Compact XYC-table fluid planar drive system for micro milling

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Abstract

In this paper, a compact XYC-table design for manufacturing of micro parts is presented. The drive principle is based on the selective control of different air nozzles, whose fluid jets generate feed forces for planar motion. In combination with an aerostatic contactless guide and the according control system, very precise motion with a positioning accuracy up to 270 nm and feed forces up to 1 N were achieved in an experimental test setup. Further investigations demonstrate the extension of the current system by an additional rotational degree of freedom in order to enable more complex milling operations.

1. Introduction

Currently for manufacturing of small workpieces with edge lengths in the range of a few micrometres to a few millimetres typically conventional, while precise, machine tools are used. As they are usually equipped with conventional drive and guide systems, they have not only disadvantageous workpiece to machine size ratios, but also are less energy efficient. Therefore, an innovative new XYC-table design for the application in desktop machine tools is presented in this paper.

2. Fluidic drive and guide principle

In the past a fluidic XY-drive was developed [1]. The system mainly consists of a slide on the top and a machine frame on the bottom (Fig 1a). Pressurized air is streaming out of three vertical nozzles arranged at the frame. Thrust forces on the slide are generated by deflecting these air jets at defined triangle profiles on the slide. A commutation algorithm for the drive nozzle units, consisting of three nozzles, was implemented and allows defined movements in both directions. Since the commutation algorithm takes yawing into account, it is already possible to program defined yaw angles up to ± 15° in the centre position with the existing XY-table design. With the realised design, thrust forces up to 1 N at a flow rate of 170 l/min at 6 bar supply pressure could be provided in both directions. The work area is 15 x 15 mm² with an overall size of 100 x 100 mm².

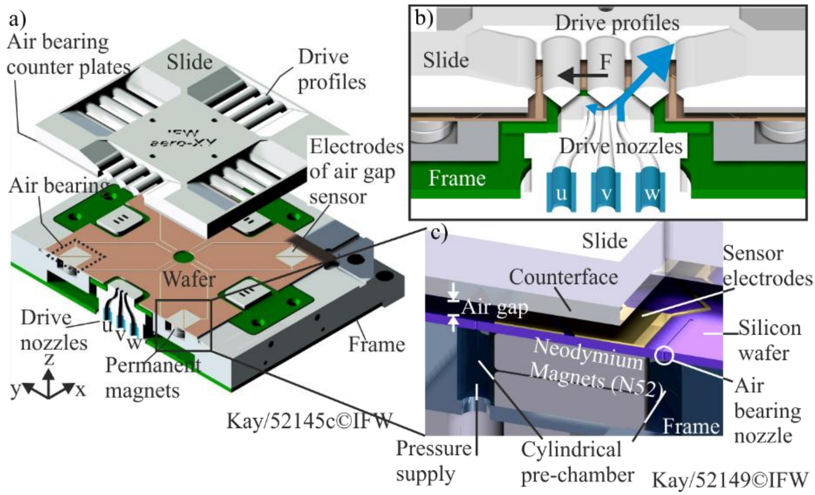

Figure 1: XY-table setup (a) with drive (b) and guide (c) principle

Air bearings for the active guidance of the slide are located in the corners of the system. Due to prestressing with permanent magnets, high static stiffness is achieved. A ceramic waver combines the air nozzles for the bearings and the gap measuring system. The measurement system is based on the capacitive principle, where the electrodes are directly sputtered on the waver surface. For the counter face, segments of electrical sheets have been mounted on the slide. In the air gap range between 0 and 25 µm, the noise of the measurement system is below 200 nm whereby a very high precision can be provided [1]. In order to investigate the suitability of the fluidic XY-table in micro milling operations, it was used as a workpiece table. A high speed spindle was used to enable appropriate cutting speeds with a tool diameter of 0.5 mm. A feed per tooth of 10 µm/tooth and a cutting depth of 5 µm have been chosen. Apart from the tilted alignment of the workpiece, the experiments showed good results.

