Flexure Based Feed Unit – A Progress Report

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Abstract

A flexure based feed unit actuated by piezo actuators is a promising concept for positioning tasks with high precision and accuracy. Manufacturing and assembly errors can cause large deviations between the simulated and real behaviour of such mechanism. This paper presents a test bench for the characterisation of the feed unit. Its results are used for the calibration of an open-loop control.

1 Introduction

During the euspen conference last year a small machine tool for laser marking and micro milling, called Micro Machining Unit for micro production, was presented [1] Its development is based on the Square Foot Manufacturing concept of modular, ad-hoc configurable and function integrated small modules. One such module – a flexure based feed unit – has been developed by the Institute of Production Engineering at the Helmut-Schmidt-University (Figure 1). The monolithic structure of the mechanism combined with piezo stack actuators allows not only a compact configuration, but also excels in high precision.

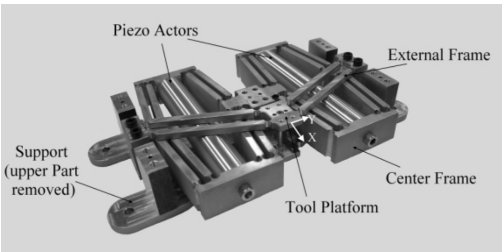


Figure 1: Flexure based feed unit [1]

Due to the high requirements of micro parts, static and dynamic accuracy in a range of one to several micrometers is needed. This requirement can be met by using flexure hinges which, for example, avoid the positioning error of the commonly used sliding guideways for machine tools. However, machining imperfections [2], assembly errors and inhomogeneous material can cause big deviations between real behavior and simulated behavior. In this paper the movement of the end effector is quantified and its consequences for the control of the feed unit are discussed.

2 Experimental Setup

Due to the complex structure of the compliant mechanism the measurement of the movement at every flexible joint requires great effort. Yet, the essential characteristics of the feed unit are the displacements of the end effector and the applied voltages for the piezo actuators. In order to determine the kinematic behavior a laser interferometer is used as the measurement system whose collimators are positioned around the end effector (Figure 2). With this setup the planar movements of the feed unit – the displacements along the x-axis and y-axis as well as the rotation about the z-axis - can be quantified. It is obvious that such parasitic errors as the rotation about the y-axis can influence the measured data. To compensate for this, two additional collimators are added which are also used as a comparison. In the shown experimental setup the measurement uncertainty is estimated in the range of ±10 nm. To avoid dynamic influences the sinusoidal control signal with a frequency of 0.0125 Hz was chosen for the voltage of the actuators.

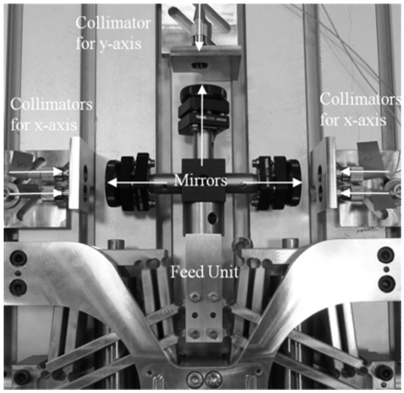
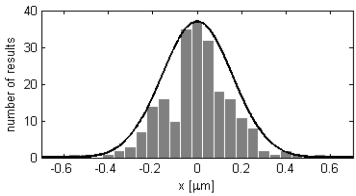


Figure 2: measurement system with laser interferometer

3 Measurement Results

3.1 Repeatability

Because of the elastic deformation of the material and the high accuracy of the piezo actuators themselves a repeatability of 0.36 μm for the y-axis and 0.16 μm for the x-axis is achieved. A possible reason for the higher accuracy of the x-axis can be the smaller gain between the displacements of the actuators and the end effector along the x-axis which also amplifies the position errors of the actuators. Due to the parallel structure of the mechanism the rotation error around the z-axis is minimized to 0.0029°.



