Verification of the Square Foot Manufacturing Concept Through the Process of Micro Milling and Drilling with a Flexure Based Feed Unit

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Abstract

The need for micro parts and micro structured parts within the medical, aerospace, automotive and other industries has drastically increased over the last years. To meet the demand for an ecological, cost-saving and individual production with short innovation cycles, the Institute of Production Engineering at the Helmut-Schmidt-University has developed the concept of Square Foot Manufacturing (SFM). A Micro Machining Unit (MMU) consisting of a flexure based feed unit and a high-speed air bearing spindle is used to prove the practical usability and reliability of the SFM concept for chipping technologies. This contribution focuses on verifying the micro drilling and especially micro milling process taking cutting forces and oscillations into account and analyzing the resulting dimension and shape accuracy as well as surface quality.

1 Introduction to Square Foot Manufacturing

Ultra precision machines based on the concept of ordinary machining centres are being used within the industry to manufacture three-dimensional micro structures but are mostly uneconomical for small batch sizes. Therefore, the idea of SFM has been developed which represents an enhancement of desktop manufacturing concepts and emphasizes modularity and mutability [1]. The concept incorporates the idea of placing various MMUs on a surface area of one square foot. Those MMUs are characterized by minimal complexity, cost and space requirements. In addition, they are quickly interchangeable and several MMUs can share the workspace of a workpiece and operate simultaneously. By decreasing the size of those machines, new materials such as ceramics and hard metals as well as new technologies such as piezo actuators and monolithic joints can be implemented thus avoiding the drawbacks which occur by simply downscaling existing machining concepts [2]. To demonstrate the potentials of SFM, a MMU based on a monolithic flexure based feed unit has been developed [3]. For this study it is combined with a micro high-speed air bearing spindle [4] as shown in Figure 1b.

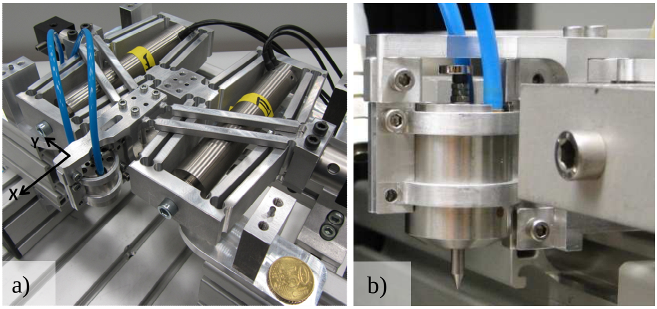

Figure 1: MMU consisting of flexure based feed unit [3] and air bearing spindle [4]

2 Experiments

Previous investigations at the institute have successfully proven the usability of a laser cutting tool combined with the existing flexure based feed unit as a MMU [3]. Now, this study is designed to evaluate the capability to drill holes and mill simple two-and-a-half-dimensional structures based on a strategic design of experiments. Compared to a force free laser machining process, the impact on the feed unit caused by counter- and cutting forces as well as oscillations have to be considered affecting the dimension and shape accuracy as well as surface quality of the final result.

Hard to machine titanium alloy TiAl6V4, a common material found in medical and aerospace appliances, is used as workpiece material. The high-speed air bearing spindle is equipped with single-edged tools which are actually part of the shaft to obtain a very high run-out accuracy [4]. Diameters of between 20 µm and 120 µm are utilized for this series of experiments.

3 Results and conclusion

Due to the shape of the cutting tool it is also possible to drill holes, which is considered a pre-experiment for the following milling process. All holes result in a slightly tapered shape with a conical structure at the bottom. Using a 120 µm tool the holes end up to be 8 to 12 µm bigger in diameter than the tool itself for 10 samples.

For a 42 µm tool the deviation is between 2 and 3 µm. It is believed that this results from the deflections and shape of the cutting tool. A satisfactory result in circularity is achieved. Therefore the general ability to drill micro holes with a MMU is proven and the transition to micro milling can be done.

