Design, set-up and test of completely levitating contactless micro-milling machine linear axis.

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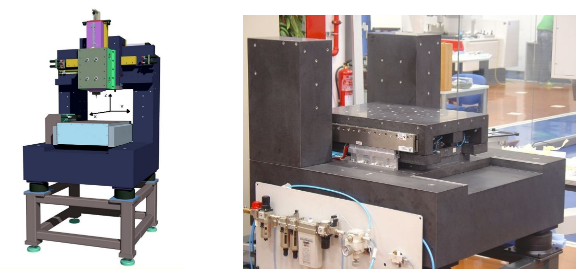
Abstract

Dry friction is a primary source of non-linearity in mechanisms, mainly the well known "stick slip" effect related with static and dynamic friction coefficients. On the other hand, the resolution of optical linear scales or laser interferometers has been increased in the last years due to the improvement of processing methods and electronic treatment of signals, and sometimes mechanics are hindering the possibility to obtain better performances in micromanufacturing tasks. Repeatability and precision of axes are nowadays constrained in great extent by-non linearities introduced by thermal effects, actuators, guideways or peripheral equipment such as bellows or wires. In this paper, a new concept of linear axis is presented, in which there is not physical contact between machine base and moving slide, developed to be installed as the working table of a vertical spindle micro-milling machine, and therefore ready to work in quite an aggressive industrial environment. Working pieces are clamped to the table and vertical spindle is able to micromill the part in working volume of $240 \cdot 10^{-3}$m, $400 \cdot 10^{-3}$m and $200 \cdot 10^{-3}$m in the axes X, Y and Z respectively from the figure 1a.



a) b)

Figure 1: a) Final design of ultraprecision micromilling machine. b) Picture of ultraprecision axis assembled in micromilling bed.

The structural parts of this ultraprecision axis are made of South African "Belfast-Black" granite, all guides are aerostatic and two cogging free linear motors have been installed in order to avoid yaw. Control loop is closed with an optical linear scale with 10·nm resolution in the 240·mm travel length of the mechanism. The results of the validation tests carried out in this prototype are presented in the paper, together with aspects dealing with the design of guiding systems and integration of linear scales in different machine configurations, moreover main issues in manufacturing and set-up of ultraprecision milling machines.

1 Design of the ultraprecision axis

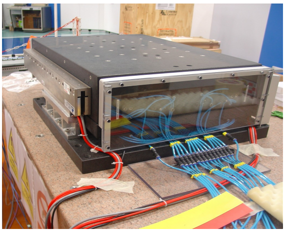


Figure 2: Test bench of axis.

The configuration of the X axis has been designed in order to obtain excellent dynamic accuracy and minimum incremental move. Two motors and two linear encoders are positioned symmetrically and assure the alignment of the actuation to the centre of gravity and the feed back system, which will eliminate tilting, rolling and yawing moments. All active elements such as reading heads, linear motor primary and air bearings are placed at the base of the stage and no bellows or telescopic guards are used in this axis. This makes that no contact is produced between the moving slide and the base: the table of the machine is fully suspended in air.

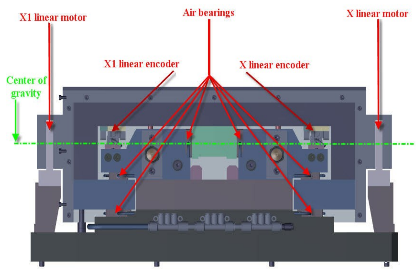


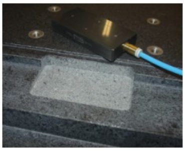
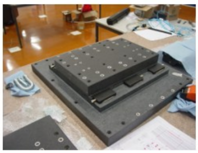
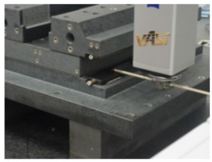
Figure 3: Configuration of axis

The big force that motors can provide allows achieving high dynamics in this axis. Acceleration up to nearly 3g is achievable and, since no contact is produced between moving slide and basement, the speed is only limited by the stroke of the axis and the linear encoder. In extreme conditions, 240m/min can be achieved in 240mm.

2 Assembly procedure

In this prototype a stiff link has been designed, by gluing the pads to the stone directly[1,2]. This makes of course the assembly much more critical and risky but, on the other hand, avoids maintenance to a great extent and improve the stiffness of the guiding system. The procedure to glue the pads in correct tight geometrical tolerances is based on using the counterparts as references to position the bearings. The desired gap between air bearings is obtained by means of precision gauges. This procedure is explained in next sequence.

Table 1: Procedure for gluing air bearings in a correct geometrical position.

 Cavities prepared	 Air bearings in place	 Sticked by vacuum
 Glue applied in cavities	 Bearings glued	 Measuring of bearings

3 Verification and results

3.1 Verification of positioning accuracy and repeatability of the axis

The aim of this verification is to measure the positioning accuracy and repeatability of the linear displacement of the ultraprecision axis. It consists in two parts:

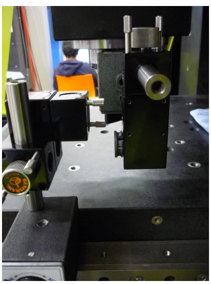


Figure 4: Interferometer and mirror disposal.

- Positioning from -100mm to 100mm in 10mm increments in both positive and negative directions in order to obtain the positioning accuracy to input the correction factor to the CNC.
- Verification of the positioning accuracy and repeatability according to VDI 3441 standard.

3.2 Results

Table 2: Obtained results.

Axis	**X** Measured length	**P** Positioning precision	**Pa** Positioning deviation	**Ps** Positioning repeatibility	$\mathbf{U_m}$ Average backlash error
X	200 mm	1.123 µm	0.360 µm	0.893 µm	0.136 µm

4 Conclusions

The axis has been designed with two principles: alignment of actuation, feed-back and mass, and to completely eliminate non-linearities. The results quoted above have been obtained after applying the correction parameters to the CNC. After the correction, the positioning average error and the backlash error have values around 0.1 µm. The positioning error P is 1.1 µm in the whole displacement. The main component of the total repeatability error reaches a maximum value of 0.89 µm, with an average error of 0.64 µm. The results don't change with positioning speed, the tests have been carried out at 20, 30, 40, 50% of the maximum speed and no considerable changes have been measured.

The configuration of the axis of the milling machine allows testing different possibilities. The axis is equipped with two linear encoders and two actuators in order to try gantry or tandem strategies in order to reduce dynamic errors in the whole working range and different payloads. But it can perfectly work with one single axis, with one motor and the corresponding encoder, or with two motors and the linear encoder at different positions as shown in figure 3. they can be mounted in both sides or in the center. It gives the opportunity to test all these configuration.

References

[1] Slocum A, Basaran M, Cortesi R, Anastasios JH, Linear Motion Carriage with Aerostatic Bearings Preloaded by Inclined Iron Core Linear Electric Motor, Precision Engineering 27 (2003) 382–394

[2] Cortesy R, An Easy to Manufacture Non-Contact Precision Linear Motion System And Its Applications, Doctoral Thesis presented in Department of Mechanical Engineering at the Massachusetts Institute of Technology