to form a large 3D model.

The reconstruction of the micro-roughness standard is performed using the 100x objective since this allows the finest Z-resolution and thus provides the best reconstruction result. Once the 3D model has been reconstructed a surface profile is extracted from the model along a horizontal profile path that is at the same position as those used for the calibration by Halle.

Afterwards roughness parameters Ra and Rz are calculated according to [4][5][6]. This includes in particular the correct filtering of the surface profile using Gaussian filters with a Lc value of 0.8mm to filter the roughness from the waviness components [9]. The profile length is 4mm to provide comparable results to Halle.

4 RESULTS

A 3D model of the roughness standard reconstructed using the InfiniteFocus device is provided in Fig. 3. The model is shown in pseudo colour mode where each colour represents a specific height. Details of this model are provided in Fig. 4 which show the random structure of the profile along the x-direction and the similar structure along the y-direction. The left part of Fig. 3 shows the 3D model with the extracted colour image mapped onto the surface.

The colour image (Fig. 5) has been automatically extracted by the InfiniteFocus software and is perfectly registered to the topographical data. It shows the regular structure along the y-direction which visualizes that all extracted profiles at different y-positions are rather similar. The profile path used for the extraction of the surface profile is shown in pink in the colour image. The extracted surface profile is provided in Fig. 6.

The roughness measurement results of Halle are provided in Table 1 showing the Ra and Rz values. According to the calibration certificate the measurments of Halle have an uncertainty of +-6% (the uncertainty is mainly due to the randomness of the surface not due to the measurments) which leads to the minimum and maximum values for the specific values in the table. The Ra and Rz values delivered by InfiniteFocus are very close to the measurements by Halle and lie well in the uncertainty interval.

A major limiting factor of contact stylus instruments is the stylus tip that typically has a radius of several µm and produces a smoothed surface that has a lateral resolution dependent on the radius of the stylus tip. In contrast to this the optical instrument has a lateral resolution of about 0.5µm which mainly results from the wavelength of visible light. In order to find out the influence of the stylus tip on the roughness results we filtered the surface obtained by InfiniteFocus using a morphological closing operation with different radii and calculated the roughness values of the filtered surface. At a radius of 4µm the Ra value was 1.514µm and thus identical to the original value. At a radius of 15µm the Ra value was 1.512µm and thus only marginally smaller. The reason for this similarity despite the morphological closing operation is that the roughness standard does not contain roughness at very small scales.

Value	Mean (Halle)	Min (Halle)	Max (Halle)	InfiniteFocus
Ra	1.47µm	1.38µm	1.56µm	1.514µm
Rz	9.61µm	9.03µm	10.19µm	9.809µm

Table 1: Comparison of roughness parameters obtained by a certified contact stylus instrument (Halle) and by the InfiniteFocus system.

5 CONCLUSIONS

It has been shown that the InfiniteFocus device by Alicona Imaging is able to measure roughness parameters of a calibrated micro-roughness standard that are similar to those of a calibrated contact stylus instrument. In order to provide comparable results we applied morphological closing operations in order to model the effect of the stylus tip of contact stylus instruments.

In contrast to tactile instruments the optical device InfiniteFocus is not limited to the measurement of surface profiles but allows the three-dimensional reconstruction of whole areas of a surface. The 3D models obtained by the system can be measured and analyzed using various methods, including profile, area and volume measurements. Since it does not only provide topographical data but also sharp colour images which are perfectly registered to the height data, it facilitates many measurement tasks.

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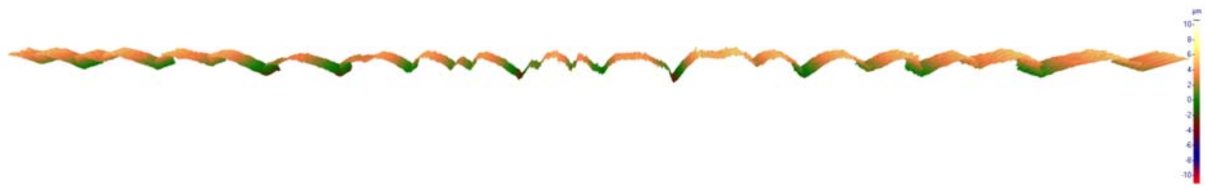

Figure 3: 3D model of the roughness standard reconstructed using the InfiniteFocus device (pseudo colour mode).

