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Study of Z-direction performance of a XY nanopositioning stage

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Abstract

The NanoPla is a 2D nanopositioning platform stage that has been developed at the University of Zaragoza. The platform consists of a three-layered architecture: a fixed superior base, a fixed inferior base and a moving platform placed in the middle. The movement of the platform is performed by four Halbach linear motors while three air bearings keep it levitating and a 2D laser system works as positioning sensor. The NanoPla is capable of positioning with a submicrometre uncertainty in a range of 50 × 50 mm^2 and it has been designed to work together with different kinds of tools and probes in various metrology or nanomanufacturing applications. In particular, the main application of this first prototype is surface topography characterisation at atomic scale of samples with relative big planar areas, using an atomic force microscope (AFM). This work, analyses the spurious motion in Z-direction of the NanoPla in order to validate its use for surface topography characterisation.

Nanopositioning, capacitive sensor, spurious motion

1. Introduction

The demand of accurate, repeatable and long travel range precision positioning systems is rapidly increasing. In this line of research, a Nanopositioning platform stage (NanoPla) has been designed, manufactured and built at the University of Zaragoza [1]. The NanoPla has a large working range of 50 × 50 mm^2 and it is capable of achieving submicrometre accuracy. It has been designed to work together with different kinds of tools and probes in various applications such as metrology or nanomanufacturing. In particular, the main application of this first prototype is surface topography characterisation at atomic scale of samples with relative big planar areas. Before integrating an atomic force microscope as the final solution, due to its fragility, the implementation of a confocal sensor is proposed.

In metrological applications, the NanoPla control system performs the coarse motion to position the measuring instrument along the working range, fixed to the moving platform, and a commercial piezostage (model NPXY100Z10A from nPoint) performs the fine motion of the sample during the scanning task. Therefore, it is crucial to monitor the position in Z-axis of the moving platform at each position in order to compensate the effect of its spurious motions in the measuring results. For this reason, three capacitive sensors have been implemented in the NanoPla. This work analysis the performance of the capacitive sensors and the stability in Z-axis of the XY-positioning control system.

2. NanoPla design overview

The NanoPla has a three-layered architecture that consists of an inferior and a superior base that are fixed and a moving platform that is placed in the middle, as shown in Figure 1. The moving platform of the stage is levitated by three air bearings, four Halbach linear motors have been selected as actuators and a 2D plane mirror interferometer laser system works as positioning sensor. The NanoPla positioning control system was developed in a previous work and its positioning uncertainty was calculated to be ±0.5 µm along its whole working range [2].

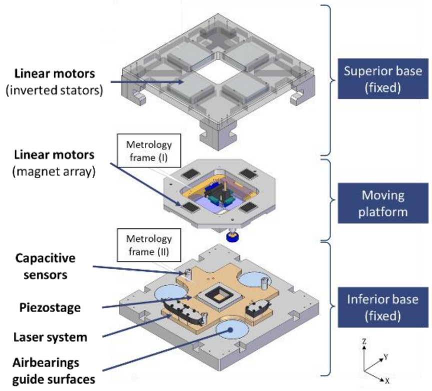

Figure 1. Exploded view of the NanoPla

On the other hand, commercial capacitive sensors are used to measure and compensate parasitic out-of-plane motions (Lion Precision, model C5-E). The capacitive sensor probes are placed at the metrology frame of the inferior base, while the target surfaces are placed at the bottom of the moving platform. The three probes are approximately separated 120°.

3. NanoPla capacitive sensors performance

When using the NanoPla for the metrological characterisation of a surface is necessary to measure the out-of-plane deviations and compensate them in the measuring results. In this section, the performance of the capacitive sensor system of the NanoPla is experimentally validated. The experiment was carried out in an environmentally controlled laboratory (ΔT=±1 °C).

3.1. Static analysis

The capacitive probes implemented in the NanoPla have a working range of 100 µm, and a maximum root mean square

(RMS) resolution of 28.45 nm, according to the manufacturer. Firstly, the performance of the capacitive sensors implemented in the NanoPla, with the positioning control system off was tested. That is, the moving platform remains completely static, with the air bearings off. The readouts of the sensors were recorded during 2 hours and the deviations observed corresponded to the thermal expansion of the platform, which was analysed in [3]. To reduce the effect of the thermal variation, the RMS deviation (RMSD) was calculated every 10 minutes, and the maximum value during the experiment was 57.08 nm. This deviation, higher than the one provided by the calibration certificate, may be due to the fact that the relative position between probes and target surfaces is slightly varying. That is, the metrology frame of the inferior base where the probes are placed, and the moving platform which contains the target surfaces are expanded separately. It must be mentioned that, although the selected material for the metrology frame is Zerodur due to its low thermal-expansion coefficient, in this first prototype, it is made of aluminium alloy 7075-T6.

