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Tool/workpiece contact detection via acoustic emission in micro grinding

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Abstract

The microstructuring of technical surfaces by micro machining represents a promising methodology for component optimization by miniaturization of functional elements. For the use of micro end mills and micro pencil grinding tools (MPGT) the initial tool/workpiece detection represents an important procedure to ensure a defined depth of the machined structures. The present paper describes the design and validation of a tool/workpiece contact detection system via acoustic emission (AE) for tools at the micro scale. The sensor design and data analysis required to measure the tool/workpiece contact marks are described. The tests were performed using an electroless plated MPGT with a diameter of 50 µm, both dry and applying metal working fluid (MWF). The accuracy of the initial tool/workpiece contact detection system via acoustic emission was characterized via the contact marks on the workpiece surface.

Micro grinding, acoustic emission, initial tool/workpiece contact detection

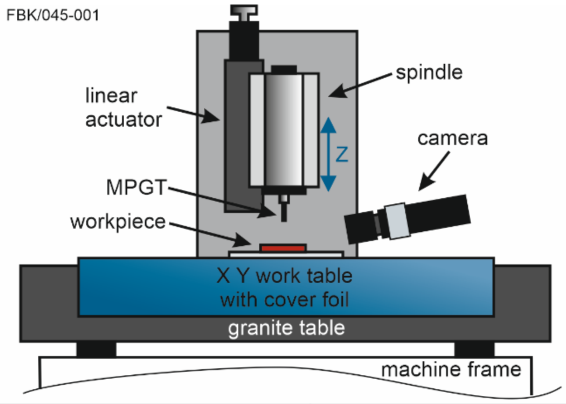
1. Introduction

Micro grinding with micro pencil grinding tools (MPGTs) and micro milling with micro end mills offer the possibility to machine structures on the micro scale. To assure reproducible microstructures, the initial tool/workpiece contact detection is essential, as it determines how accurate the depths of the machined grooves will be. Two common variants for the contact detection are the optical and the electrical detection. With optical tool/workpiece detection the initial chip removal is observed by the machine operator. This method excludes the use of MWF as it blurs the field of view. Another disadvantage of this method is that the accuracy of the initial tool/workpiece contact is influenced by the operator's skills. With the electrical tool/workpiece contact detection, an electrical potential is applied between the tool and the workpiece which breaks down on contact. In this process, both the tool and the workpiece must be electrically conductive and no electrically conductive MWFs can be used. Furthermore, workpiece materials like glass and ceramics are excluded as well. The acoustic initial tool/workpiece detection is a third method. Min et al. showed that it is possible to perform an initial tool/workpiece detection with this method [1]. In this study, the smallest tool diameter of the micro end mills they applied was 77 µm. The depth of the milling contact marks on the workpiece was used as a measure for the accuracy of the process and amounted to 0.7 µm [1].

This paper provides an experimental setup for a workpiece holder with integrated acoustic initial tool/workpiece contact detection sensor. A description of machines, tools and process parameters is given. Furthermore, results are presented based on the contact marks on the surface. Finally, in the summary the potential of the process for future works is discussed.

2. Experimental setup

The contact detection device was implemented on a four axes machine tool. The machine tool setup and the machine specifications as well as the process and the tool parameters are



precision machine tool	
linear axes: X, Y, Z	process parameters
accuracy: < 1 µm	spindle speed: 30,000 rpm
travel: 100 mm	feed rate in Z: 1 mm/min
resolution: 2.54 nm	incremental step: 0.2 µm
air bearing main spindle	tool parameters
max. spindle speed: 54,000 rpm	tool diameter: 50 µm
	grit size: 5-10 µm

Figure 1. Machine tool according to [2] in front view and relevant Parameters

given in Figure 1. The translative axes X, Y and Z are driven via precision ball screws. The X- and Y-axes are air-bearing mounted while the Z-axis has a cross roller bearing.

Three electroless plated MPGTs with a diameter of 50 µm were used for the experiments to validate the AE-tool/workpiece contact detection system. Figure 2 shows a SEM image as well as a schematic cross section of the tool applied. The tool consists of a steel base body which serves as a substrate for the abrasive layer. The layer is a nickel-phosphorous alloy matrix containing cubic boron nitride grits (cBN) with a nominal size of 5-10 µm. The layer thickness is about 5 µm [3].

Figure 3 shows the design of the workpiece holder for small workpieces. It consists of a brass base with an implemented cavity onto which a piezo disc was soldered. The piezo disc has an outer diameter of 27 mm and can oscillate freely due to the cavity. Rose's metal was used as solder due to its low melting point of 93 °C [4] to reduce thermal stress on the cables and their solder joints. The workpiece used for the test was made of hardened 16MnCr5 (660 HV 30), had a size of 20 x 10 x 5 mm, and was glued directly on the piezo disc of the holder. The top surface of the workpiece was polished to enable a precise measurement of the contact marks' depths.

