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Servo tool for chip formation studies in micro milling

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Abstract
In this research paper a servo tool to investigate the chip formation and surface generation in micro end milling is presented. In micro milling, the chip formation is not observable, therefore the process kinematic of micro milling is transferred with a self-developed piezo driven servo tool to an ultra-precision lathe. This servo tool allows to investigate the influence of the non-continuous chip formation as well as the variing undeformed chip thickness in feed direction to enhance process knowledge and to improve the micro milling process, the tool geometry as well as the resulting surface.

Servo tool, micromachining, ultra-precision turning

1. Introduction

The increasing demand for miniaturized and function integrated components which are, for example, used in biological or medical applications involves the use of appropriate manufacturing technologies [1]. Many methods such as lithography are only appropriate for the economical production of high batch numbers. A suitable and cost-efficient process to manufacture such components, in single or small batch production, is micro milling with ultra-small micro end mills [2]. This manufacturing technology allows the economical production with a high diversity of usable materials, a wide range of possible geometries combined with a high material removal rate for micro machining processes. The disadvantages of this process is a high formation of burrs and a high tool wear, especially on the cutting edges, due to the ploughing effect [3]. To improve the tools and thereby the surface quality it is necessary to understand the chip formation process. Due to the small dimensions, the inaccessible cut and the process kinematics the investigation of the chip formation and therefore the surface generation is a challenge. It is possible to study the tools, the work pieces and the resulting chips, but the actual chip formation in micro milling is not observable.

In the research described in this paper, the physical characteristics as well as the usability of the servo tool for the investigation of chip formation are shown.

2. Method

One solution to make the micro milling process observable is to transfer the chip formation process of micro milling, with its typical interrupted cut, to a turning process on a precision lathe with the help of a servo tool. The advantage of this transfer is a better accessibility and observability of the chip formation. Transferring the process on an ultra-precision lathe without the servo tool is only possible for a small range of process parameters because of the required high acceleration and speed. For this research the developed servo tool was mounted on an ultra-precision lathe (LT Ultra MTC 250). The used configuration allows the investigation of the chip formation by a high speed camera microscope (Fig 1).

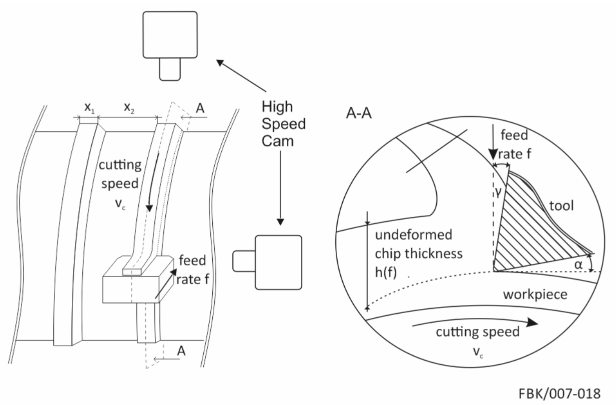

Figure 1. Process conditions

3. Servo tool design

Fig. 2 shows the CAD-Model of the servo tool and the built demonstrator.

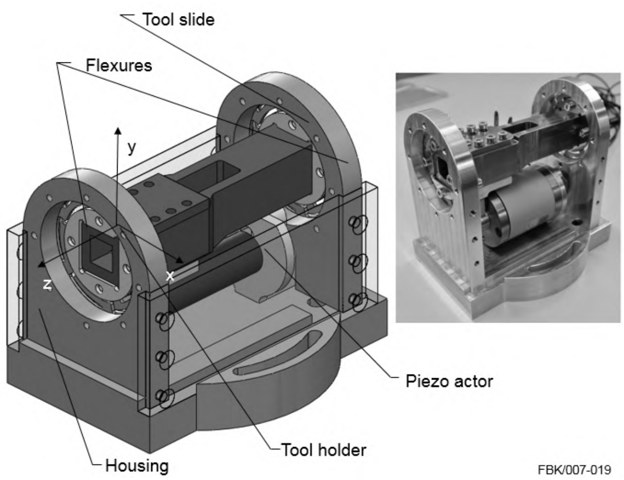

Figure 2. Servo tool, CAD-Model left and demonstrator right

The servo tools's base is a rigid aluminium housing for using a high bandwidth of frequencies and therefore a great range of possible cutting parameters. This housing carries the tool slide which is guided by two monolithic flexure hinges. The slide has an integrated tool holder and is driven by a piezo actuator (PI P844.20). The actuator generates movement of 40 µm in the z-axis direction. The movement is dependent on the signal of the piezo actor control.

