First Results of an Interferometric Controlled Planar Positioning System for 100 mm with Zerodur Slider

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1 Introduction

Positioning systems with uncertainties in the nanometer range and travel ranges of 100 mm and higher - this is the ambition of many R&D institutes throughout the world. As a part of the SFB 622, the authors are researching the scientific foundations for "Nanopositioning- and Nanomeasuring Machines" [1]. The basic idea is to allow high-precision positioning of a zerodur reflector and measure the movement along all six axes using laser interferometers [2], [3]. A major challenge thereby is to achieve lateral positioning of the reflector throughout a large traversing range with reproducibility and uncertainty values in the nanometer range. The use of integrated direct drives here leads to significant advantages compared to conventional drive systems with stacked linear axes [4], [5]. Nevertheless for the operation of the laser interferometers there is always the need for a reflector that has the same lateral dimensions as the intended travel range. At travel ranges of 100 mm or higher this leads to high masses that have to be supported and accelerated by the drive system as well as to a high centre of gravity with respect to the plane where the drive forces act on the moving part. Moreover it is a challenge to achieve a stiff transfer behaviour from the point of action of the motor forces to the point where the position resp. the rotation is measured with the laser interferometers. In addition in the conventional approach the combination of different materials, the reflector made of zerodur and the slider made of aluminium, demands special attention for a statically determined support that allows different temperature induced elongations.

2 Planar positioning system

With this background a planar positioning system was designed where the moving part of the direct drive is made of zerodur and has zerodur reflectors bonded to it [6].

Thereby the slider of the integrated direct drive and the reflector for the laser interferometers are incorporated in only one moving body. On the one hand this enables a high stiffness in the actuation chain and on the other hand the problem of connecting different materials is reduced considerably. The planar positioning system is intended for a circular travel range of 100 mm in diameter. It consists of three linear drive units in a 120° arrangement that act simultaneously on the slider, who carries the permanent magnets and has the reflectors for the x-, y- laser interferometers bonded to it on the upper side (**Error! Reference source not found.**). The slider is supported on three vacuum preloaded air bearings to achieve a nearly frictionless movement in x and y together with a high stiffness in z-direction. The movement of the slider is controlled with the drive system in x, y and r_z and measured with a single beam (x) and a double beam (y, r_z) laser interferometer [7]. In addition the system is equipped with three capacitive probes. They provide an absolute measurement system for the determination of a reproducible reference position of the slider with respect to stator.

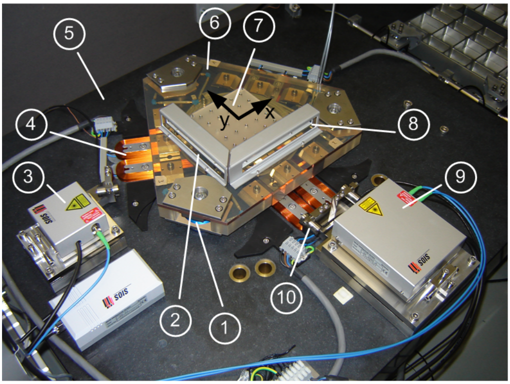

Figure 1 Planar Positiong System 1 air bearing

1	*air bearing*	*6*	*zerodur slider*
2	*x-reflector*	*7*	*object table*
3	*x-interferometer*	*8*	*y, r_z-reflector*
4	*drive coils*	*9*	*y, r_z-interferometer*
5	*granite base*	*10*	*capacitive probes*

2.1 Integrated direct drive

Each drive unit consists of a pair of flat coils mounted to the stator and corresponding magnet circuits on the slider. With the three drives it is possible to create a resulting horizontal driving force in any direction to control the x, y-position of the slider. In addition a torque can be generated for controlling the r_z rotation. In the current configuration the moving mass is 9.6 kg and there is a maximum driving force of 20 N. While the acceleration is limited to 150 mm/s^2 the maximum positioning velocity is 5 mm/s. The position of the slider is measured with laserinterferometers with a resolution of 0.1 nm. The control loop is closed by a dSpace DS1103 DSP-board where the control algorithm is implemented.

2.2 Aerostatic support of the slider

The three vacuum preloaded air bearings are vital to fully benefit from the integrated drive principle. They are mounted to the slider with fastening elements made of invar to reduce thermal stress. Depending on the supply pressure, the vacuum pressure and the load of the air bearings a certain air gap will appear when the slider is lifted. Figure 1 shows the measured lift-load curve of the slider at a supply pressure of p_s=4.1 bar and a variable vacuum pressure p_v to generate the varying bearing load. From these measurements the working point of the air bearings was set to p_s=4.1 bar, p_v=0.75 bar where the lift of the slider is approx. 4 µm. Based on the lift-load curve it is possible to calculate the stiffness of the air bearings in the working point, which is 22 N/µm in the described working point. The air bearing stiffness has a strong influence on the resonance frequencies of the assembled system. Figure 2 shows the result of a FEM-modal analysis of the slider, where the air bearings were modelled as elastic support with a varying stiffness. It can be seen that with an air bearing stiffness of 22 N/µm the lowest eigenfrequency of the slider is expected to be in the range of 380 Hz.

