Development of an Active Work Piece Holder for Vibration Assisted Micro Milling

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Abstract

Vibration assistance becomes more and more common practice for different machining processes such as ultra sonic grinding, polishing, milling and electrical discharge machining. By inducing vibrations at the tool and/or the work piece the processes can be optimized in terms of achievable surface roughness, chatter behavior, tool wear and machining time. This article reports of an active work piece holder for vibration assisted micro milling. An attached real time control circle enables systematically influencing the cutting conditions whilst micro milling and reproducible surface structuring.

1 Introduction

Micro Milling is well-established for die and mould fabrication. An increased utilization for medical and biotechnical components can also be stated. The process performance is mainly limited by the work piece's material properties. According to that decreased tool life or premature tool breakage are the consequences. Also size effects and small uncut chip thickness have negative effects on the process results in the form of ploughing, burr formation and form deviation.

Vibration assistance for milling with end mills has been introduced by various researchers. Mostly sinusoidal vibrations are induced by actuator enhanced spindles [1] or work piece holders [2]. For certain parameter sets increased process stability and high surface quality could be achieved. In order to analyze the effects of sinusoidal work piece actuation on the sensitive process behavior of micro milling preliminary tests are carried out to define the required actuation frequencies and amplitudes. Also the influence of the cutting forces on the spindle speed is analyzed. Subsequently the system design and a control circuit are presented.

2 Preliminary Tests

For the tests a three axis micro milling machine tool WISSNER Gamma 303 HP with a Precise SC3062 spindle is used. The work piece is clamped between two piezo electric actuators in a moveable vice. During the cutting process the work piece is excited with frequencies up to 20 kHz and an amplitude of 0.5 µm normal to the feed direction. Figure 1 shows the measured surface roughnesses at two different spindle speeds and two microscope images at two different operating points.

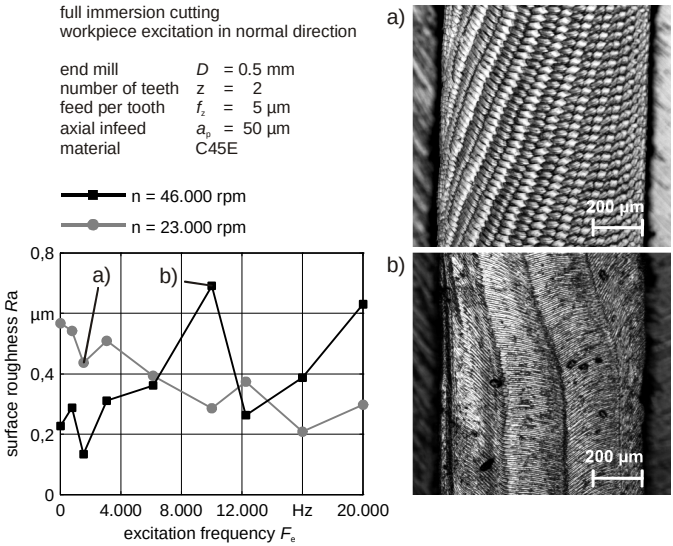
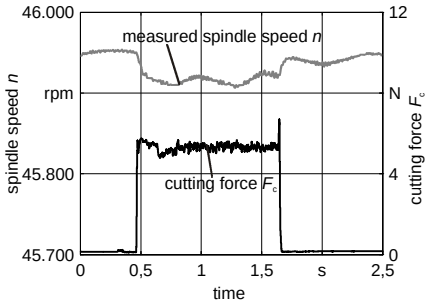


Figure 1: Surface roughness and topography with vibration assisted micro milling

The graphs show that for a spindle speed of 23.000 rpm the surface roughness can be significantly reduced. However, only one operating point at a spindle speed of 46.000 rpm shows this behavior. A possible reason for that are process machine interactions (PMI) caused by the interrupted cutting conditions that interact with the flexible end mill and the machine tool structure. Complex deviations of the Tool Center Point (TCP) are the consequences [3] and presumably intensified by the work piece excitation. The showed surface topographies possess visible irregularities that confirm this assumption. Nevertheless, the generated surfaces, especially in Figure 1.a) obviously contain promising properties for surface structuring. Considering its minor irregularities small changes of the spindle speed are a possible reason.