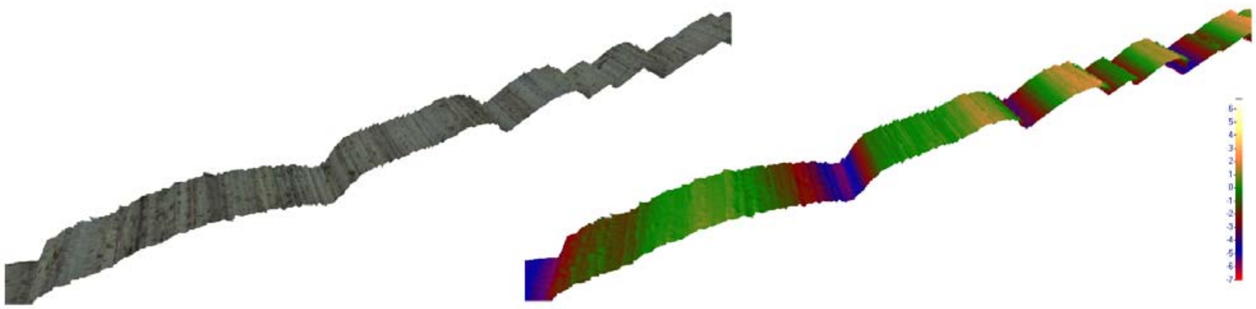

Figure 4: Surface detail of the reconstructed model. Left: model with the registered colour image of the surface. Right: model in pseudo colour mode.

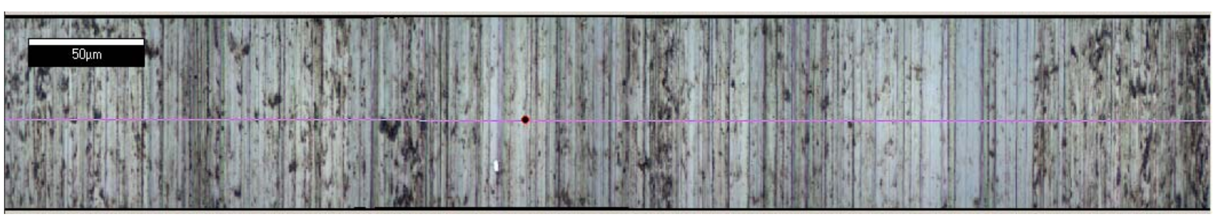

Figure 5: The 2D measurement path of the profile drawn in the registered colour image

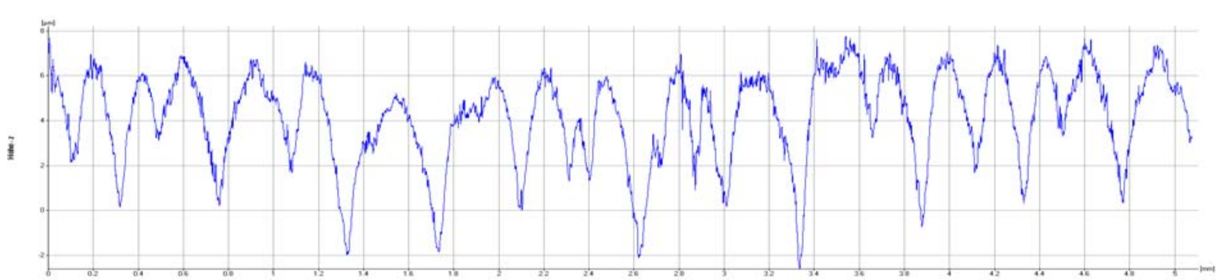

Figure 6: The extracted surface profile used for measurement.