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Two-axis vibration system for targeted influencing of micro-milling

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Abstract
Micro milling is a well-established manufacturing process for mould and die industry, which gains an increasing scope of usage for medical and biotechnical components and applications. Apart from manufacturing of microsystems, micro milling is also being applied for production of function-oriented surfaces, which improves the component functionality. The influence on surface topography and surface roughness in the process of micro milling can be achieved by means of targeted high-frequency vibration of a workpiece. There was developed a system to perform vibration assisted micro milling, which excites a workpiece in two directions horizontally to the spindle axis. For exploring of vibration assisted micro milling there was developed a system which excites the high-frequency vibration of a workpiece in two directions horizontally to the spindle axis. Frequency, amplitude and phase shift of the oscillation are controlled in accordance to the rotational angle of the machine tool spindle. Therefore, a closed loop control of a workpiece actuation considering the actual spindle speed is implemented. The system enables 2 DOF vibration assisted milling up to f = 10 kHz with a maximum amplitude of a = 7,5 µm. With usage of necessary industrial hardware vibration assisted micro milling offers a new and fast way of process optimization and surface structuring. This paper presents detailed information on the device for vibration assisted micro milling and the results of the milling tests in order to show the high potential for further research activities in the area.

Keywords: micro milling, vibration assisted processing

1. Introduction

Production of micro systems using micro milling has a great potential in the fields of optics, medical and fluid technology. Micro milling can be used for the production of complex geometries with dimensions in the micrometer range. Compared to other micro manufacturing processes, such as laser ablation or electrical discharge machining (EDM), it is characterized by high flexibility for workpiece shape and low processing time.

On the other hand, micro milling is also used for the production of function-oriented surfaces which improve the component functionalities and find application in several fields [1]. It is possible to distinguish between micro-structured, textured and edge zone affected areas that have an influence on optical, mechanical, aero- and hydrodynamic, thermal, and tribological properties of a component [2]. The influence on surface topography and surface roughness in micro milling can be achieved through specific high-frequency stimulation of a workpiece [3, 4].

An active workpiece holder for the realization of such vibration assisted milling was developed in the Institute for Machine Tools and Factory Management IWF of the Technical University Berlin. This enables a highly dynamic horizontal vibration of a workpiece in two directions, which permits the configuration of frequency, amplitude, and phase for cutting mesh frequency.

2. Design of the Active Work Piece Holder

Figure 1 shows the setup of the active workpiece holder. It consists of a parallel kinematic 2 DOF stage with flexure hinges, on which a workpiece holder is mounted. The flexure hinges are set into motion by two high voltage piezo actuators PSt VS25 made by the company Piezomechanik GmbH, which have a maximum static stroke of a = 20 µm in combination with an amplifier LE 500/200 from the same company. The specially designed shape of the flexure hinges, which was manufactured with hardened spring steel 1.1260 by wire EDM, allows the independent movement of the workpiece holder along two axes and includes shear forces on the piezo actuators. The dynamic behavior of the prototype is improved by a squeeze film damper that was incorporated between the workpiece holder and the stage with flexure hinges.

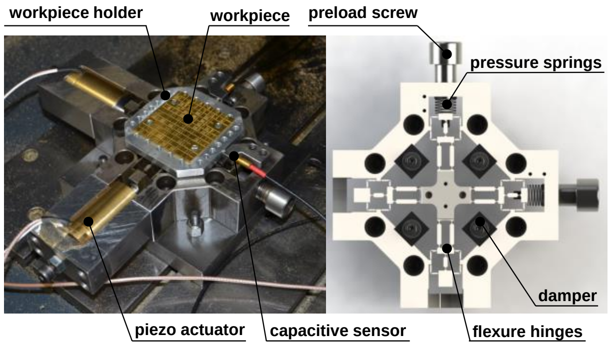


Figure 1. Prototype of the active work piece holder

3. Controller design

The real-time system ADwin Gold II made by the company Jäger Messtechnik GmbH was used to control the prototype. It has a 32-bit signal processor TS101 TigerSHARC ADSP with a clock rate of f_{CPU} = 300 MHz, which can generate and process a signal down to the nano second range. The control tasks have been programmed with Matlab/Simulink software.

The control circuit, see Figure 2, generates a sinusoidal control signal for each piezo actuator separately. This signal is based on the spindle frequency f_S and the angular position of the tool edge ϕ_{se}. The current position of the workpiece holder is detected by two capacitive sensors CS02 made by the company Micro-Epsilon Messtechnik GmbH & Co. KG.

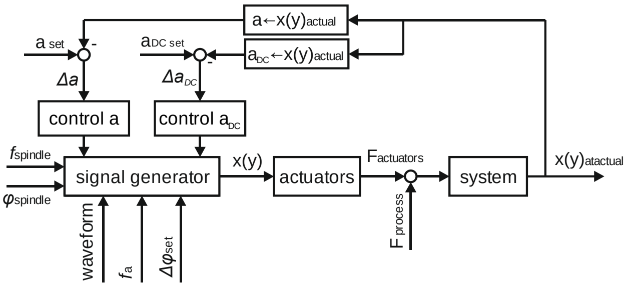


Figure 2. Control circle of the active workpiece holder

The maximum possible frequency of workpiece holder is $f_a = 10$ kHz, although the vibration amplitude is dependent on the vibration frequency. By the modal and operational vibration analysis it was found that the frequency range of $2.4 \text{ kHz} \leq f \leq 2.9 \text{ kHz}$ is critical for the system and should be avoided during the selection of process parameters to protect the piezo actuators.