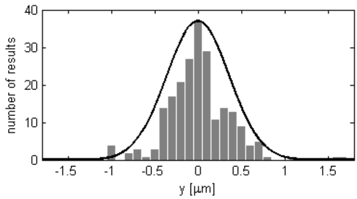


Figure 3: Repeatability along x-axis and y-axis

3.2 Working Space and Calibration

According to the finite element simulation the working area of the feed unit has a planar rhombic form with 2302.7 µm length and 1015.9 µm width, when the piezo actuators are fully deflected (Figure 4). The size of the measured working space is not only smaller than the simulated working space, but the orientation of its principal axis also differs from the y-axis by 2.58°. One way of compensating for this rotation error is by aligning the complete feed unit to the work piece, which requires high manual effort. Another method is to change the shape of working space to a deltoid whose axis of symmetry is along the y-axis. Consequently, the length and the width are reduced to 1769.4 µm and 845.5 µm.

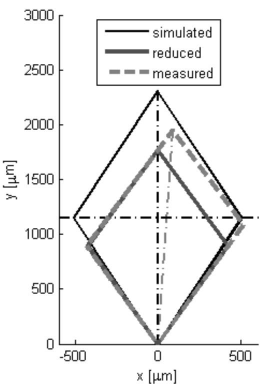


Figure 4: working area of the feed unit

An almost linear relationship between the applied voltages u_1 and u_2 of the two piezo actuators and the displacement of the end effector can then be verified. This allows the following linear model for the feed unit which is used for the calibration of the control:

$$x = k_{1x}u_1 + k_{2x}u_2; \qquad y = k_{1y}u_1 + k_{2y}u_2.$$

The factors k can also be interpreted as the stiffness of the left and right half of the mechanism.

The deviation between the desired form of a deltoid with 1770 µm length and 840 µm width and the path of the feed unit is shown in Figure 5. The positioning error within the working space is provoked by parasitic movements around the x-axis and y-axis of the center and external frame. This error is dependent the deformation of the left and right side of the mechanism. In this case the factors k would be a function of the current position of the end effector.

$$x = k_{1x}(x,y)u_1 + k_{2x}(x,y)u_2; \qquad y = k_{1y}(x,y)u_1 + k_{2y}(x,y)u_2.$$

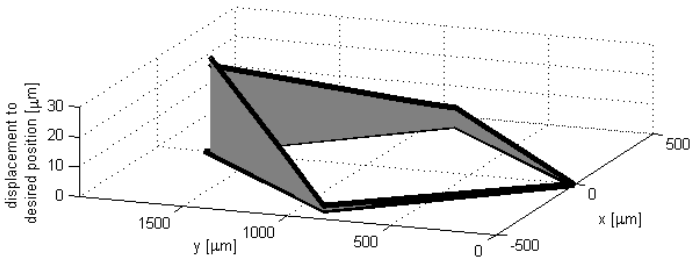


Figure 5: positioning error in x-y-plane for a deltoid with 1770 µm length and 840 µm width

4 Conclusion and Outlook

In this paper it was shown that a high precision for positioning the end effector can be achieved by resorting to a flexure based mechanism in combination with piezo actuators. A linear model for the mechanism is the first attempt for the calibration of an open-loop control. Its accuracy is influenced by the structure of the mechanism and its compliancy. For the further improvement of the accuracy a non-linear model is needed for a more accurate characterization of the displacement at the end effector. Another method is to maintain the linear model and extend the current open-loop control to a robust closed-loop control for which a direct measurement system will be designed.

References:

[1] Kohrs, P., Hoffmann, S., Wulfsberg, J.P., Implementation of a flexure based feed unit for the Square Foot Manufacturing Concept; Proceedings of euspen International Conference – Delft – June 2010

[2] Ryu, J.F., Gweon, D.-G., Error analysis of a flexure hinge mechanism induced by machining imperfection; Precision engineering 21, 83-89, 1997