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A linear and lifting stage on basis of compliant mechanisms for the realisation of a correction mechanism in a machine tool to perform micro deep hole drills in a round stock

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Abstract
This paper demonstrates with examples of a linear and a lifting stage the complex design process of planar compliant mechanisms with flexure hinges. For the realisation of a correction mechanism in a machine tool to perform micro deep hole drills in a round stock a linear and a lifting stage each with a travel range of 0-400 µm has to be developed. Due to costs and complexity the mechanism was manufactured by conventional machining without wire electric discharge machining (EDM). In this paper the development process and the manufacturing process of the mechanisms are proposed and discussed.

Keywords: Micro Manufacturing, Compliant Mechanism, Flexure Hinge, Micro Deep Hole Drilling

1. Introduction

Machining of micro parts is very demanding in terms of accuracy and precision of tools and machine components. In particular, high standards apply for movement axes in micro machines. In comparison to a conventional axis with a motor and gear, an axis based on compliant mechanisms powered by a piezo electric stack actuator has several advantages. Piezo actuators excel in high accuracy, stiffness and output force. However, the maximum stroke of piezoelectric actuators is very limited. Therefore, the compliant mechanism is used as an amplifier to elongate the working range of the piezo stack actuator. In operation of these axes there is no attrition, friction or backlash and in addition no lubrication is needed. Thus, the service in micro manufacturing and if needed under cleanroom conditions are predestined [1].

In this paper the process of designing and manufacturing a linear and a lifting stage that base on compliant mechanisms is proposed. Therefore the application is characterised. Then the used methodology of the design process is shortly presented. This leads to the derived designs of the stages.

2. Application

The intention is to set up a machine tool which is capable of performing axial micro deep hole drilling in a transparent PMMA (polymethylmethacrylate) round stock with varied diameters. The desired diameters of the drills are in the range of 200-500 µm with a targeted depth of 10 mm which leads to high aspect ratios of hole depth to diameter up to 50. Round stock with diameters of 365-750 µm result in small wall thicknesses. Due to the drift of the drill bit in the material a correction mechanism is needed to achieve a proper drill path. For this mechanism the proposed linear and lifting stage of this paper were designed which both require travel ranges of 0-400 µm and a resolution of 0.5 µm [2]. The completed machine tool with the included stages is illustrated in Fig. 1.

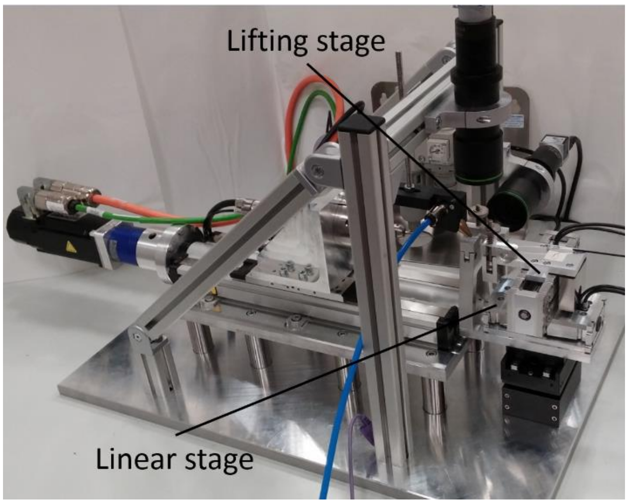

Figure 1. Micro Deep Hole Drilling Machine.

3. Methodology

The approach is divided into five steps. In the initial problem definition step the restrictions and specifications for the compliant mechanism with respect to the application are gathered and analysed. On that basis the objectives of the feed units are derived in the specification step. Here, the constraints resulting from the overall machine design are considered. Subsequently in the design step the feed units are designed. In the evaluation step a comprehensive FEM-simulation is carried out which is formulated by the Taguchi Method. Afterwards a step for a redesign and optimisation is executed. Then the finished design is manufactured.

4. Design and Manufacturing

Resulting from the overall machine design (Fig. 1) a compact design and compatibility between the units are needed. Thus, the initial design of both stages is a simple lever mechanism with circular hinges (Fig. 2). Here the small input and larger output displacements are depicted. To minimise complexity both stages work in a similar way using the same mechanism.

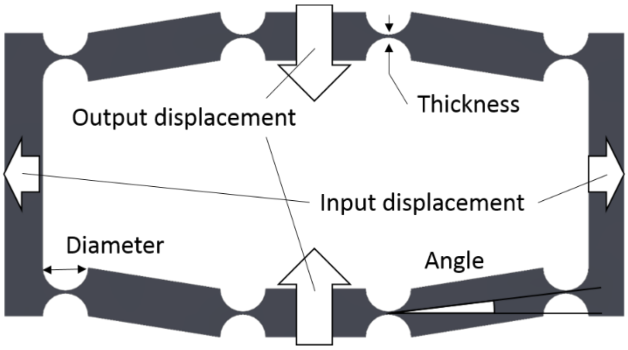

Figure 2. Initial lever design.

