Fast Nanometer Positioning System by Combining Fast Resonant Mode and Accurate Piezostack Direct Drive

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Abstract

This work aims at the development of a fast nanometer positioning system, combining the high speed capability of an ultrasonic piezomotors (resonant mode) with the fine positioning capability of a piezostacks (direct-drive mode). The two modes can be operated simultaneously with capability of achieving **speed of more than 200 mm/s** and **positioning accuracy of 10 nm**.

1 Principle of Multi Drive Motor

The multi drive motor is able to do two different actuation modes simultaneously. The first actuation mode is the resonant mode where the two piezos of the motor are excited by two sine voltages with varying phase or amplitude. This excitation results in an eliptical motion of the contact point. Since this contact point is preloaded against a slider, it creates a stick and slip operational regime that results in macroscopic drifting of the slider position. The second mode, the direct-drive mode, drives the piezostack with a quasistatic voltage which results in microscopic displacement with nanometer accuracy, over an operation stroke of ± 5 µm. The principle of the two modes are shown in figure 1.

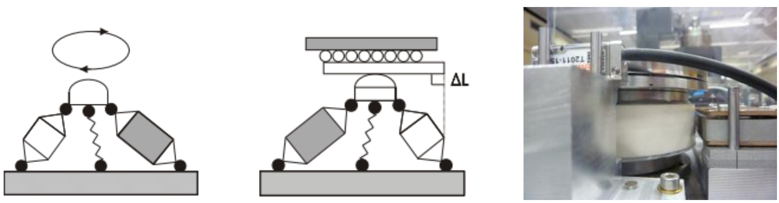

Figure 1: (Left) Principle of resonant mode; (Middle) Principle of direct-drive mode; (Right) Picture of multi-drive motor mounted against rotational stage.

2 Resonant Mode

In resonant mode, two different output control parameters are investigated. The first is by adjusting the phase difference between the two sine. The response of the phase input to output speed is shown in the graph below. The second input parameter is the voltage amplitude. This type of control posseses nonlinear behavior in the form of a deadzone. To acquire the advantage of each mode, phase control is implemented for low velocity and gradually move to amplitude control when high velocity is desired.

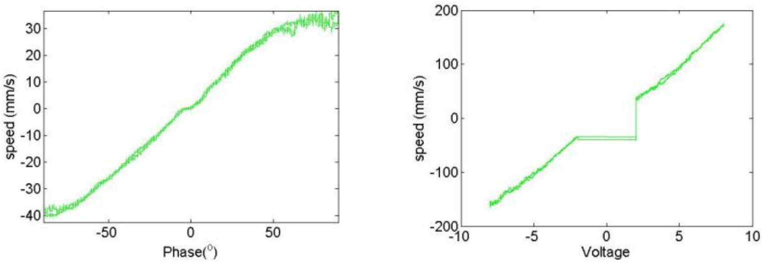

Figure 2: (Left) phase regimes employed on the resonant operation; (Right) voltage regimes employed on the resonant operation.

3 Direct-Drive Mode

The direct-drive utilizes two piezostacks driven by two independent quasistatic voltages. To compensate the hysteresis of the piezostack, a maxwell slip hysteresis compensation is implemented. In this research, two different actuation techniques are investigated. The first technique drives one piezostack for moving the contact point to one direction and drives the other piezostack for the oposite direction. The second technique is implemented by giving a fix offset voltage and add an antagonistic driving voltage to the two piezos. The two modes has been tested with good results, with the first technique offers the advantage that for zero/initial position it requires negligible voltage input, resulting in lower power consumption. Figure 3 shows the comparison between the measured voltage input-output and the given input-compensated output for the first method. The negative voltage shown on the X axis of the Figure 3 (Left) means that the right piezo is given a positive voltage, while positive voltage means that the left piezo is given a positive voltage.