3.2. NanoPla spurious motion

In [4], control of out-of-plane motion was proven to be unnecessary due to the high stiffness of the air bearings. Similarly, in the NanoPla, the moving platform is levitated by three air bearings, with a stiffness of 13 N/µm at the working conditions. Therefore, the control system of the NanoPla leaves out-of-plane motion uncontrolled in open-loop. This section analysis the spurious motion of the moving platform while the positioning control system is working (air bearings on).

Firstly, the moving platform was set to maintain still at a target position during 2 hours. In this case, the thermal deviations are minimal because the positioning control system maintains constant the relative position between moving platform and inferior base. The maximum value of the RMSD calculated every 10 minutes is 38.59 nm, lower than the value of 57.08 nm, which was obtained when the control system was off. As expected, the stiffness of the air bearings absorbs the deviations in Z-axis load that may be introduced by the vertical force generated by the Halbach linear motors [5]. In addition, the width of the air gap created by the air bearings during the levitation was measured by recording the capacitive probes measurements while turning the air bearings on and off, as shown in Figure 2. It is observed that the measured air gap is different in the three probes. This is because the air gap created between the guide surface and each air bearing depends on the air supply conditions and supported load. This load is slightly different for each air bearing due to the unavoidable assembly errors and asimmetries of the design.

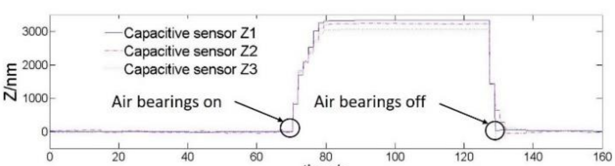

Figure 2. Capacitive sensors measurements while turning on and off the air bearings of the NanoPla.

It has been also observed that, when the moving platform displaces along the working range, the distances between probes and target surfaces vary. The measurement of the three capacitive sensors have been recorded (Figure 3a) while the moving platform is displacing in X-axis (Figure 3b). Simultaneously, a flat ceramic reference block placed on the piezostage -that remains static- has been measured by the confocal sensor implemented in the moving platform. The confocal sensor has a working range of 4 mm and a reading noise higher than the capacitive sensors. As shown in Figure 3a, every surface has a different slope. The reason is that the target surfaces of the three capacitive sensors have different alignments. In addition, a perfect alignment between the target surfaces of the capacitive sensor and the guide surfaces of the air bearings is not possible.

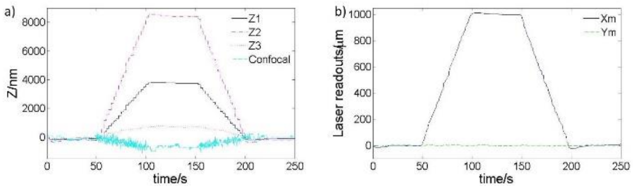

Figure 3. a) Measurements of the NanoPla capacitive sensors (Z1, Z2 and Z3) and confocal sensor. b) Laser system readouts in X and Y-axes

Figure 4 shows the slope of a target surface measured by its respective capacitive sensor. The three target surfaces have been measured under different NanoPla operating conditions and it has been verified that the misalignments remain constant. Therefore, once the misalignments of the target surfaces have been characterised, they can be compensated in the spurious motion measurements.

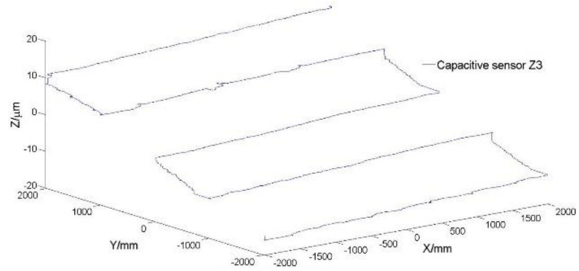

Figure 4. Measurements of a NanoPla capacitive sensor while performing motion in the XY plane.

4. Conclusion

The NanoPla, a nanopositioning stage capable of providing submicrometre accuracy in a large working range, is intended for the metrological characterisation of surfaces. In order to compensate the effect of the spurious motions in the measurements, the displacements in Z-axis are recorded by three capacitive sensors. In this work, the correct performance of the system is validated. In addition, it is proven that the high stiffness of the air bearings absorbs the vibrations in Z-axis that may be generated by the NanoPla positioning control system.

Acknowledgements

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