To optimise the given mechanism FEM-Simulations are executed by using the Taguchi Method [3]. The input parameters are the diameter of the circular hinges, the remaining thickness of the material at the thinnest point and the angle between the line through the centres of the joints and the horizontal. The output variables are the output displacement and the force to be applied at the input, which is decisive for the choice of a suitable piezo actuator. Considering the stability of the mechanism and the available tools for manufacturing the diameter is chosen as 5 mm, the thickness as 0.3 mm and the angle as 3.93°. This leads to an output displacement of 570 µm with an input of 40 µm. Thus, an amplification of 14.25 is achieved. The force to be applied at the input is 147 N. The chosen piezo actuator provided a needed resolution of 1.2 nm and input force of 2000 N.

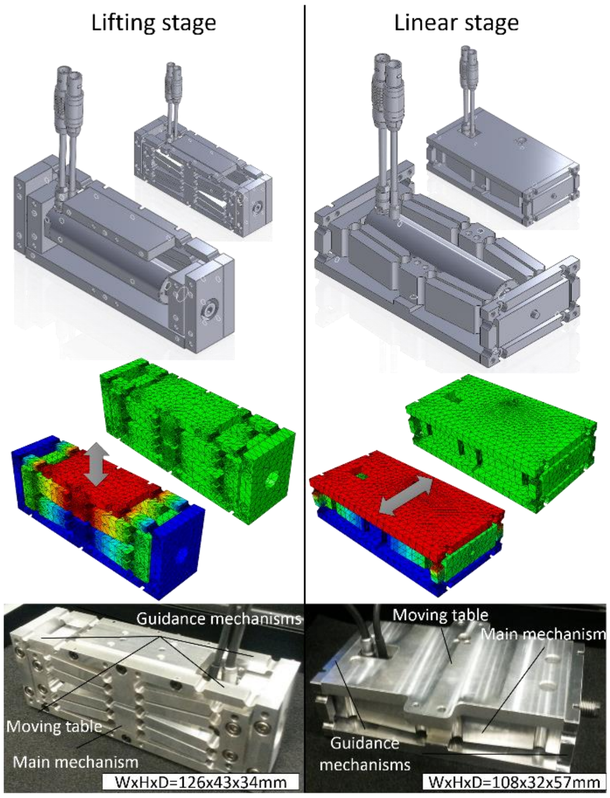

Figure 3. Lifting Stage and linear stage.

In Fig. 3 the lifting stage and the linear stage are shown. In each case a cutaway CAD-model is depicted where the included piezo actuator can be observed. Furthermore a meshed FEM-model is shown where areas of displacement can be obtained in the corresponding direction of movement.

For stabilisation the lifting stage is realised by duplicating the mechanism. Besides the mechanism is inversed in the lifting stage. Furthermore in both stages guides by compliant mechanisms are installed to prevent the shift of the output in undesired directions.

Typically planar compliant mechanisms are manufactured by wire electric discharge machining [4]. In this case it is manufactured by using a precision milling machine. The material is the high-strength aluminium alloy Hokotol.

5. Results

The achieved drilling results of the developed machine tool meet the given requirements. A drilled fibre can be seen in Fig. 4. Detailed information about the overall setting of the machine tool and the corresponding correction mechanism can be looked up in [5].

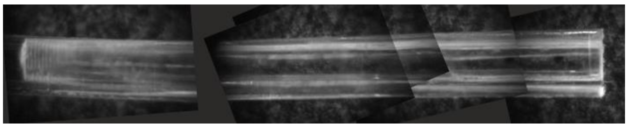

Figure 4. Drilled fibre.

6. Summary and Future Work

This paper proposes the development of a lifting stage and a linear stage for an application of micro manufacturing. It is shown how the design process is executed and a resulting drilled fibre is presented.

For further research a measuring set up is designed and the stages are extensively tested in their travel ranges and compliance properties.

Acknowledgment

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References

[1] Kong N, Sanders A and Wulfsberg J P 2015 On the Design Methodology of Flexure-Based Compliant Mechanisms by Utilizing Pseudo-Rigid-Body Models with 3-DOF Joints *Proceedings of the 14th IFToMM World Congress* Taipei

[2] Sanders A and Wulfsberg J P 2015 Concept of a correction mechanism to prevent the drift of a drill bit for micro deep hole drilling *Proceedings of the 15th euspen International Conference* Leuven 329-330

[3] Klein B 2014 Versuchsplanung-DoE: Einführung in die Taguchi/Shainin-Methodik *Oldenbourg Verl. München*

[4] Choi K B and Lee J J 2008 Analysis and design of linear parallel compliant stage for ultra-precision motion based on 4-PP flexural joint mechanism *International Conference on Smart Manufacturing Application* 35-38

[5] Sanders A, Wulfsberg J P 2016 Micro Deep Hole Drilling Machine with an integrated Correction Mechanism *Proceedings of the 11th International Conference on Micro Manufacturing* Irvine