3D MEASURMENTS OF MICROSTRUCTURES WITH LARGE LATERAL DIMENSIONS

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Abstract:

Modifying the surface of highly loaded materials like cylinders of piston engines is a method of minimising wear and friction. There are already coatings like Alusil, that are used in the cylinders of some combustion engines. The advantage of this coating are the very hard silicon particles, that are raised compared to the aluminium matrix, in which the silicon is embedded. Below the silicon particles there is volume to store oil improving the tribological performance. Another new method of modifying a surface for this purpose is a cutting process, which can produce structures with a scale from a few micrometers to some millimetres. The lateral dimension of these microstructures can be up to a few millimetres, which complicates the measurement and data pre-processing. There are several methods of measuring the surface of these structures in order to acquire more properties.

In this paper several methods of measurement data pre-processing are presented, which are necessary before the properties of the microstructures can be evaluated.

A method to stitch a single microstructure, using several high resolution measurements with an areal profilometer like a white light interferometer, is shown. The principle is based on properties of the structure and does not depend on the information of the relative shift of each measurement.

Microstructures can be integrated within flat but also within curved materials like the inner surface of a piston cylinder. The form of this cylinder has to be removed from the measurement data. A common way of removing the form is a least square fit with an appropriate polynomial with a degree of two. But since the microstructures have such a large lateral dimension, the surface fit is strongly influenced by the microstructures that results in an inaccurate fit. The proposed method uses a segmentation step, which recognises the microstructures even in the measurement data including the form. Then the microstructures are removed from the surface and the fit is applied to the surface without the microstructures. This fit does contain the correct form of the cylinder. Afterwards the fitted surface is removed from the surface with the microstructures. The result is a robust surface fitting method.

Keywords: roughness metrology, pre-processing, robust surface fitting, segmentation, stitching

1. INTRODUTION

In the research unit *microstructuring of thermo-mechanically high stressed surfaces*, financed as the research unit 576 by the German Research Foundation (Deutsche Forschungsgemeinschaft abbreviated by DFG), five institutes of German universities search for improvements of tribological properties, especially for cylinder liners in piston engines [1]. They deal with the following issues:

1. simulation of microstructures,
2. production of microstructures by means of a cutting process,
3. production of microstructures by means of a thermal spraying process,
4. measurement and characterisation of microstructures and
5. test under motored conditions.

In this paper pre-processing subjects of project 4 [2] are discussed that are necessary between the measurement and the characterisation.

2. MICRORSTRUCTURING

In the following the two production methods used in this research unit are introduced.

Production Method: Thermal Plasma Spraying

In thermal spraying a plasma stream is created (see Figure 1). Within this stream a solid powder is inducted, that is being molten and accelerated by the plasma stream towards a workpiece. On this workpiece the powder becomes solid again with a stochastic distribution of the overlapping pieces of powder.

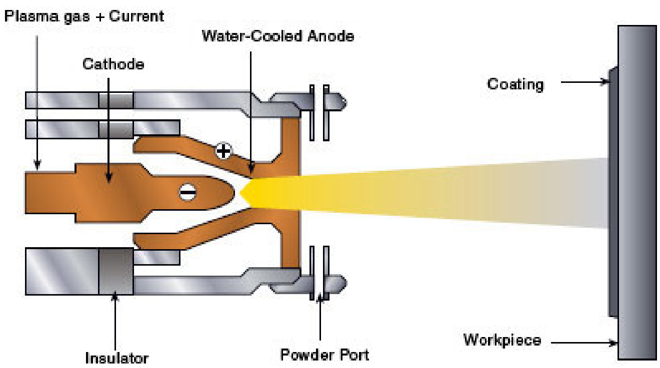

Figure 1: production method thermal spraying [3]

Production Method: Cutting

A cutting tool is moved on a circular path through the workpiece and so removes material (Figure 2). The cutting machine can be positioned in several ways in order to create different types of structures with different characteristics like depth and distance.