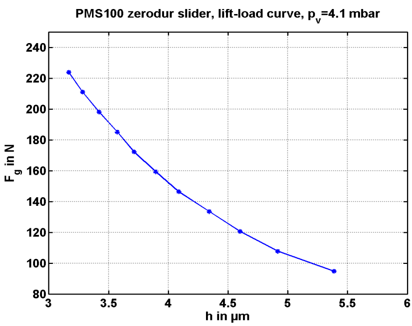

Figure 1 Measured lift-load curve of the slider

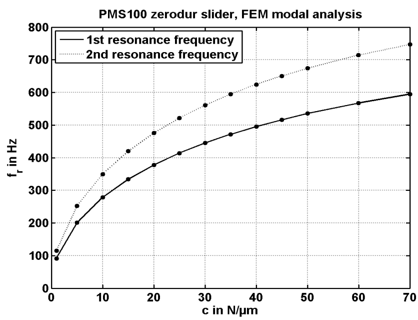

Figure 2 Slider eigenfrequencies f_r depending on the air bearing stiffness c

2.3 Initialisation of the laser interferometers with a floating slider?

The slider of the planar positioning system has no mechanical fixture to prevent slider rotation and besides the air tubes no mechanical contact to the stator. This is positive for precise positioning but it is a challenge when working with laserinterferometers. That is because for the interferometer initialisation the reflected beam must be coincident with the outgoing beam, which means that the slider with the reflectors must be precisely aligned to the fixed measuring heads. The angular tolerance thereby is ±30 arcsec. To achieve this, a constant current is applied to the three drive units so that the resulting forces lead to a centering of the slider with respect to the drive coils. Experiments show that with a centering current of I_c=1.5 A the oscillation of the slider position is less than ±1 µm in x- and y- direction and less than ±1 arcsec in r_z (see Figure 3). The experiments proved that this centering position can be precisely reproduced so that the interferometers can be initialised and the controller can be taken into operation.

With the described method of applying a centering current the positioning system can be securely taken into operation. With the position- and rotation-controller in operation a servo error of less than 1 nm was achieved. Figure 4 shows the measured position signal (primary values for x, y, r_z) for a command position (x,y)=(0,0). The servo error, characterised by the standard deviation of the measured position signal is σ_x = 0.5 nm and σ_y = 0.7 nm.

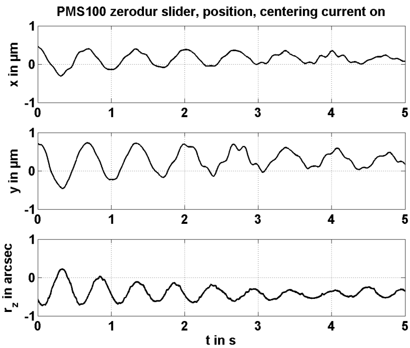

Figure 3 Position oscillation with centering current I_c=1.5 A

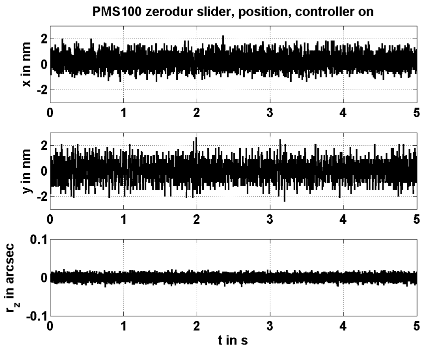

Figure 4 Measured position signal with controller on

Future work on this set up aims at analysing and reducing external and internal disturbance sources, mainly examining the coil heating and the influence of the air bearings on the laser interferometers.

Acknowledgements

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References:

[1] SFB 622, Nanopositionier- und Nanomessmaschinen, funded by the DFG-Deutsche Forschungsgemeinschaft;

http://www.maschinenbau.tu-ilmenau.de/mb/sfb622/index.htm

[2] T. Hausotte: Nanopositionier – und Nanomessmaschine, Diss. TU Ilmenau 2002

[3] T. Ruijl: Ultra Precision Coordinate Measuring Machine; Design, Calibration and error Compensation. Second edition, 2002, ISBN: 90-6464287-7

[4] S. Hesse, C. Schäffel, M. Katzschmann, T. Maaß, H.-U. Mohr: Planar motor concept for positioning with nanometer position uncertainty, proc. of the 8th euspen International conference 2008, Zurich, Vol 1, p.150-154

[5] S. Hesse, C. Schäffel: Reducing the positioning uncertainty of a linear direct drive system with 200 mm travel range, proc. of the 7th euspen International conference 2007, Bremen, Vol 1, p.204-207

[6] 3-D-Präzisionsmessmaschine, Abschlussbericht, DFG-Forschungsvorhaben JA 779/5-1, Scha 771/1-1, Ka 956/12-1, (2003)

[7] H.-J. Büchner, G. Jäger: A novel plane mirror interferometer without using cube corner interferometers, Meas. Sci. Technol. 17 (2006)746-752