Acoustic Emission-based micro milling tool contact detection as an integrated machine tool function

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Abstract

Various sensor-based methods for referencing tool and work piece position are available for the contact detection between tool and work piece. In this article the robustness of the acoustic emission-based contact detection will be investigated which is a vital requirement for such a system in order to be integrated into machine tools.

1 Introduction

One of the key challenges in micro milling is the precise and reliable detection of tool position and work coordinate system. The system proposed in this paper uses a direct method for tool contact detection. Via the application of an Acoustic Emission sensor to the work piece holder of a micro milling machine tool, the contact detection can be performed through the detection of acoustic emission generated by the contact of work piece and rotating tool. A major advantage of such direct method is the possibility of measuring the contact point with a rotating spindle, thus eliminating the thermal error due to the axial expansion of the rotating spindle.

2 State of the art

Acoustic Emission (AE) is structure-borne sound of high frequency that is generated by solids under mechanical strain. Sources of AE are plastic deformation, friction, crack formation and material breakage [1]. In the context of the proposed application, the AE signal is utilized to determine the moment of physical contact between a work piece and the rotating milling tool in a vertical approach. This approach was already proposed and experimentally evaluated by Bourne et al. [2] and Min et al. [3]. The focus of this contribution, besides the further evaluation of the feasibility, is on the integration of the AE-based contact detection into the control of the machine tool and the accuracy of repetitive approach processes.

3 Experimental setup

The proposed system was implemented on a prototypical 3-axes micro milling machine with a Sycotec 4064 DC high speed spindle and a CNC of the type Beckhoff TwinCAT. The Acoustic Emission sensor 8152B of the manufacturer Kistler is inserted into a specially designed work piece fixture and thus mounted to the bottom side of the work piece. After preamplification through a Kistler 5125B amplifier module, the signal was acquired through a National Instruments USB-6351 data acquisition device. TiAlNi-coated two flute end mills with a diameter of 500 µm were applied in vertical approach experiments. Brass and steel (X38CrMoV5-1) were examined as work piece materials. Before and after nine consecutive approaches, the mills were analysed in a scanning electron microscope. The work piece surface was optically scanned using the focus-variation-based surface metrology system Alicona InfiniteFocus.

An incremental approach algorithm [4] was applied by implementing a semaphore communication between the signal processing module and machine control. This implies that the machine control initiates a downward movement of 1 µm after receiving an explicit approval from the signal processing module. Subsequently, an AE signal is acquired with a length of 500 samples at a sampling rate of 1 MHz and the signal is filtered. If the signal energy of the processed signal is below a defined threshold, no contact is detected and thus, an approval for the next downward motion will be sent to the machine tool control.

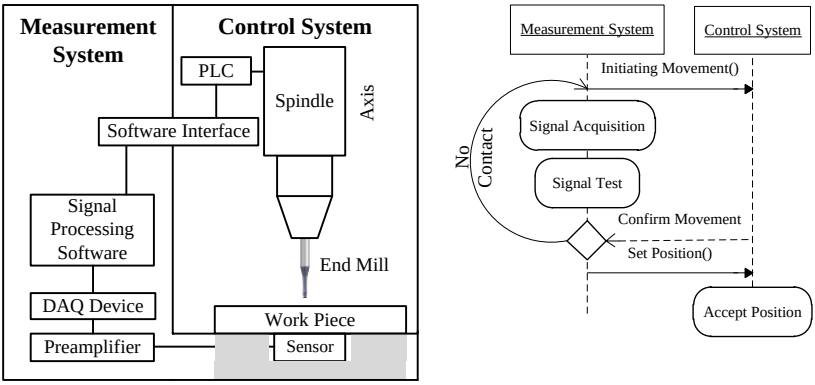


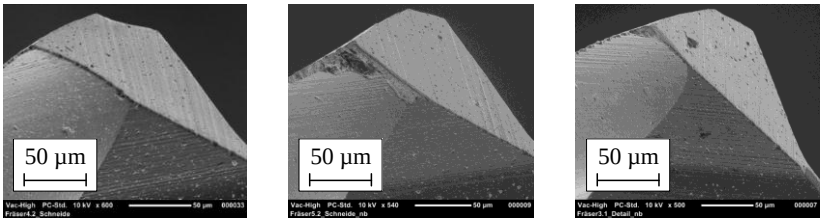
Figure 1: Experimental setup and sequence of incremental approach algorithm

In case of a threshold excess, the current z-coordinate is sent to the machine control as the new reference point and an upward movement is initiated to prevent unnecessary friction between tool and work piece.

4 Results

4.1 General results

The tools were affected by the contact event as it can be seen in Figure 2. Compared to steel, brass as a work piece material imposed greater strains to the TiAlN-coated tool.



New | After nine approaches on brass | After nine approaches on steel

Figure 2: Milling tool cutting edges before and after approach experiments

4.2 Reproducibility experiments

To evaluate the contact detection for the determination of the work piece surface the approach was repeated 400 times in an automated procedure for each of the work piece material (Figure 3). In both cases, each contact detection was performed successfully. For compensating the inclination of the work piece surface due to mounting error, a regression plane of the measured z-coordinates was determined.

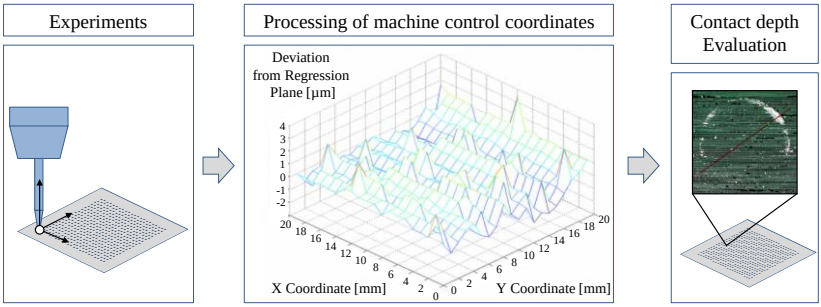


Figure 3: Process sequence of the reproducibility experiments

For evaluating the significance of the tool contact detection the deviations of the z-coordinates were compared to the cutting depths of ten points. Executing the experiments with the brass alloy, the optical measurements indicate an average cutting depth of 1.061 µm. The average deviation of the z-coordinate to the actual work piece surface is 0.554 µm. These values are material specific and have to be taken into account for determining the actual work piece surface with AE-based tool contact detection.

n=400	Average Deviation of the z coordinates from Regression Plane [µm]	Range of the Deviation of z coordinates from Regression Plane [µm]	Average Deviation from Regression Plane to actual Work piece Surface [µm] (n=10)
Steel	0.829 µm	[-2.0, 3.4]	0.554
Brass	0.581 µm	[-2.6, 2.5]	1.061

Table 1: Results of the Reproducibility Experiments

4.3 Discussion and further research

The presented work demonstrated the potential of an automatable AE-based contact detection for micro milling machine tools. Further research will consider the contact detection in x, y direction to determine the work piece position. Furthermore the material-dependent depth variation of the surface damage should be investigated to obtain a fixed offset between the regression plane and the actual work piece surface.

References:

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