The feed unit itself is capable of a diamond shaped workspace of approximately 1,900 µm in length (x-direction) and 800 µm in width (y-direction). It has to be examined if the whole area can be sufficiently machined. To acquire the best settings for the feed unit control and high-speed air bearing spindle a series of cross-shaped structures is milled as shown in Figure 2a. The results of 12 runs each showed a deviation for the width of groove of 0 to 6 µm for a 42 µm cutting tool and 0 to 17 µm for the 120 µm tool. The difference in length in x-direction is between 4 and 7 µm and in y-direction 11 to 17 µm regardless of the tool size. At this point it is not possible to determine how much of the deviation can be attributed solely to the feed unit or the spindle. All the results also showed a deflection of 2.0 to 2.5° for the line in y-direction which is assumed to be caused by manufacturing tolerances of the various monolithic joints of the feed unit which could also be responsible for the rather big length differences in y-direction. This finding also occurs when the outline of the complete workspace is milled as shown in Figure 2b.

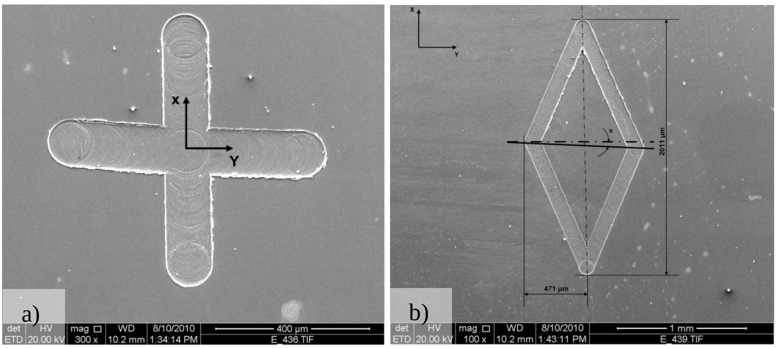

Figure 2: Milled cross-shaped structure and outline of the workspace using a 120 µm cutting tool (SEM)

Looking at the top corner of the milled outline of the workspace as pictured in Figure 3a consistent marks can be seen on the right hand side versus more irregular marks on the left hand side. Further tests can be conducted to enable a more even surface. Although the feathering of the edges is very low it is still significant compared to electrical discharge machining. A face milled surface area of 0.5 x 0.5 mm done with a 120 µm tool showed a roughness of R_a=0.110 µm and R_z=0.960 µm measured with a confocal microscope.

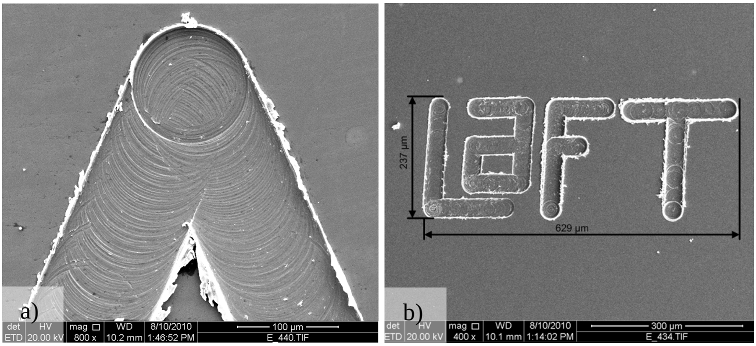

Figure 3: Top corner of the diamond shaped workspace milled with a 120 µm tool; logo of the institute done with a 20 µm tool (SEM)

To emphasize the potentials for micro chipping, the logo of the institute has been machined with a 20 µm cutting tool. The result in Figure 3b underlines the capability to drill and mill titanium alloy with an acceptable precision shown throughout this study. Further research will focus on reducing deviations between the milled structrure and the tool shape caused by the feed unit and improving the manufacuring process of the monolithic joints to depict the given trajectory without any angular deflections.

References:

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