Position encoding and phase control of resonant MOEMS-mirrors

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Abstract

Assuring stable resonant oscillation with well controlled amplitude under varying environmental conditions is a major challenge for electrostatically driven MOEMS mirrors. For this reason, we developed a compact device comprising a resonant MOEMS micro-mirror, optical position sensing, and driver electronics with closed loop control, which ensures operation close to the mirror resonance. Closed loop control is realised by adjusting the driving frequency to minimize the phase offset of the mirror oscillation, which is notably applicable for high frequency devices. Here we present our position encoding and feedback scheme, and show first experimental results, which demonstrate the capability of our device.

Keywords: MOEMS; closed loop control; scanner mirrors;

1. Introduction

Resonantly driven oscillating MOEMS mirrors are of high interest for various fields in optics, telecommunications and spectroscopy. They gain more and more importance as industry demands light-weight, miniaturizable, and cheap solutions for many opto-mechanical applications. Among others, micromechanical scanning mirrors like the one shown in Fig. 1 are used in bar-code scanners, miniaturized spectrometers, light barriers, and other applications. 2D-scanning mirrors are at the core of different projection applications. One of the important challenges in this context is to assure stable resonant oscillation with well controlled amplitude under varying environmental conditions.

We developed a compact device comprising a resonant MOEMS micro-mirror, optical position sensing, and driver electronics, with closed loop control, which ensures operation close to the mirror resonance. Closed loop control is realised by adjusting the driving frequency to minimize the phase offset of the mirror oscillation, which makes our unit especially applicable for high frequency devices, where synchronized excitation [1] is difficult. In this contribution we present our position encoding and feedback scheme, and show first experimental results with a 23 kHz MOEMS mirror, which demonstrate the capability of our device.
2. Experiments and Results

2.1. MEMS Device

Micromechanical scanner mirrors (Fig. 1), are fabricated using CMOS compatible technology [2]. The mirrors are driven electrostatically with a pulsed driving voltage close to the double of their eigenfrequency. The amplitude is frequency dependent and the resonance frequency, where the amplitude is maximal, strongly depends on environmental parameters like temperature or pressure.

Fig. 2 shows characteristic curves of a typical device, driven close to resonance. Mirror oscillation is initiated with a frequency sweep from higher to lower frequencies. The amplitude increases steadily and, upon passing the resonance, the oscillation very rapidly stalls completely.

2.2. Position sensing

Since the motion of the mirror is not linear but a quasi-harmonic function, position encoding of the movement of the mirror is crucial for most applications. This can be done by measuring a laser beam reflected from the backside of the mirror, as schematically shown in Fig. 3. The angular position of the mirror is encoded by an optical trigger signal combined with a harmonic extrapolation function [3].

Accurate optical position sensing also allows determining the time delay between the switching of the driving signal and the zero-deflection of the mirror. This phase difference is a sensitive measure for the resonance frequency, as highlighted in Fig. 4(a).
Fig. 3. (a) Scheme of the optical position sensing principle. The beam from a red laser diode (LD) is reflected from the backside of the MOEMS mirror. Two fast photodetectors Det0 and Det1 measure the timing of the passage at the zero position and at a fixed angular deflection, respectively. (b) Schematics of the relevant signals: from top to bottom: Mirror elongation; rectangular driving signal with twice the mirror frequency; the signals from the photodiodes, which allow to determine the angular movement within the harmonic approximation

Adjusting the frequency such that the phase difference is minimized causes the mirror to oscillate close to its resonance frequency, thus ensuring stable operation with large amplitude.

2.3. Electronics

All electronics for controlling the device are mounted on a 4x20 cm$^2$ board. Details will be published elsewhere. Very briefly, we use a PIC microcontroller, which deals with the mirror driver, all communication, averaging, and data processing. The timings of the photodiodes are measured with ps temporal resolution using a time-to-digital converter. Precise frequency generation was performed with a direct digital synthesizer IC. The driving voltage can be controlled between 50-150 V.

2.4. Results

In our device, which has a size of only ~1.5 cm$^3$, the timing is measured and controlled with a precision of <10 ns (corresponding to a phase difference of ca. 0.2 mrad). If necessary, the amplitude can further be regulated via the driving voltage. (Fig. 4 (b) shows the dependence of the amplitude on the driving voltage.)

In first experiments, we exposed the device under closed loop control to temperature variations and continuously monitored the relevant parameters. The mirror was heated up from 26 to 31 °C and the frequency was autonomously

Fig. 4. (a) Phase as a function of frequency (for a mirror with a resonance frequency of 23.03 kHz) (b) mechanical amplitude as a function of driving voltage (driving frequency =46.1 kHz).
adjusted by the device electronics, in order to minimize the phase. The voltage was kept constant at 100 V. Frequency and amplitude were monitored. Fig. 5 demonstrates the results. An increase of temperature leads to a reduction of the resonance frequency and an increase of the amplitude, probably due to the reduced modulus of elasticity of the mirror material. This is clearly reflected in the experimental curves. The device autonomously follows the temperature dependent resonance frequency, ensuring optimal operation of the delicate MOEMS mirror und varying environmental conditions.

More detailed analysis of our experiments indicates that a phase stability of better than 2/10,000 can be obtained by this method, sufficient even for demanding display applications.

3. Conclusions

In this article we presented a novel unit for closed-loop control of electrostatically driven MOEMS mirrors which will significantly improve the performance of these components. The first experimental results prove the feasibility of our phase-locking concept and demonstrate the abilities of our device. We expect it to provide significant impact for applications of these MOEMS mirrors e.g. in compact projection devices and MEMS-based spectrometers [4].

References

[1] K. Roscher, U. Fakesch, H. Schenk, H. Lakner, D. Schlebusch, Proc. SPIE 4985, 121 (2003)
[2] H. Schenk, P. Dürr, D. Kunze, H. Kück, International Mechanical Engineering Congress and Exposition, MEMS-Vol. 1, pp. 333-338, Nashville (1999)
[3] A. Kenda, W. Scherf, R. Hauser, H. Grüger, H. Schenk, Proc. IEEE Sensors 2004, 1312 (2004)
[4] M. Kraft, A. Kenda, T. Sandner, H. Schenk, Proc. IEEE Sensors 2008, 130 (2008)