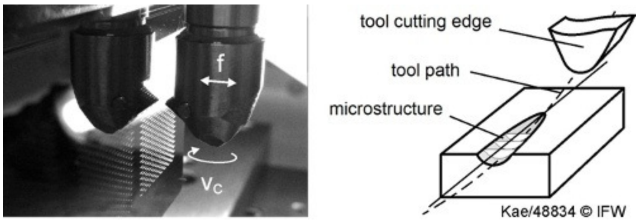

Figure 2: production method cutting [4]

Comparison of Production Methods

The microstructures produced by thermal spraying have a stochastic distribution and form and are mostly small in contrast to the larger microstructures made with the cutting process, that have a deterministic distribution and form. Figure 3 and Table 1 show measurements and dimension data.

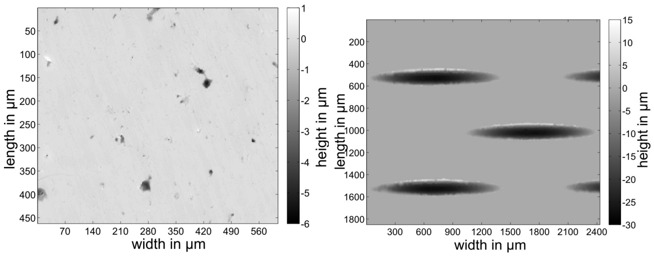

Figure 3: microstructures made by thermal spraying (left) and cutting (right)

	thermal spraying	cutting
width in µm	5 – 50	20 – 100
length in µm	5 – 50	500 – 3000
depth in µm	2 – 10	10 – 70

Table 1: comparison of microstructures' dimensions

In the following only the larger deterministic microstructures are being processed.

3. MEASUREMENT

There are several methods to measure this kind of microstructures. One device to obtain the measurement data is an areal white light interferometer shown in Figure 4.

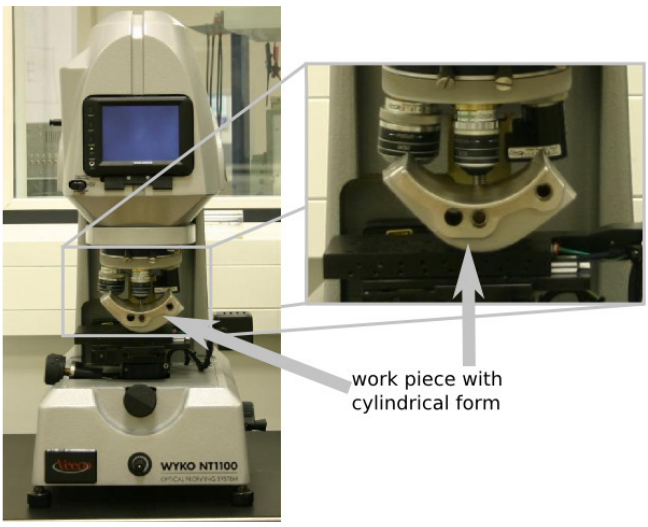

Figure 4: areal white light interferometer

In areal measurement devices several objectives image the measurement work piece to a ccd matrix. By using an objective with a low magnification, a large field of view can be measured but also the numeric aperture and lateral resolution is low. If an objective with a greater magnification is used, the lateral resolution increases but the field of view decreases. So, there is always a trade-off between field of view, lateral resolution and numeric aperture.

4. STITCHING

A method to have the advantages of both large and small magnification is the stitching of overlapping measurements with large magnifications and small field of view. There are several methods, that mostly have some computational requirements due to complex calculations like autocorrelation [5, 6].

In order to get a high resolution measurement of single microstructures, which have a large lateral dimension like the microstructures made with the cutting process (see Table 1), a stitching method is proposed, that only relies on properties of the microstructure itself. In Figure 5 there are three measurements of different parts of the same microstructure with the large magnification objective.

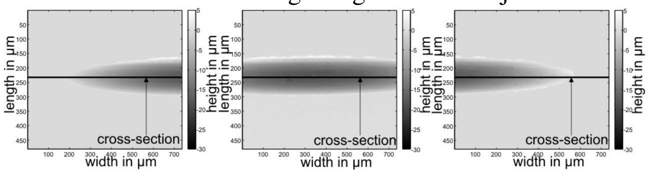

Figure 5: three measurements of different parts of the same microstructure

Figure 6 shows the curve of the characteristic *area cross-section* of the microstructure, which has a smooth developing due the principle of the production process. With this a-priori knowledge the following simple method can be used.

