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Current Sampling in a Control Strategy for a Linear Motor of a 2D Nanopositioning Stage Based on Vector Control

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Abstract
In the University of Zaragoza, a 2D Nanopositioning Platform (NanoPla) is on development. The platform is expected to achieve nanometre resolution in a large working range of 50 x 50 mm². Concerning its control strategy, firstly, the regulation of one motor on a linear stage is being implemented. Later, this control will be extrapolated to the four motors of the platform to perform a 2D movement. The proposed strategy implements a vector control that decouples the regulation of the two orthogonal forces generated by the motor. This allows keeping the vertical force constant to levitate the moving platform, while the horizontal force moves the platform to the desired position. The hardware that has been chosen is a commercial control card of Texas Instruments that generates the desire phase voltages acting on three-phase PWM signals. In addition, the control card can read the phase currents at any moment and use them as a feedback to perform vector control. The work here presented studies the current sampling technique of the proposed control strategy.

Control; Positioning; Precision; Current Sampling

1. Introduction

The importance of nanotechnology has rapidly increased over recent decades, demanding not only more accurate positioning systems, but, also, larger working ranges. Different devices can be integrated in nanopositioning systems for applications such as nanomanufacturing or measuring. Within this line of research, a novel 2D Nanopositioning Platform (NanoPla) has been developed with a large working range (50 mm x 50 mm) and a submicrometre uncertainty [1]. The first device to be implemented in the NanoPla will be an AFM.

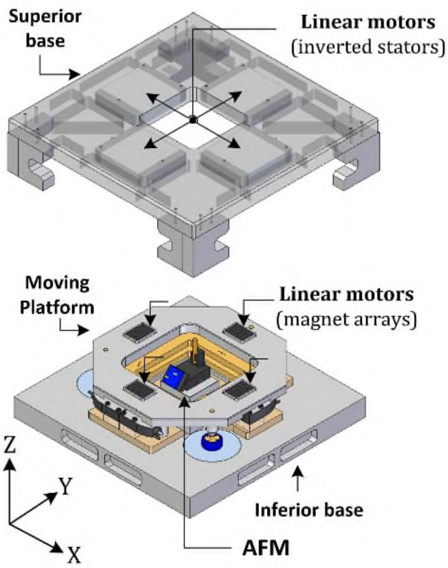

Figure 1. Exploded view of the NanoPla Prototype.

The design of the NanoPla system is shown in Figure 1. It consists of three stages; the inferior and the superior base, that are fixed, and the XY-moving platform. The actuation scheme is comprised by four Halbach linear motors that perform the motion. The stators are installed in the superior base and the magnet arrays in the moving platform. A plane mirror laser interferometer system works as 2D positioning sensor in XY plane. Three air bearings provide air lift to the moving platform in order to achieve relative non-contact motion between parts. Three capacitive sensors evaluate the tip-tilt-Z deviations.

In order to obtain accurate positioning, a control strategy able to regulate the movement of the linear motors is needed. In another work a current custom-made controller was specifically design and built for this purpose [2]. As a novelty, in this work, a commercial control card for rotative motors that acts on phase voltages is used. The implementation of the control strategy in a linear motor along one dimension was performed and presented in [3]. This strategy uses as feedback parameters the resulting phase currents that are read by the control card. This work analyses the influence of the current sampling technique in the control task.

2. Method and materials

A linear motor consists of two parts: a stator with three field coils and a linear Halbach magnet array. The electromagnetical interaction between the magnetic field of the magnet array and the currents driven through the coils concludes in a horizontal and a vertical force. In the NanoPla, the vertical forces of the four motors, together with the air bearings, levitate the moving platform. The horizontal forces move the platform in the XY-plane. These generated forces directly depend on the phase currents in the stator [4]. The selected device to perform the control of the motor is a Digital Motor Control Kit of Texas Instrument to operate with Permanent Magnet Synchronous Rotative Motors. This card generates phase voltages by Pulse Width Modulation (PWM). In addition, the current sense amplifier of the card is able to read the value of the phase currents and feed them back to the controller.

2.1. Performance conditions

In the NanoPla, the platform levitates while it is moving. According to the design, each linear motor needs to generate a constant Z-force equal to 0.625 N [4]. Once the NanoPla arrives to the desired XY-position, the moving platform is in a stable equilibrium, which means that the horizontal force generated by the motors must be null. Considering the motor law, to fulfil these conditions, the phase currents working range is ±0.25 A.

2.2. Control strategy

The controlled parameters are the position (Xs) and the vertical force (Fz), in two independent loops, as it can be seen in Figure 2. The laser system readouts are used as positioning feedback. In addition, the horizontal force (Fx) is also controlled in an inner loop. A vector control is implemented, which allows knowing the value of the orthogonal forces generated by the motor by reading the phase currents (Ia, Ib and Ic).