4. Vibration assisted micro milling test

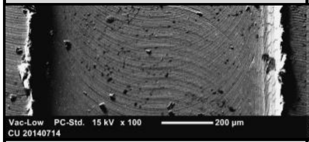
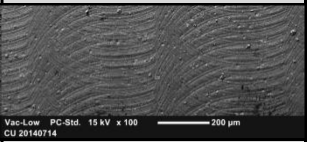
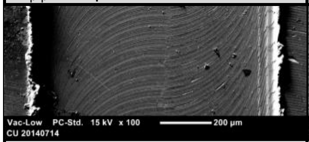
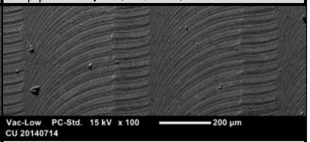
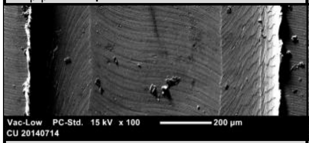
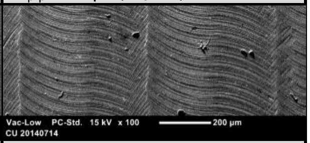
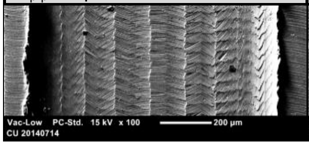
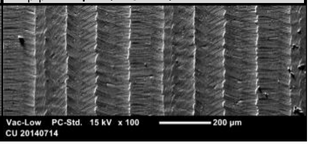
In order to investigate the effects of a workpiece side vibrational excitation on the processing result the settings of the machining and vibration parameters were varied. A three axis micro milling machine tool WISSNER Gamma 303 HP with the integrated two axes system was used for the tests. The tests were carried out with uncoated double edged micro shank tools with a diameter of D = 1 mm. In order to minimize the influence of tool wear to a minimum, there was selected brass CuZn39Pb3 as a workpiece material. The evaluations of the generated surfaces presented a significant influence of the processing and the vibration parameters on the surface structure; see Table 1.

By targeted vibrational excitation of a workpiece in the feed direction different zones of the surface topography are produced, which are based on the characteristics of the excitation. In an up-milling workpiece movement the tool has a negative camber angle, resulting in convex tracks. On the other hand, in a down-milling workpiece movement the resultant camber angle is positive, which leads to concave tracks. Through the synchronization of the vibration with the cutting position it becomes possible to structure the surface of a workpiece in different zones of convex and concave tracks.

The number of these zones is directly dependent on the ratio between spindle frequency f_s and workpiece frequency f_a. For example, by the slot milling with a vibration frequency $f_a = 2 \times f_s$ it can be observed the production of two zones: with convex and concave tracks. The boundary between the zones is the point of maximum or minimum actuator stroke. By amplifying of the vibrational frequency relatively to the spindle frequency, the number of zones is increased.

Comparable effects can be seen by the excitation of a workpiece perpendicularly to the feed direction. However, they are not always reproducible. The effects described above are no longer observed during a significant increase of the tooth feed $f_z > 30$ µm and the depth of a cut $a_p > 200$ µm. In this case the surfaces are structured only in the form of convex tracks.

Table 1. Surface roughness and topography with vibration assisted micro-milling

Processing parameters: Tooth feed $f_z = 10$ µm; depth of cut $a_p = 50$ µm; spindle speed n = 15 000 min^{-1}	
Slot milling	Surface milling
Without vibration	Without vibration
	
$f_a = 500$ Hz = 2 x f_S ; $a_{p\text{-}p} = 10$ µm	$f_a = 500$ Hz = 2 x f_S ; $a_{p\text{-}p} = 10$ µm; $a_e = 0{,}5$ mm
	
$f_a = 1$ kHz = 4 x f_S; $a_{p\text{-}p} = 10$ µm	$f_a = 1$ kHz = 4 x f_S; $a_{p\text{-}p} = 10$ µm; $a_e = 0{,}5$ mm
	
$f_a = 4$ kHz = 16 x f_S; $a_{p\text{-}p} = 4$ µm	$f_a = 4$ kHz = 16 x f_S; $a_{p\text{-}p} = 4$ µm; $a_e = 0{,}5$ mm
	

5. Conclusion and Outlook

Scientific fundamentals of vibration assisted micro milling were presented as a part of the work. The effects of the excitation types on the micro milling for generated surface structures have been determined by experiments. The high-frequency displacement of a workpiece, which is based on the spindle frequency f_s, enables a targeted and reproducible surface structuring. But the generated topography also shows a strong dependence on the machining boundary conditions such as ~~a~~ tool overhangs and cutting edges wear. In order to extend the vibration assisted micro milling for the production of complex workpiece geometries it is necessary to investigate an influence of abovementioned machining boundary conditions on the surface structuring.

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