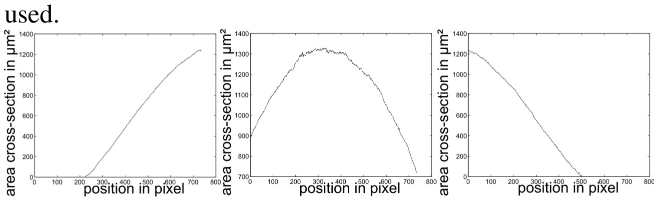

Figure 6: characteristic area cross-section of Figure 5

In order to get the information of the relative shift of the measurements only the information of the characteristic is used: The plots are moved together and thus provide this information. Now the actual measurement data can be shifted using the same information (see Figure 7).

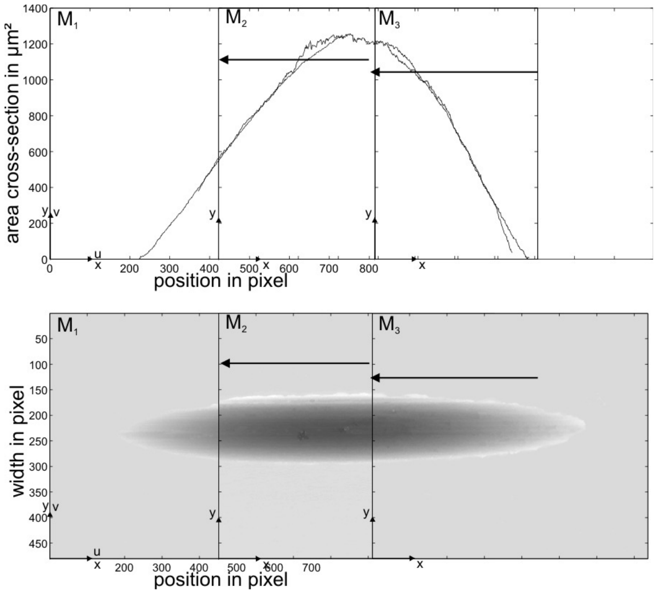

Figure 7: stitching using the shift information

5. FORM ELEMENATION

If a work piece has a form like the cylindrical form of the work piece shown in Figure 4, this form has to be removed before the microstructures can be evaluated.

Basic Fit

Figure 8 shows an un-processed measurement data of two microstructures. In both, the top view and the cross-section, the form can be easily recognized with a range from -5 µm up to 10 µm.

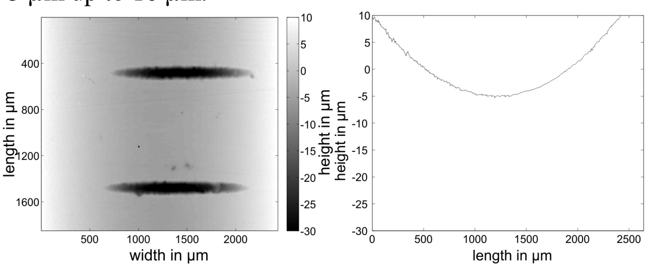

Figure 8: unprocessed measurement with form

This form has to be eliminated. A common way is a least-square-fit F_{basic} of the whole measurement data M :

$$\min(M - F_{basic}) \Rightarrow M_1 .$$

The result of this basic fit can be seen in Figure 9. There is still form existent in a range from -2 µm up to 2 µm. The reason for this bad fit is the strong influence of the microstructures providing negative measurement data below the surface: Since the microstructures have a large lateral and vertical dimension, the fit creates a surface that has too much positive data and thus creates the distortion as Figure 9 shows.

