Flexure Based Feed Unit for Long Feed Ranges: Concept and Design

N. Kong, S. Grimske, B. Röhlig, J.P. Wulfsberg
Helmut-Schmidt-University, University of the Federal Armed Forces Hamburg, Germany

nanxi.kong@hsu-hh.de

Abstract

In this paper a novel flexure based feed unit with large and planar feed motion ranges for small cutting machine tools is presented. It consists of a compliant mechanism, driven by piezo stack actuators, which are able to perform high forces and high resolution in their displacements. Manufacturing and assembly errors can still cause parasitic motions like as the displacement orthogonally to the motion plane or rotary motion. This errors cannot be corrected by the given piezo stack actuators. Therefore, a planar ball guide is proposed as a support for the motion of the tool platform.

1 Introduction

Compliant mechanisms with flexure hinges are often used as manipulators with high degree of precision and accuracy [1]. With a monolithic structure and by deforming elastically negative effects such as backlash, friction and wear can be avoided compared to conventional bearings [2]. Consequently, compliant mechanisms driven by piezo actuators are capable of ultra-precise motion with high dynamic and high resolution. Due to the small motion ranges of the piezo stack actuators the compliant mechanism not only transmits the displacement of the actuators to the end-effector, but also amplifies it to extend the working area.

Although the sizes of micro parts are decreasing, they are still in range of several millimeters. The micro parts are often machined by micro milling, micro boring or micro turning. Therefore, a compliant mechanism with high stiffness and long ranges is designed to meet the demands of micro production.

2 Design of the flexure based feed unit

Based on a previous design of a bell crank lever for a flexure based feed unit [3] a compact design of a compliant mechanism is achieved by combining serial and parallel flexure systems to hybrid flexure systems. Parallel kinematics may reduce parasitic rotation errors. By stacking the parallel flexure systems in series longer ranges and more degrees of freedom are possible.

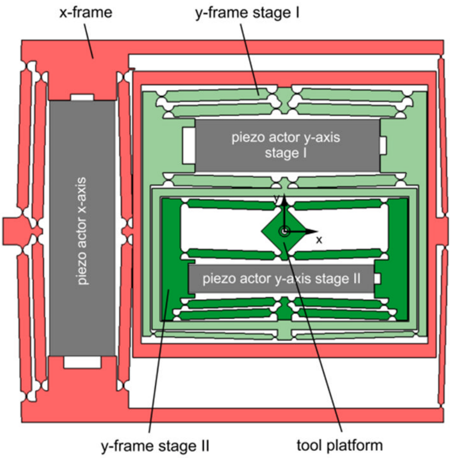


Figure 1: Layout of the feed unit

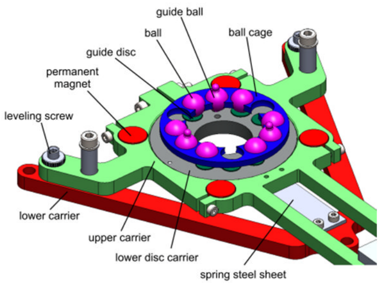
Figure 1 shows a first preliminary design of the monolithic compliant mechanism, which can be divided in three frames. Due to the smaller available space the motion in y-axis is realized by two frames which are connected serial to each other. The motion in x-axis can be provided by one frame. Consequently, the movements along the x-axis and y-axis are independent to each other. Circular notch hinges are used as flexure hinges to avoid additional eigenmodes in case of leaf hinges and to maintain a small displacement of the center of rotation between each rigid body [4]. Consequently, a high mechanical stress is expected for circular flexure hinges, which restrains the maximal range of the compliant mechanism. Therefore, materials with high ratio between yield stress and Young's modulus like AW 2024, AW 7075 or HOKOTOL etc. are preferred.

Machining processes can cause relatively high cutting forces, which lead to the deformation of the compliant mechanism. Beside the geometry and the number of the flexure hinges the piezo stack actuators are the essential parts, which can increase the stiffness of the feed unit. By implementing preloaded piezo stack actuators the compliant mechanism can also be assembled with compression force. According to finite-element-simulations this measure expands the available working area up to 5.15 mm along the x-axis and 3.68 mm along the y-axis even with static loads of 20 N in x- and y-directions at the tool platform.

3 Planar ball guide

Parasitic motion is a common problem for compliant mechanism. A few of the parasitic displacements may be eliminated by the parallel and symmetrical structure of the mechanism. However, some parasitic effects like the displacement orthogonally to the motion plane or rotary motion cannot be corrected by the given piezo stack actuators. Therefore, a planar ball guide is implemented as a support for the motion of the tool platform in three degrees of freedom. Different to planar air bearings and linear bearings systems, which are arranged orthogonal to each other a ball guide shows a higher rigidity as well as a more compact design [5].

a) b)



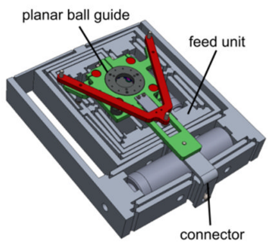


Figure 2: a) Design of the planar ball guide; b) assembled feed unit

The design of the planer ball guide is shown in Figure 2 a). Six ceramic balls with two guide discs each are used to set the guide plain for the motion of the tool platform. Three guide balls and the ball cage keeps the ball between their discs. Furthermore, four permanent magnets provide the necessary preload of 378 N to enable the contact of the balls to their discs and increase the rigidity of the ball guide. In the current design a stiffness of 200 N/mm may be achieved.

The lower carrier is fixed on base frame of the feed unit. The adjustment of the feed unit with the planar ball guide to the work piece is accomplished by two leveling screws between the lower and upper carries. Both carries are connected by a spring steel sheet to each other. As seen in Figure 2 b) the position of compliant mechanism is fixed to the upper carrier by the connector. Finally, the tool platform is fixed to the upper disc carrier (Figure 3), which can be moved with respect to the lower disc carrier.

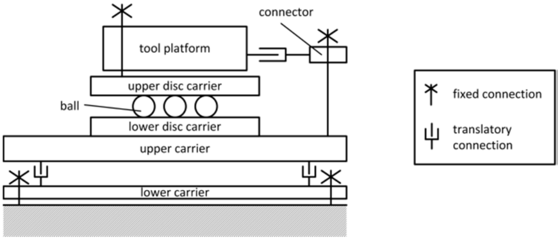


Figure 3: Schematic setup of the feed unit

4 Summary and Outlook

This paper described a flexure based feed unit, which can achieve a large planar working area. Further developments will be made to widen the working ranges even further. A promising approach is the application of parabolic flexure hinges.

The design of the planar ball guide was provided analytically. Its feasibility will be proven experimentally. The following research will be focus on the influence of the friction forces.

Acknowledgements

Research funded by the German Research Foundation.

References:

[1] Dunning, A.G., Tolou, N. and Herder, J.L., Review Article: Inventory of platforms towards the design of a statically balanced six degrees of freedom compliant precision stage, Mechanical Sciences., 2, 157–168, 2011.

[2] Howell, L., Compliant Mechanisms, Wiley-Interscience, New York, USA, 2011.

[3] 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.

[4] Dirksen, F., Lammering, R., On Mechanical Properties of Planar Flexure Hinges of Compliant Mechanisms, Mechanical Sciences, 2, 109-117, 2011.

[5] Heyne, M., Erbe, T. and Theska, R., Concept of high precision ball guideway with three DOFs, Proceedings of 15th International Conference – Kaunas – 2010.