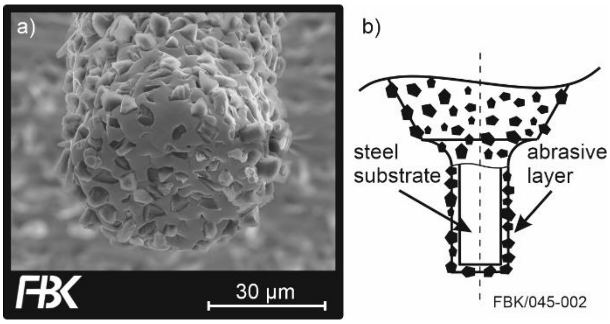


Figure 2. a) SEM image of an MPGT b) cross section of an MPGT

To carry out the test, the MPGT was brought close to the surface of the workpiece observed with the camera. The rotational speed of the tool was set at 30 000 rpm. The feed in the direction of the workpiece was done in incremental steps of 0.2 µm at a feed rate of 1 mm/min. The contact between tool and workpiece generates an AE-signal, which was converted by the piezo disc into a voltage signal.

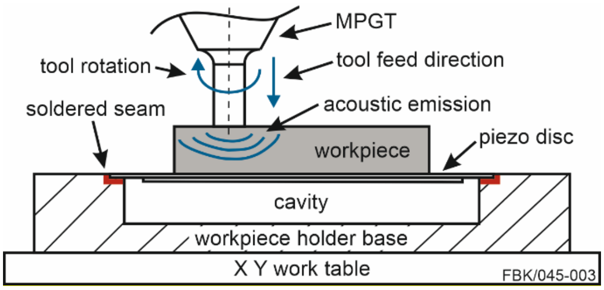


Figure 3. Schematic of the workpiece holder with piezo disc

The signal processing is shown in Figure 4. The analogue signal was amplified and converted into a digital signal via a measuring device. The signal processing was conducted via LabVIEW. Potential signal drifts were removed by a digital high pass filter with a cut-off frequency of 10 Hz. The signal was displayed and evaluated by the machine operator to determinate the initial tool/workpiece contact based on the initial peak beyond the background noise.

The tool/workpiece contact was performed three times dry and three times with MWF using the same MPGT in each experiment. Pure Twinmax, a commercially available cutting oil from Steidle GmbH[1], was used as MWF. The workpiece surface was wetted with drops of the MWF.

The evaluation of the experiment was done with a confocal microscope from NanoFocus[1] µSurf explorer using a 20x objective (NA 0.9). The measured topography was used to evaluate the depth of the contact marks.

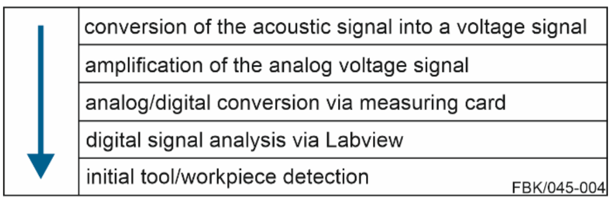


Figure 4. Procedure of the AE-signal analysis

3. Results

Figure 5 shows the contact marks of one of the experiments. Figure 5a) displays the contact marks in top view while Figure 5b) shows the cross-section through them. The high positive values in Figure 5 b) are not relevant due to the fact that they can be interpreted as measurement errors as an effect of burr. The maximum depth of each contact mark relative to the workpiece surface is within a few hundred nanometers while the deepest measured contact mark is approximately -230 nm. There is no significant difference between an initial tool/workpiece contact with or without MWF due to the fact that the appearance of all contact marks looks similar.

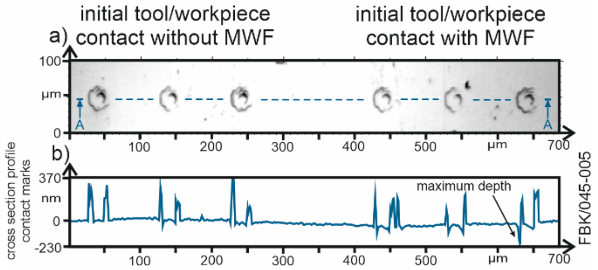


Figure 5. Depth profile evaluation of the contact marks: a) top view of the workpiece surface, b) cross section A-A of the workpiece surface

4. Conclusion and outlook

In this paper, a workpiece holder with an integrated piezo disc for contact detection via acoustic emission was presented. The validation of the AE detection system has shown that it is possible to perform precise initial tool/workpiece contact detections using a simple piezo disc. On a precision machine tool, the initial tool/workpiece contact with an MPGT could be detected by means of an AE sensor with and without the presence of MWF. The resulting contact marks were used as a criteria for the accuracy and are in the range of a few hundred nanometers showing that the system is reliable with and without MWF.

The concept shown allows optimizations in the use of MPGTs for research purposes and industrial applications. The next step is to automate the process in order to perform it independently of influences of the machine operator. Furthermore, the change of the tool length due to wear can be measured and compensated during the grinding process. This enables structures of higher accuracy and a better evaluation of the mechanisms in the fields of micro grinding with MPGTs.

Acknowledgments

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[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."

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