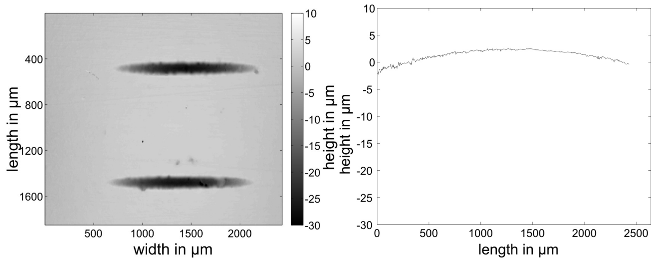

Figure 9: measurement M_1 after basic fit

Segmentation Methods to Identify the Microstructures

The measurement data of the microstructures has to be removed in order to create a sufficient fit. There are several methods like the following:

1. **Threshold**: All the data that is below a threshold of a height of -0.5 µm is considered to be a microstructure. This method is very simple but may be too vulnerable depending on the threshold.
2. **Watershed transformation**: The watershed transformation [7] floods the measured data with virtual water and raises the level of this virtual water sequentially. Thus, the structures with the largest depth are filled with this virtual water first. While the water level increases the structures with a smaller depth are being filled (compare Figure 10). If the level reaches a specific value, the water floods the whole surface and not only the structures. On this value watersheds are constructed on the edges of the microstructures, which keep the water in the structures and avoid the flooding of the whole surface.

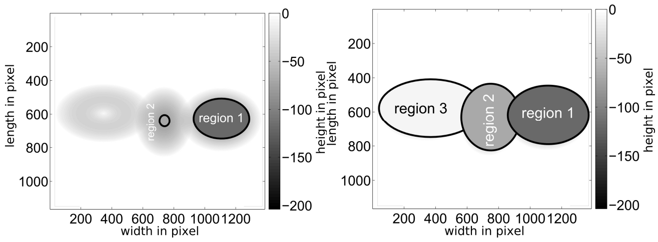

Figure 10: two steps of watershed transformation principle

The result is a bitmask R (see in Figure 11) that is further processed in the next step. In order to remove the microstructures

$R_{zero} = -1 \cdot (R - 1)$

is used.

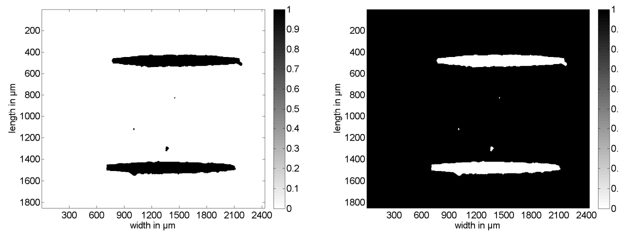

Figure 11: bitmask R (left) and R_{zero} (right)

Accurate Fit

With the information of the position of the microstructures in the measurement data it can be modified in the following ways:

1. Replace the measurement data of the microstructures with zeros:
   $M_{2,zero} = M_1 \cdot R_{zero}$.
2. Replace the measurement data of the microstructures with an interpolation of the neighbourhood:
   $M_{2,interp} = \text{interpolate}(M_1 \cdot R_{NaN})$.

The result of these multiplications is displayed in Figure 12. In $M_{2,zero}$ the position of the microstructures can still be recognised since the neighbouring measurement data is not zero due to the bad basic fit in M_1. In contrast to that, the interpolation in $M_{2,interp}$ is better since the remaining form of M_1 is also interpolated and thus not relevant.

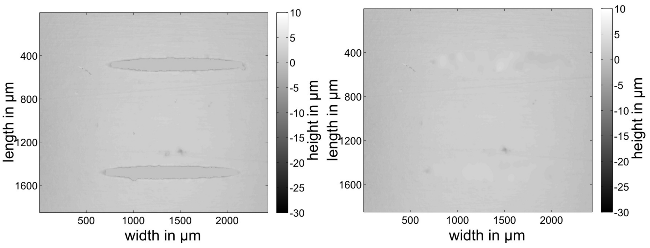

Figure 12: microstructures replaced by zeros $M_{2,zero}$ (left) and interpolation $M_{2,interp}$ (right)

Now the second least-square-fit, the accurate fit, can be applied to the measurement data without the structures:

1. $\min(M_{2,zero} - F_{accurate,zero}) \Rightarrow M_{3,zero}$
2. $\min(M_{2,interp} - F_{accurate,interp}) \Rightarrow M_{3,interp}$.

