High precision flexure hinges – functional-based machining optimization

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Abstract

Micromanipulators can perform small movements with very high precision. Flexure hinges improve the accuracy in such devices through their friction and backlash free design. To ensure the exact motion of high precision variants, the realization of high shape accuracy and very good surface integrity is important for the production of the component. These high demands on the workpiece quality are given through the primary functional-based hinge design process. To achieve those quality characteristics refined machining processes, like Wire-EDM, are required. Within this work the possibilities and limitations in Wire-EDM machining of flexure hinges are investigated. The focus of the subsequent machining optimization is the realization of a precise and minimal damaged surface. The remaining tolerances are finally given back to the manufacturing-based hinge design optimization to reduce the impact on the hinge functionality.

1. Introduction

To improve the accuracy of positioning and assembling processes new designs of manipulators are necessary. An approach for achieving high precision manipulators is a layout of hinges without backlash and friction, like flexure hinges [1]. To ensure the high precision movement the hinge must be machined highly accurate, although every manufacturing process implies inaccuracies. Figure 1 shows examples of possible deviations for the machining process on a Wire-EDM (W-EDM) machine tool. Analyzes by Corves et al. [2] show, that imprecision in web thickness reduces the functionality of the hinge most, therefore minimizing this error is the main target.

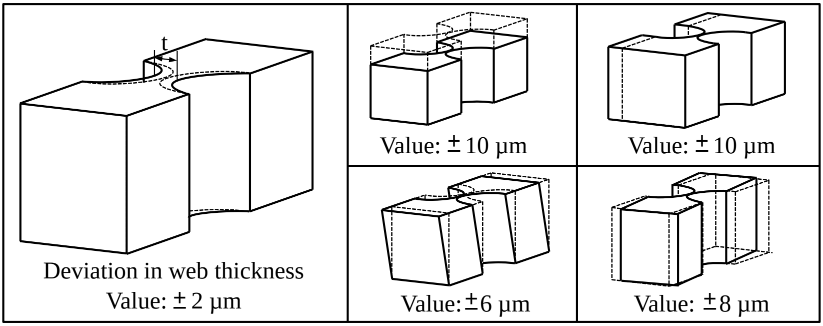

Figure 1: Possible deviations in machining flexure hinges on a W-EDM machine tool.

2. Preliminary investigation on machining accuracy of W-EDM

Figure 2 illustrates the setup for the shape accuracy analysis and the achieved contour accuracy after main and trim cuts during basic Wire-EDM machining (deionized water, high workpiece height). For analyzing the geometrical deviations in W-EDM operations, both sides of the pictured plate were machined. The first part of the plate (position 1-5) was just machined with a main cut on both sides. The last part (pos. 6-10) was machined with main- and all 4 trim cuts. The plate thickness was measured at every position with a micrometer-gauge, allowing identifying the shape errors.

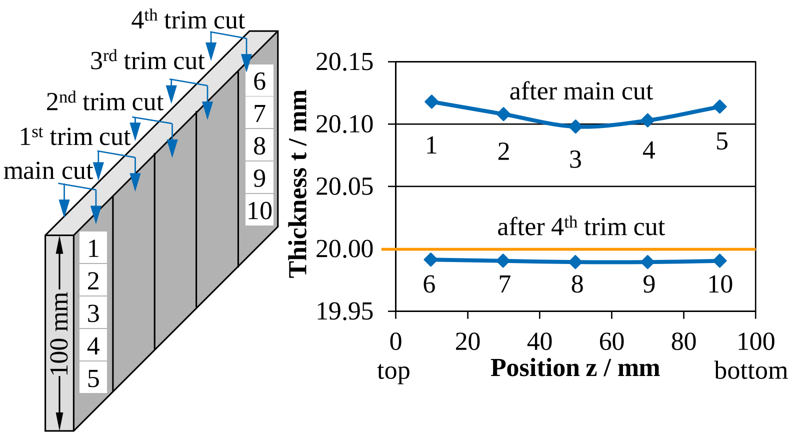

Figure 2: Reduction of the bulge error after main cut through trim cut operations

So the errors in the thickness correspond with two times the process inaccuracy. It is visible that after the main cut a significant bulge in the contour occurs. Although the main cut is very productive it is impossible to achieve the required accuracy. After four trim cuts the bulge is nearly completely reduced, but the thickness of the workpiece is Δt = 10 µm below the target contour of t = 20 mm due to variations in the discharge gap. This shows the necessity of a detailed process design for the machining of flexure hinges, like adapted offset compensations.

3. Manufacturing of flexure hinges using Wire-EDM

The hinges were manufactured on a Sodick AP200L machine tool. The machine is working with CH-based dielectrics, in this case the oelheld IonoFil OH 3567. The diameter of the uncoated brass wire is d = 0.2 mm. The main cut is followed by nine trim cuts to improve shape accuracy and surface integrity. The powder metallurgical cold work tool steel Vanadis 4 Extra (X140 CrMoV5-4-4 PM) was selected as workpiece material, because this tool steel combines high strength with good ductility. Therefore no special heat treatment took place. The hinge blanks were machined previously to the analyzed process. Figure 3 a) illustrates how the flexure hinge is positioned inside the W-EDM machine tool.

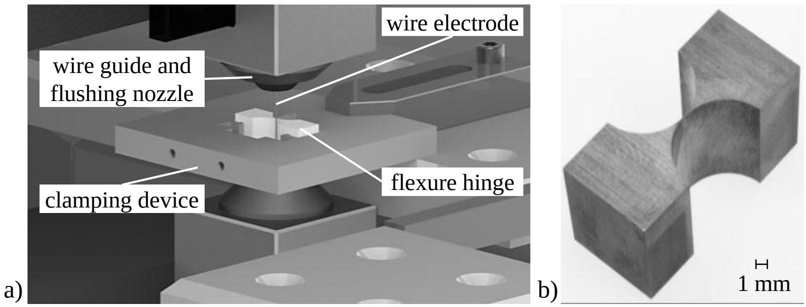

Figure 3: a) Flexure hinge in the clamping device attached to the machine tool
b) Machined flexure hinge with a minimal web thickness of t = 40 µm

Possible movement of the hinge during the machining would highly reduce the accuracy of the geometry, especially the web thickness. Therefor and due to the forces of flushing and discharges it is necessary to fix the blank properly, by fixing both ends while machining it on the W-EDM machine tool. The locating surfaces of the clamping device are machined very precise. Thus the hinge could be positioned with high accuracy in the device. To cut the geometry at the right spot of the workpiece it was measured using the auto touch function of the W-EDM machine tool. By cutting both notch geometries without reclamping, the internal error between the notches is minimized and the accuracy is close to the machine accuracy. Fundamental analyses on the effects of the machining parameters on the hinge behavior have been conducted. Finally in Fig. 3 b) a finished hinge with a web tolerance below $\Delta t = 2$ µm and a surface roughness below Ra = 0.09 µm is shown.

4. Conclusion

Through optimizations in the machining design the very crucial deviation of the web thickness was reduced to the range of the value of the machine accuracy. The other deviations are allowed to be higher, especially the deviations in height and width. The discovered geometry errors can be used for an improved hinge design process. The designer could take the quantified inaccuracies into account and get the chance to minimize the effect on the hinge functionality. In future also the thickness and condition of the heat affected zone [3] could be implemented in the hinge design process [4] to improve the precision of the flexure hinge.

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