euspen's 23rd International Conference & Exhibition, Copenhagen, DK, June 2023
www.euspen.eu

Semi-deterministic manufacturing process for roughness standards for involute gears

Rudolf Meeß, Martin Stein, Dorothee Hüser, Stefan Verhülsdonk

Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

Rudolf.meess@ptb.de

Abstract
Traceable roughness measurements on complex-shaped surfaces are a challenging task due to the spatial distortion of the profile or area to be measured. A novel type of traceable roughness standard for involute gears is therefore being developed at PTB. This material measure is designed for both use in modern gear measuring systems and for standardized roughness measurements. In this study, a multi-step process chain is presented to manufacture such line profiles on curved surfaces in hardened steel and carbide. It is based on a novel semi-deterministic grinding process, using a 5-axis ultra-precision machining centre. The desired roughness profile is calculated with the knowledge of the topography of a ground trace. A computer program superposes and assembles partial profiles. The geometrical information of the completed artificial profile is then converted into an executable program for the machining process. The experiments show that the predictability and repeatability of the grinding process are sufficient to achieve the desired roughness values. In one of the first steps, the novel semi-deterministic grinding process is validated in-plane.

Development, grinding, roughness, ultra-precision

1. Introduction

The spatial distortion of a profile or area is found in roughness measurements on complex surfaces. Mathematical transformations of the measurement data are necessary to validate a measurement because the roughness plot needs to be compared to results of calibrated instruments and planar standards. A new kind of traceable involute roughness standard is therefore being developed at PTB. The material measure is designed for both use in modern gear measuring systems and for standardized roughness measurements [1].

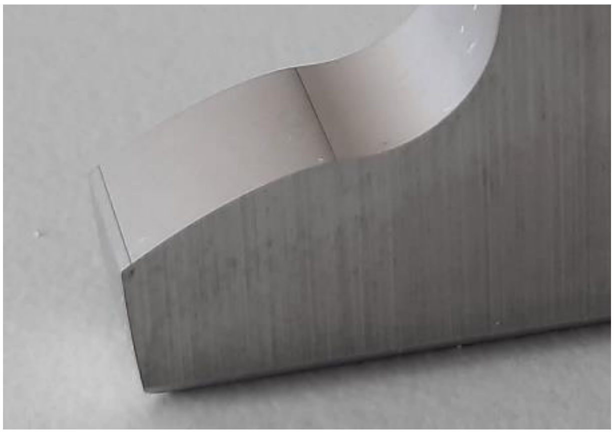

Figure 1. Prototype for gear tooth roughness standard with laser marks – tooth width, 5 mm; measurement path between laser marks, 6 mm.

Figure 1 shows a prototype of a single gear tooth made of tool steel, hardened to HRC 61, as manufactured by wire electrical discharge manufacturing (EDM). Two line marks are implemented to identify and reproduce the measurement path. The roughness of the EDM surface is moderately low, has a Gaussian height distribution and was used for the first studies with measurements and results from different devices. The average roughness is Ra=0.1 µm, and the height is Rz<1.5 µm. In the developed process chain, this EDM surface is even used as a blank for the succeeding steps.

The final roughness profiles of the standard need to be closer to the real functional surfaces of a gear wheel. By taking up the idea of using repeated sub-structures for the generation of roughness profiles [2], highly reproducible spatial grinding traces are superposed and thus used to generate a roughness profile in this study.

Nickel-phosphorous plating is too soft for the gear tooth measurements. Thus no deterministic processes with shaped-diamond tools can be used with the sufficiently small nose radius of around 5 µm, even when using ultrasonic-assisted chipping processes [3,4,5].

A novel multi-step process chain is being developed to manufacture such surfaces in hardened steel and carbide. This includes measurement and transformation routines to realize the curved surfaces on a 5-axis machine. It also comprises the development of the grinding process itself, as this is required for generating the desired roughness profiles. The EDM part needs to be precise so there can be a defined and sufficient offset for the succeeding grinding process with infeeds in the single micrometre range.

2. Methods

For the grinding process, a 5-axis ultra-precision machining centre (Moore 650FG) with an additional milling spindle (Professional Instruments ISO 2.25) is used. A resin-bond diamond grinding tool with a diameter of 20 mm and 325 mesh was used with a water-based coolant. A typical parameter set for the grinding process consists of a spindle speed of

10,000 rpm, a feed of 1 mm/min and an infeed of 10 µm. These machining parameters are close to conditions for the ductile machining [6] of brittle materials.

Figure 3. Grinding mark for measurement and simulation; field of view 645 µm · 645 µm

In the first step, a typical surface profile of the grinding process (see Figure 3) is measured. A high-resolution profiler instrument is used for the measurements [7]. This grinding mark is superposed at several distances at the infeed and in the normal direction by using custom-made software (see Figure 4). With this software, a repeated roughness profile can be generated with synthetic roughness values. The wear of the tool must be known and must have been quantified to realize a sufficient repeatability for the real profile in hardened steel or carbide.

