Development of a Quick-Stop-Device to investigate chip formation in micro- and nanomachining

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Keywords: quick-stop-device, chip formation, micro- and nanomachining

Abstract

Compared to conventional cutting processes, additional effects influencing the material surface have to be considered in micro- and nanomachining processes. To obtain an understanding of the material removal process it is necessary to investigate chip formation. The aim of this paper is to present the development of a quick-stop-device (QSD) to investigate chip formation in micro- and nanomachining. The QSD is integrated into the periphery of an ultra-precision turning lathe. In this paper the construction, the function as well as the functionality of the QSD are shown and described.

1. Introduction

Micro- and nanomachining processes represent viable technologies to produce miniaturized components as well as to microstructure surfaces to achieve better functionalities due to a high number of possible geometries combined with a high material removal rate. Compared to conventional cutting processes, additional effects influencing the material surface such as the size effect and the ratio between the cutting edge of the tool and the depth of cut have to be considered [1].

To obtain an understanding of the surface generation it is necessary to investigate chip formation. The methods to investigate this formation in micro- and nanomachining are often very complex and time consuming, like the direct SEM (scanning electron microscope) observation technique [2]. In contrast, conventional machining uses the quick-stop-method: a fast and easy to use technique, but of limited use in micromachining. An example for the application is given in [3]. The aim of this paper is to present the development of a QSD to investigate chip formation in micro- and nanomachining. With the development of the QSD, the fundaments for the investigation of chip formation may become reachable, and thus enabling future optimizations and machining strategies in micro- and nanomachining.

2. Quick-stop-device assembly

The assembly presented in this paper is divided into three main functional parts: the quick-stop device (1), the piezoelectric dynamometer (2) and the lift stage (3). The QSD's interface is entirely mounted onto a piezoelectric dynamometer which records all the process forces. The tools peak high can be regulated by a lift stage, the basis of the QSD.

The different components of the QSD and its periphery are shown in Figure 1 and Figure 2 (a). The main component of the QSD itself is its housing. It includes all the elements needed for the operation of the device. The interface between the tool and the QSD is the tool holder. This part can be rotated around a supporting shaft like shown in Figure 2 (a) and (b), clamping the tool with a grub screw.

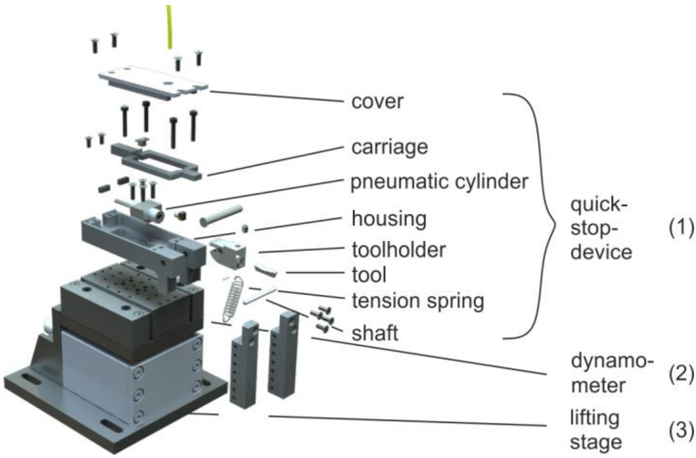

Figure 1: Exploded view

The QSD works by accelerating the tool towards the cutting direction, thereby interrupting the cut. The acceleration is provided by the abrupt release of a pre-loaded spring. A magnetic valve operates the release mechanism. This allows the integration of the QSD into the machine tool's control. The magnetic valve triggers a pneumatic cylinder which pushes the slide back, releasing the tool holder. The loaded spring then accelerates the tool holder downwards, hence eliminating its contact with the workpiece (Figure 2 (b)). The spring tension can be adjusted to provide different retreating speeds. For example the disengagement time for a cutting speed of 26 mm/s is about 30 µs with an acceleration of nearly 700 m/s^2. The sudden interruption of the cutting operation causes the chip formation process to "freeze", so that the chip remains stuck at the surface of the workpiece.

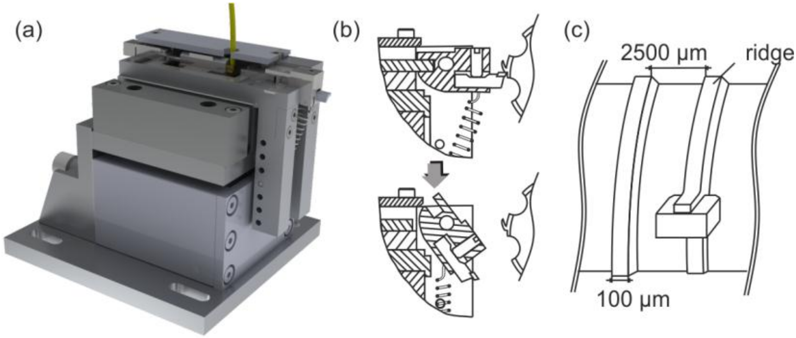

Figure 2: (a) Perspective view of the assembly (b) Details of the release mechanism (c) Process conditions in orthogonal cutting.

3. Functionality

To test the functionality of the QSD, orthogonal cutting experiments were conducted using an ultra-precision turning lathe and diamond cutting tools to guarantee a small uncut chip thickness. A commercial pure titanium bar with a diameter of 50 mm was used as workpiece material. In a first step, ridges with a width of 100 µm were manufactured (Figure 2 (c)) to test the QSD. In Figure 3 two results of quick-stop-tests (QST) are presented. On the left side a QST with an undeformed chip thickness of 10 µm is shown and on the right a QST with an undeformed chip thickness of 1 µm. The cutting speed of each test was 26 mm/s. The chip is still connected to the workpiece, enabling the measurement of several geometrical parameters such as the chip thickness or the radius of the curvature. The geometric features available for example in second electron microscope images (Figure 3) contribute to the understanding of the chip formation process because, apart from elastic deformations, they are assumed to be similar during the in situ process.

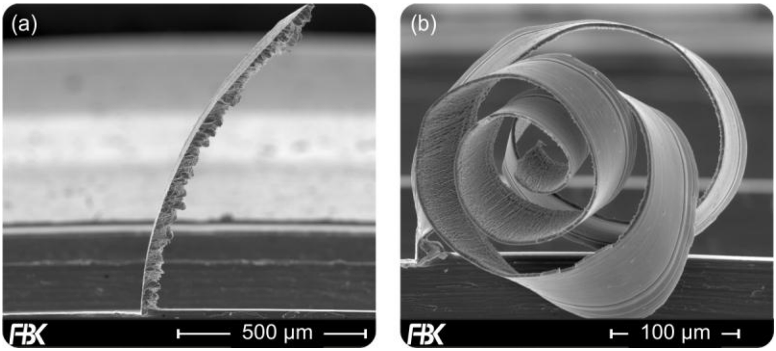

Figure 3: (a) QST with an undeformed chip thickness h = 10 µm and (b) an undeformed chip thickness h = 1 µm.

4. Conclusion and Outlook

In this paper, a new Quick-Stop-Device for the investigation of the chip formation process in micro- and nanomachining is presented. First, the individual components of the QSD are shown and then the trigger mechanism explained. Finally the functionality of the assembled equipment was experimentally validated by quick-stop tests in two different undeformed chip thicknesses.

Acknowledgement:

This research was funded by the German Science Foundation (DFG) within the Collaborative Research Center 926 "Microscale Morphology of Component Surfaces" MICOS.

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