To verify the influence of the cutting force on the spindle speed additional tests without work piece excitation are carried out. Therefore signals of an incremental encoder are analyzed. The spindle integrated sensor provides a quasi sinusoidal signal with six periods per spindle revolution.



The actual spindle speed shows already deviations to the default value of 46.000 rpm of 0.5 % to 1 %. During the cutting process the spindle speed decreases significantly. Thus, small irregularities on the work piece's surface as shown in Figure 1.a) can be explained.

Figure 2: Spindle speed deviation under cutting conditions

Considering the results of the preliminary tests it can be stated that systematically influencing the micro milling process by uncontrolled work piece excitation cannot be realized. Therefore a system has to be developed that takes into account the actual spindle speed and the dynamic process behavior.

3 Design of the Active Work Piece Holder

Figure 3 shows a setup of the active work piece holder and the control circuit. By means of a parallel kinematic 2 DOF stage with flexure hinges the work piece can be excited in two directions horizontally to the spindle axis. The excitation signals of the actuators have to be in highest accordance to the rotation angle of the end mill. Therefore a real time control is connected to the mechanical unit that ensures the signal processing as well as the closed loop control of the actuators. The actuators are controlled in terms of frequency and amplitude as well as occurring phase shift between the actuator oscillation and the rotation angle of the end mill due to load-dependent variations of the spindle speed. Adjustable pressure springs are used to preload the system. The system enables 2 DOF vibration assisted milling up to 10 kHz with a maximum amplitude of 10 µm. Controlled vibrations of the work piece relatively to the cutting edge allow exerting influence on the cutting conditions

below the critical chipping thickness. Also precise excitations other than sinusoidal signals can be used in order to systematically influence the surface structure.

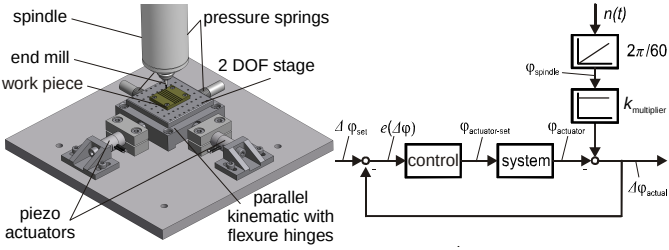


Figure 3: Setup and control circle of the active work piece holder

4 Conclusion and Outlook

A design concept for 2 DOF vibration assisted micro milling is presented in this article. In order to verify major influences on the process preliminary tests are carried out. Deviations of the spindle speed as well as process machine interactions PMI are constraints of the process. Therefore a closed loop control of the work piece actuation considering the actual spindle speed is implemented. As the necessary hardware is at industrial grade vibration assisted micro milling offers a new and fast way of process optimization and surface structuring. Future research on this topic will be conducted in close collaboration with technological research on process machine interactions in order to allow portability between different machine tools.

References:

[1] Ries, M.; Pankoke, S.: Increasing the Stability of the Milling Process by an Active Milling Spindle. Proceedings of the CIRP 1st International Conference on Machine Interactions. Hannover, Germany, 2008

[2] Chern, G.-L.; Chang, Y.-C.: Using two-dimensional vibration cutting for micro-milling. International Journal of Machine Tools and Manufacture Volume 46, Issue 6, 2006

[3] Shi, Y, Mahr, F., von Wagner, U., Uhlmann, E.: A Spatial Multiple Degree of Freedom Machine Tool Model for Micro Milling Simulation. CIRP 2nd International Conference, Process Machine Interactions (PMI), Vancouver, Canada, 2010