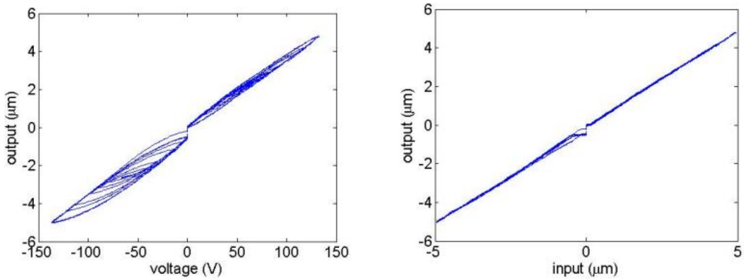

Figure 3: (Left) voltage input with its measured output position relation; (Right) input and measured output position relation with Maxwell Slip hysteresis compensation.

4 Simultaneous Control of the two modes

A control scheme combining the two modes is implemented in a D-Space controller. The global scheme of the control system is shown in figure 4. A more detailed explanation of the scheme and its initial results of the applied scheme can be found in [1].

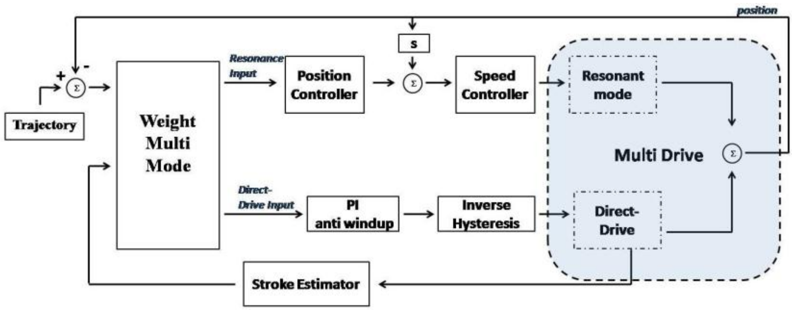

Figure 4: Scheme of the simultaneous control for the two modes [1].

5 Experimental Results

For identification and testing the capabilities of the multi drive motor, a rotational stage is implemented using ball bearing guides. The motor contact point is preloaded against the ceramic contact ring fixed on the stage. The position is measured by converting the angle acquired from a Renishaw Tonic rotary encoder. The converted resolution of the sensor is 1.72 nm with a noise level of ± 6 nm and a maximum allowable velocity of 50 mm/s.

In figure 5 and table 1, the experimental results for optimized resonant mode are shown. The tests involve a smoothed step position trajectory with specified maximum velocity. The maximum jerk of this trajectory is limited to 5 mm/s^3. The results' steady state error and the low velocity tracking error are at the same order of magnitude as the sensor noise.

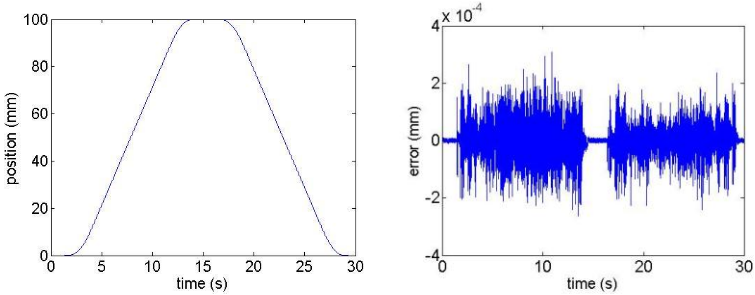

Figure 5: (Left) position input for constant velocity of 10 mm/s; (Right) the trajectory following error

Table1: Error for different velocity value

Velocity	Trajectory Length	Max Error	RMS Error
40 mm/s	400 mm	1.7 µm	0.147 µm
20 mm/s	200 mm	0.93 µm	0.062 µm
10 mm/s	100 mm	0.31 µm	0.046 µm
100 µm/s	1 mm	0.30 µm	0.033 µm
10 µm/s	0.1 mm	0.066 µm	0.007 µm
1 µm/s	0.01 mm	0.022 µm	0.004 µm
100 nm/s	0.001 mm	0.015 µm	0.003 µm

References:

[1] A. Santoso, J. Peirs, T. Janssens, and D. Reynaerts, Simultaneous Resonant and Direct-Drive Control of a Piezomotor, for Combining Fast and Accurate Motion, 13th International Conference on New Actuators (2012), 730-733.