In the last step both the basic and the accurate fits are being removed by the actual un-processed measurement data:

1. $M_{4,zero} = M - F_{basic} - F_{accurate,zero}$
2. $M_{4,interp} = M - F_{basic} - F_{accurate,interp}$.

The results of the combination of both fits are displayed in Figure 13 and Figure 14. Both accurate fits are better than the basic fit in M_1 (Figure 9). Comparing both accurate fits, $M_{4,interp}$ is better than $M_{4,zero}$ since in $M_{4,zero}$ there is still a form visible. The reason is the same like for $M_{2,zero}$.

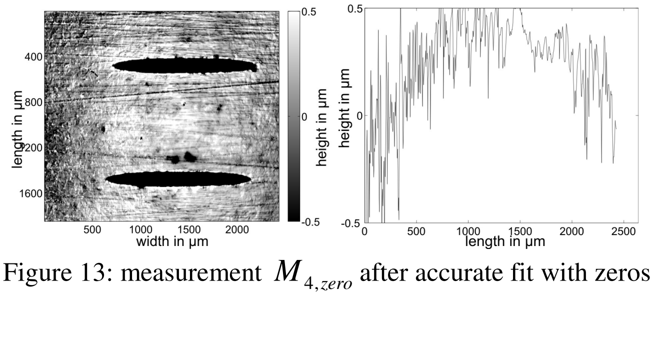

Figure 13: measurement $M_{4,zero}$ after accurate fit with zeros

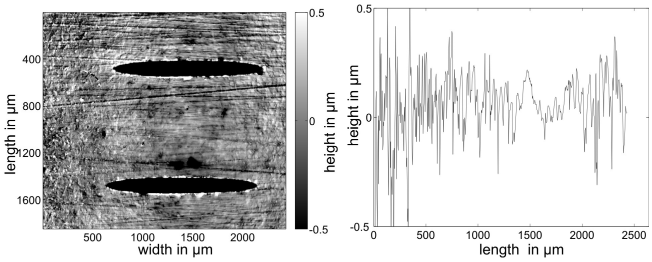

Figure 14: measurement $M_{4,interp}$ after accurate fit with interpolation

6. CONCLUSIONS

In this paper two microstructuring methods to modify surface and functionality have been presented. The measurement and characterisation of microstructures is necessary in order to find out functional properties. But the data pre-processing of large microstructures is challenging. Two methods of stitching of high resolution measurements using the characteristics of the microstructure itself and a form elimination based on robust segmentation method to ignore microstructures have been shown.

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REFERENCES

[1] Denkena B.; Knoll, G.; Bach, F.; Reithmeier, E.; Kästner, J.; Brandt, S.; Drößler, B.; Bretschneider, M.: Mikrostrukturierung funktionaler Oberflächen, wt Werkstatttechnik online Jahrgang, Heft 6, 2008.

[2] Bretschneider, M; Kästner, M; Reithmeier, E. (2009): Metrology and Characterisation of Microstructures made by Cutting Processes. Proceedings of the euspen 9th International Conference, 02.-05. June 2009, San Sebastian, Volume 2, pp. 223-226

[3] Sulzer Metco Ltd., http://www.sulzermetco.com, retrieved: 9.4.2010

[4] Jan Kästner, http://www.fg-mikrostrukturierung.de/spanen.en.htm, retrieved: 9.4.2010

[5] Heizmann, M.; Puente León, F.: Fusion von Bildsignalen (Fusion of Image Signals). In: tm-Technisches Messen 74 (2007), Nr. 3, pp. 130–138

[6] Zitova, B.; Flusser, J.: Image registration methods: a survey. In: Image and vision computing 21 (2003), Nr. 11, pp. 977–1000

[7] Vincent, L.; Soille, P.: Watersheds in digital spaces: an efficient algorithm based on immersion simulations, IEEE Transactions on Pattern Analysis and Machine Intelligence 13, Nr. 6, pp. 583–598, 1991.