In Fig. 3 the frequency response, measured with three capacitive sensors, of the developed servo tool is shown. The tool has a usable bandwidth of 400 Hz with an adjustable stroke amplitude. The maximum velocity of the servo tool is 960 mm/min at a 40 µm stroke amplitude and the usable acceleration 6.4 m/s². Thus the usable bandwidth of possible micro end mill diameters and cutting speeds is sufficient for analyzing micro milling processes with, for example, 50 µm diameter end mills, a feed per tooth f_z of 1.5 µm and a spindle speed of 650.000 rpm.

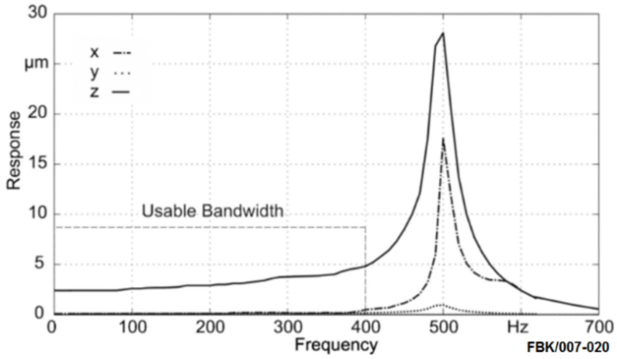

Figure 3. Frequency response of the servo tool

3. Experimental setup

The servo tool is used as an additional linear stage with high speed and acceleration and a sinusoidal stoke amplitude. The cutting tests were performed with a 50 µm diameter micro end mill. Fig.4 shows the used single-edge micro end mill made of cemented carbide by grinding [4].

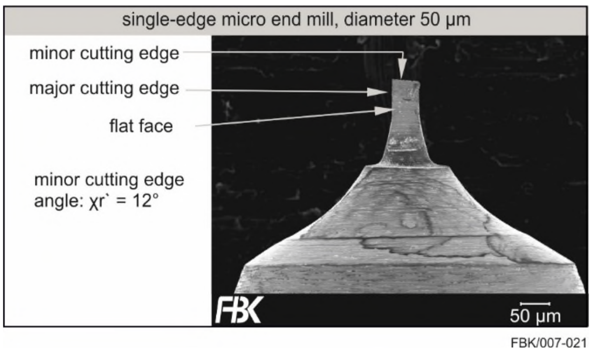

Figure 4. Micro end mill

The workpiece used was face turned in a first step, using a diamond turning tool to generate an even, optical surface. Then, in a second step, the parameters for micro milling with a feed per tooth of f_z = 5 µm, a cutting speed of v_c = 7 m/min and a depth of cut of a_p = 5 µm were transferred to the ultra-precision lathe with the help of the servo tool. Therefore, in orthogonal cutting, the stroke of the servo tool generates a depth of cut of 5 µm with the major cutting edge of the micro end mill.

5. Results

The resulting chips were compared with chips generated in the micro milling process. The chips generated with the servo tool show similar characteristics as the chips in micro milling (see Fig. 5).

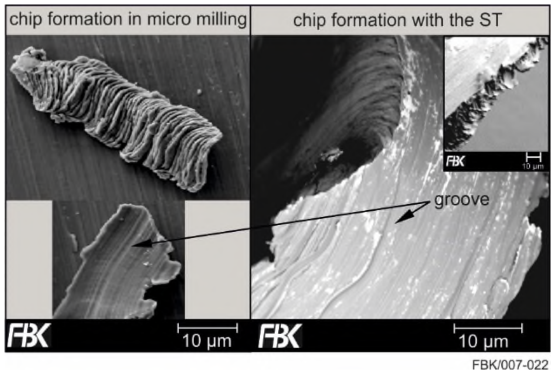

Figure 5. Chip formation at micro milling and with the servo tool (ST)

The chips are lamellar and show the expected comma-shape (Fig. 5 top right) as a result of the sinusoidal rising depth of cut. Also the grooves on the back of the chips, resulting from cracks on the cutting edge of the micro end mill, are visible. Typically, these are the size of the grains of the tungsten carbide (0.2 µm).

6. Conclusion

In this paper, a piezo driven servo tool to analyze the chip formation in micro milling processes is presented. Characterisations of the servo tool show a high acceleration and a high speed even at low increments of movement, and the ability of producing chips with similar properties as chips in the micro milling processes. In further research, the chip formation of micro milling with high rotational speed > 5 kHz [5, 6] is going to be investigated. By raising the stiffness of the servo tool's housing, the usable frequency bandwidth is going to be increased. Also the influence of the cracks on the cutting edges of the micro end mill, and their influence on surface quality, burr formation and wear behaviour are going to be researched.

Acknowledgement

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