3. Extension of the system by an additional degree of freedom

To increase the functional integration and to enable more complex milling operations, the XY-table is extended by a rotational degree of freedom. Although slight rotations are possible with the current XY-table, design modifications are necessary to enable complete 360° rotations at any planar table position.

In order to maximize the thrust force, the angle of the triangle profiles was fixed to 45° (Fig 2a) and the space between two profiles was set according to analytical models and computational fluid dynamic (CFD) simulation results [2]. Additionally the circular slide diameter was limited to 120 mm to achieve a compact design.

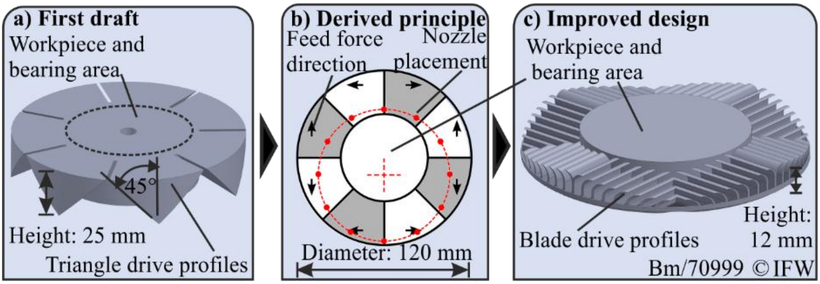

Figure 2: Extended XYC-table design

A number of dependencies determines the necessary number of drive nozzles to ensure feed forces in every slide position. On the one hand, an increasing number of drive profiles leads to an increasing amount of drive nozzles. For cost reasons, the number of drive nozzles should not exceed twelve. With this specification, seven triangular drive profiles represent the maximum number of profiles. On the other hand, a decreasing number of drive profiles leads to an increasing slide height, which limits the minimum number of triangular drive profiles. However even with a number of seven drive profiles, the height of the profile exceeds 25 mm (Fig 3b).

In order to improve the performance of the design, four triangle profiles were assumed. The derived principle (Fig 2b) has been kept and the triangle profiles were replaced by a number of blade profiles (Fig 2c), forming four arrays. CFD analyses of the system show good results for the new profiles and a calculated thrust force up to 1.4 N at a pressure of 6 bar (Fig 3c). The blade profile geometry was optimized by CFD simulations concerning shape and distance between the profiles in order to get maximum thrust forces and low force ripples during slide movements. For an optimal air flow, the profile height was arranged staggered.

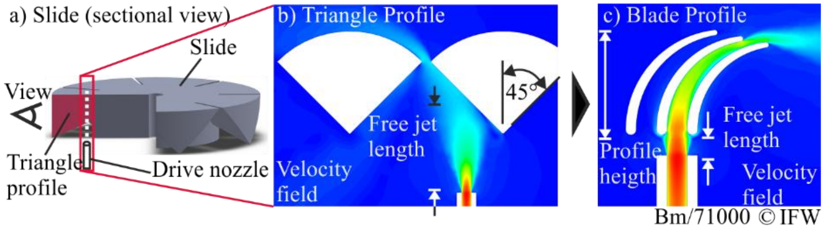

Figure 3: Numerically calculated fluid velocity fields

The improved blade design reduces the height of the slide by 50 % and allows a simpler control compared to the triangle design.

4. Conclusion and Outlook

In the first part a functional compact planar drive system suitable for low force micro milling operations was shown and verified in an experimental test setup. In the second part an extended design was presented, which enables 360° rotations. Due to new improved drive profiles, the extended concept allows to keep a very compact design even with a limited number of drive nozzles. Further studies will concern the construction and testing of the new designed XYC-table and investigations will be extended to operations with liquid media. Finally, the system will be used with other modules for assembly of reconfigurable desktop machine tools [3].

Acknowledgements

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