Position Control of a MEMS Stage with Integrated Sensor

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1 Introduction

The trend towards smaller and more accurate positioning systems stimulates the use of MEMS applications. Some examples are high density data storage, (digital) light processing, accelerometers, rate sensors, and the use of cantilevers in atomic force microscopy. Actuators in combination with flexure-based stages are able to reach positioning accuracies of several nanometers. Still accurate positioning is limited by many factors, such as drift, external disturbances and load forces. Adding feedback control, and thus position sensing, can enhance the performance of MEMS positioning systems. The object of this research project is to develop a closed-loop MEMS-based positioning stage.

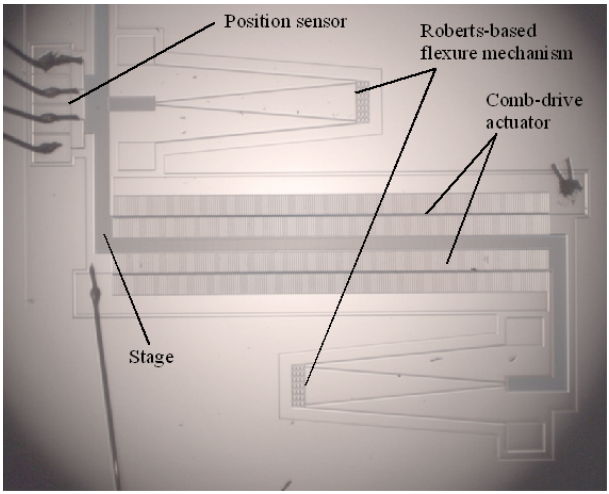

Figure 1: Optical microscope image of the produced MEMS device. The sensor as well as the actuator is connected with wire bonds to the electronics. Moving structures are perforated and therefore they appear darker in the image.

2 Conceptual design

In this work we present a one degree-of-freedom closed-loop MEMS positioning stage that consists of a flexure-based guidance mechanism, comb-drive actuators and a thermal position sensor. Electrostatic comb-drive actuators are used to actuate the stage. Electrostatic actuators also generate forces in sideways direction. Pull-in occurs when the electrostatic sideway forces become larger than the sideways support stiffness, which suffers from a large decrease in the deflected state [1]. A good straight guidance design is necessary to prevent the stage from pull-in. Several straight guidance mechanisms are tested, under which the constraint folded flexure, a flexure-based Watt mechanism and a Roberts-based flexure mechanism. Feedback is provided by a thermal position sensor, as described in [2]. An overview of the MEMS stage with integrated position sensor is given in Figure 1.

3 Fabrication

The designed closed-loop stage is fabricated in the highly-doped device layer of a silicon-on-insulator wafer using a single mask process. Deep reactive-ion etching (DRIE) is used to create thin structures (3μm) in the full device layer of 50μm thickness [3]. After DRIE, the structures are released from the substrate by HF vapour etching of the buried oxide layer, which has a thickness of 3μm. Thin structures (<10μm) are released from the handle wafer, large structures create anchor points that stay mechanically fixed to the handle wafer.

4 Measurement

The closed-loop stage, as shown in Figure 1, was experimentally characterized. The stage displacement as a function of the actuator voltage was calibrated using stroboscopic video microscopy, performed with a Polytec MSA-400 and its Planar Motion Analyzer software. The output voltage of the differential sensor as a function of the stage displacement is determined in the same calibration step. Two heaters were placed in series and a constant voltage of 12V was applied to the sensor. The output voltage of the sensor is the voltage in between the heaters, which is dependent on the stage position. The average sensitivity of the sensor was 2.8mV/μm.

The position of the stage was controlled using the signal of the integrated thermal position sensor. A PID+ controller was implemented in combination with feed-

forward control to compensate for the expected stiffness of the Roberts-based flexure mechanism from simulation. The control scheme is shown in Figure 3.

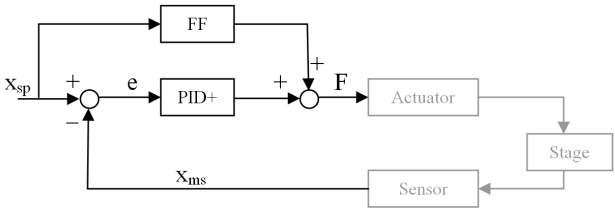

Figure 3: The control scheme for position control of the MEMS stage consists of a PID+ controller and additional feed-forward for stiffness compensation. The MEMS structure is depicted in grey.

The step response of the closed-loop system for two settings of the open-loop bandwidth is depicted in Figure 3 (left). With Kp = 0.001N/m (~0.1Hz) the mismatch between estimated and actual stage stiffness is 'slowly' compensated for by the control loop. When the Kp is increased to 0.1N/m (~10Hz), the compensation is performed much faster.

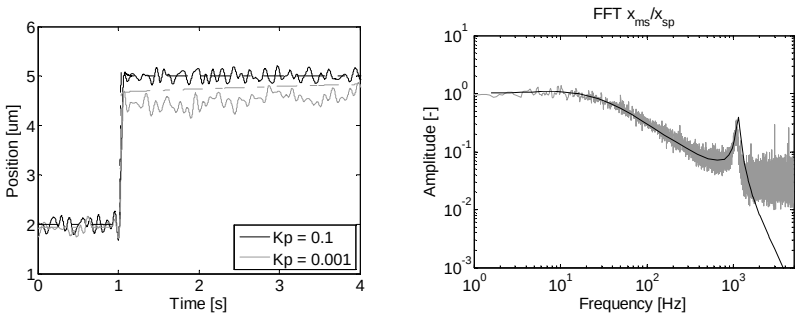

Figure 3: Step response (left) of the MEMS stage in simulation (dashed lines) and the measured step response (continuous lines) for two settings of the controller. The measured Bode magnitude plot (grey) of the closed-loop system is shown together with the expected Bode plot (black) on the right.

The closed-loop frequency response of the system is shown in Figure 3 (right). The first mechanical eigenfrequency of the MEMS stage is 1080Hz. The 2nd order low-

pass filter in the control loop has a cut-off frequency of 30Hz. The 1-σ value of the resulting noise of the integrated thermal position sensor is approximately 80nm.

5 Conclusion and discussion

Control of the flexure-based MEMS stage is straightforward; the stage hardly suffers from friction, play and hysteresis. A PID+ controller with additional feed-forward for stiffness compensation can position the MEMS stage with an accuracy of 80nm; the integrated thermal position sensor is used for feedback control.

The sensor has multiple thermal time constants in the range of 500μs to 2s, respectively caused by the heaters and the complete system. These time constants will not influence the control loop when the stage is controlled to a static position, since the thermal equilibrium of the sensor will hardly change. When a step is made or a path is followed, the thermal equilibrium changes and time constants show up in the sensor signal. This will not lead to instability, but will influence the accuracy of the sensor.

It is known that the thermal position sensor suffers from drift as a result of changes in the environmental temperature, air humidity and structural increase of the heater resistance. In the future, an extra reference sensor will be added to compensate for fluctuations in temperature and air humidity. Frequent internal calibration of the sensor using hard mechanical endstops on the stage position will be investigated to compensate for long term drift.

References:

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