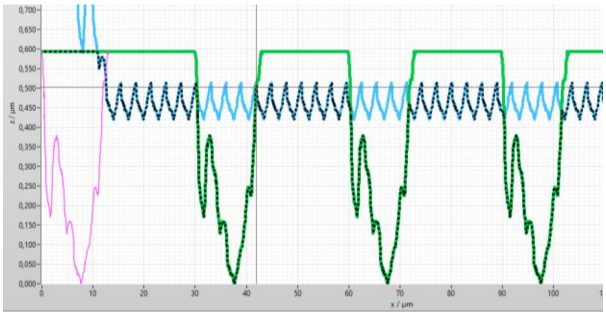

Figure 4. Principle of superposition of grinding operations – pink line: generating profile; green line: contour after first deep traces with rest of assumed blank; blue line: second pass for defining height (Rz); black dotted line: final profile, starting at 12 µm. (This graph is part of the GUI.)

3. Results

A typical flat specimen for validating the grinding process is shown in Figure 5. Two complete experimental runs on the hardened steel can be seen in the photo.

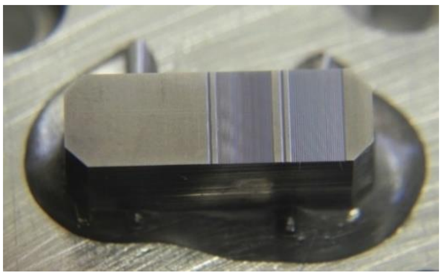

Figure 5. Carbide specimen with ground roughness profiles.

The values of the ground profiles were found to have the same values for Rt and Rz along the complete width. Single grains may break off the grinding wheel during the grinding process while generating a roughness profile. Nevertheless, the resharpening effect of the grinding wheel facilitates comparable roughness parameters with sufficient similarity.

Figure 6 shows that the reproducibility of the traces is sufficient for the generation of a roughness profile. The roughness values that were sought can be measured on the manufactured surface.

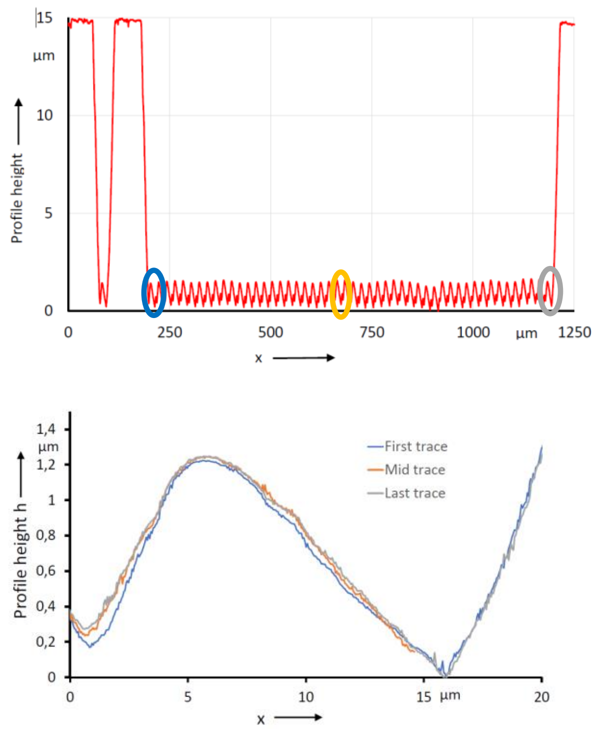

Figure 6. Manufactured profile – top: complete line scan; bottom: measurement of ground of first, mid and last trace in higher resolution.

4. Discussion and Outlook

Roughness profiles have been manufactured in carbide and hardened steel. The roughness profiles have been simulated and machining paths for the ultra-precise grinding operation have been generated by means of custom-made software. The machined flat specimen shows the expected roughness values. In the next step, the grinding process will be transformed onto curved surfaces with an involute contour. For this purpose, high-resolution spherical tactile probes are being designed and tested. A special measurement procedure is also being developed to identify tool and workpiece centre points. This will additionally have to be proved and tested on the curved surface.

Acknowledgement

The authors would like to thank Peter Thomsen-Schmidt for the measurements and roughness determinations with the high-resolution profiler instrument and Felix Steinmeyer for the very valuable work that he contributed to the project.

References

[1] Steinmeyer F, Hüser D, Meeß R and Stein M 2021 *Applied Sciences.* **11** 21:10303
[2] Hillmann W, Jäger V and Krystek M 1997 *Qualität und Zuverlässigkeit.* **42** 1, 76-79, ISSN: 0720-1214
[3] Weber H, Herberger J and Pilz R 1984 *CIRP Ann*. **33** 85-7
[4] Moriwaki T, Shamoto E and Inoue K 1992 *CIRP Ann*. **41** 141-4
[5] Moriwaki T and Shamoto E 1991 *CIRP Ann*. **40** 1 559-562
[6] Bifano T G, Dow T A and Scattergood R O 1991 *J. Eng. Ind*. **113** 2: 184-189
[7] Thomsen-Schmidt P 2011 *Measurement Science and Technology*. **22** 9: 094019-1 - 094019-11