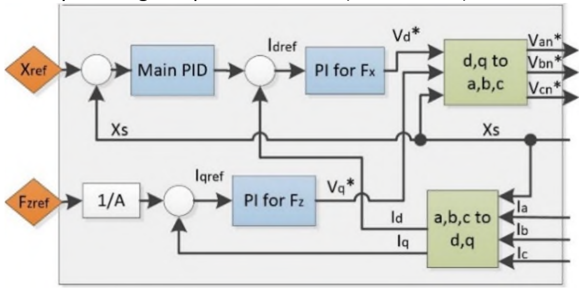

Figure 2. Scheme of the control strategy.

The control strategy acts on the phase voltages to regulate the motor movement. The phase voltage is generated and controlled by PWM. The maximum and minimum phase voltages that each PWM is able to generate are 6 V and -6 V, which correspond to 0 and 2048 in binary representation. Therefore, the resolution of 1/2048 corresponds to 12/2048 = 0.006 V. Considering that the stator winding phase resistance is 1 Ω, the PWM has a resolution of 0.006 A in phase current.

2.3. Current sampling

Texas Instrument control card includes two current shunt amplifiers that measure inline current in both directions. The voltage drop in the shunt resistor is converted to bits by an Analog to Digital Converter (ADC). The analog ADC input has a range of 3.3 V and the digital output resolution is 12 bits (0-4096 in binary representation.). The maximum and minimum phase currents that the ADC can read are 20.7 A (4096) and -20.7 A (0), respectively. Therefore, the current sampling has a resolution of 41.4/4096 = 0.01 A

In order to reduce the current ripple generated by the modulation, phase pulses are centred and symmetrical [5]. In addition, to measure the average current, the shunt voltage is sampled at the centre of the PWM Duty Cycle (DC).

3. Current sampling stability analysis

The current sampling stability analysis has been performed for eleven current values, spaced by 0.05 A, inside the working range of ±0.25 A. The current values of ±1 A and ±2 A have also been included in the study, to have a bigger spectrum. The sampling time is 0.01 s and for each experiment the data was collected in stationary state for 15 s. The magnet array of the linear motor has been separated from the stator in order to carry out a static analysis. Firstly, the current sampling stability has been studied for a continuous phase current and, then, the effect of this noise in a control loop has been observed.

3.1. Sampling of a continuous phase current

When the DC of the PWM that generates the phase voltage is constant, the resultant phase current is constant and continuous. Thus, the deviations from a continuous current in the readouts are due to the current sampling noise. Figure 3 shows, as a representative example, the ADC output for a constant phase voltage (Va) of -0.25 V. The observed trend of the current sampling stability is similar for all the currents inside the working range. The difference between the maximum and minimum readout in a sampling (noise range) for the worst case is 0.12 A. This value is considered too high, since it is almost ¼ of the working range. However, the Root Mean Square Deviation (RMSD) is ±0.022 A. For the currents of ±1 A and ±2 A the results are slightly better, having a noise range of 0.1 A and a RMSD of ±0.019 A.

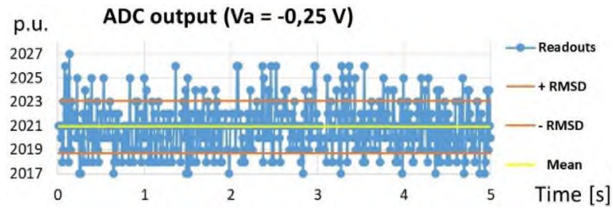

Figure 3. ADC output in binary representation.

3.2. Current sampling in a control loop

In this part of the experiment, the current value of one phase has been controlled with a PID that has been experimentally tuned. The ADC output has been used as current sensor for the feedback. Without any other external disturbance, the variations in the current are due to the sampling noise. Inside the working range, the difference between the maximum and minimum current readouts in the control loop for the worst case is 0.17 A. Nevertheless, the error between the desired current and the average current value is 0.002 A, which, for an ADC resolution of 0.01 A, is considered a negligible error. The currents of ±1 A and ±2 A provide similar results.

4. Conclusions

The RMSD of the current sampling noise is considered acceptable, being ±0.022 A. However, it has a range of 0.12 A, which is considered too high for the working range of ±0.25 A. This noise has been observed to be similar for phase currents of ±1 A and ±2 A, althought the relative error is much lower for these higher currents. Therefore, the possibility of working with higher currents should be studied, taking into account that, then, the linear motors would generate a higher vertical force. On the other hand, the current control system has proven to be effective despite of the noise.

Acknowledgements

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