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Update on 2D MEMS raster and vector scanning mirrors for medical imaging and high laser power applications

Thilo Sandner*, Thomas Grasshoff*, André Merten*, Markus Schwarzenberg*, Klemens Birnbaum*, Jan Grahmann*, Richard Schrödter*, Paul Hünig; Klaus Janschek****

** Fraunhofer Institute for Photonic Microsystems (FhG-IPMS), Maria-Reiche Strasse 2,01109-Dresden, Germany, (Tel: +49-351-8823152; e-mail: thilo.sandner@ipms.fraunhofer.de).*
*** Technische Universität Dresden; Automation Engineering, Dresden, Germany.*

Abstract: Compact 2D MEMS scan modules for vectorial (2D quasi-static) scanning of a high power laser or fast raster scanning for medical imaging are presented, enabling more compact medical laser scanning based instruments (e.g. in ophthalmology). Flatness based control algorithms with jerk-limited trajectory design was implemented for precise position control of the low damped qs MEMS scanners.

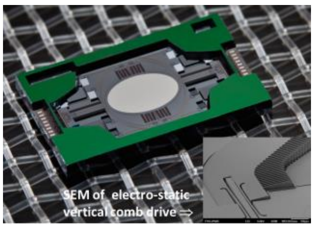
Keywords: MOEMS, 2D vector scanner, laser scanning imaging, flatness based trajectory control

1. INTRODUCTION

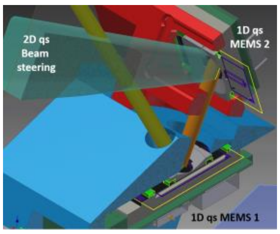
Miniaturized scanning techniques are required for (i) fast raster scanning in diagnostic imaging systems or (ii) vectorial beam steering e.g. in compact photocoagulation systems or hand guided laser surgery instruments for laser cutting of soft tissue (e.g. laryngoscopes) to eliminate common bulky galvanometers. MEMS scanning mirrors are interesting for highly miniaturized systems but typically, they are limited to small mirror diameter, resonant operation and low laser power [1]. In [2] an electro¬static driven quasi-static / resonant 2D-MEMS scanner with 5x7.1mm² aperture (limited to periodic raster scan trajectories) was presented for a medical high power ps-laser application (with 20W average power) for laser cutting of hard tissue. We give now a status update on 2D raster and vectorial (2D qs) MEMS scanner.

2. 2D MEMS RASTER SCANNING MIRRORS

In figure 1a typical 2D raster scanner is exemplarily shown (mirror aperture 2.4x3.6 mm², up to ± 10° quasi-static tilt angle of outer frame, 1600Hz resonant inner scan axis with ± 60…80° optical scan range). The electrostatic quasi-static actuation is based on LinScan technology (using wafer bonding of a second wafer to activate the quasi-static comb drives), limited to 2D raster scanner with gimbaled resonant mirror or 1D qs MEMS scanner. 2D ResoLin-scanner are used e.g. for fast raster scanning ophthalmic diagnostics.



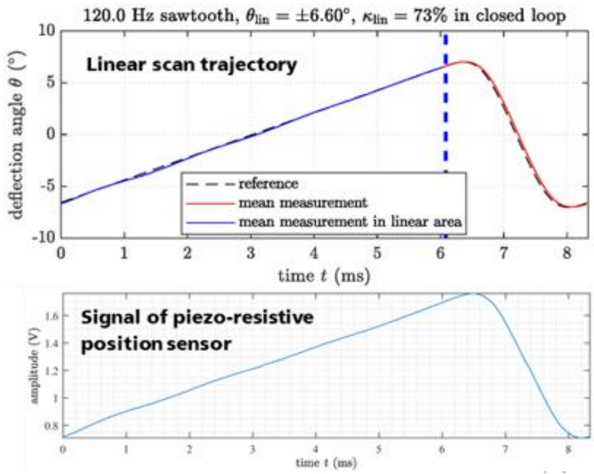
a)



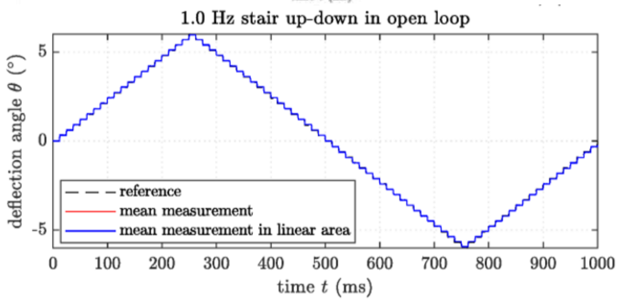
b)

Fig. 1. Electrostatic 2D MEMS raster scanner (a), compact 2D-MEMS vector scan module build of 2x 1D qs MEMS (b)

The experimental data of a linear (120Hz saw tooth) scan trajectory with $\kappa_{lin} = 73\%$ (ratio t_{lin}/T), ±6.6° linear scan, max. amplitude of ±7° and the corresponding position signal of the integrated piezo-resistive (PZR) position sensor are exemplary shown in figure 2 for a 1D qs MEMS mirror with 2.0x2.8mm mirror aperture (used in scan module of fig. 1b). Despite the high quality factor (Q = 45) of the vibratable MEMS scanner high position accuracy and repeatability of the scan trajectory is guaranteed by using a flatness-based MEMS driving control with jerk-limited trajectory design [3].



a)



b)

Fig. 2. Results of Flatness-based MEMS control with jerk-limited trajectory design; a) linear 120Hz (saw tooth) and b) step-wise (1Hz) trajectory of 1D-qs-MEMS used in fig. 1b

A compact 2D qs beam steering system can be realized also by orthogonal serial alignment of two 1D-qs MEMS scanner. The 2D qs scan module (exemplarily shown in figure 1c) use 1D qs MEMS scanner with 2.0x2.8mm aperture and ± 7.5° MSA. It has a size of < 2x2x2cm³ and was designed for an FOV of 4°x4°, which can be easily enhanced by further reduction of the module geometry, if needed. But the actual optical design still minimize optical distortions of the 2D scan field. The positions dynamic of beam steering was demonstrated by means of a stepwise trajectory (40 up/ 40 down steps, each for 0.3° step height). For this qs 1D-MEMS scanner with 517 Hz eigen-frequency a short step response time of 3.3 ms was achieved in close loop control for 1 deg step height. This is sufficient for a precise positioning of the laser pattern, e.g. in a medical laser photocoagulation system.

3. 2D VECTOR SCANNING MIRRORS

2D beam steering mirrors are required to simplify the optical system design and miniaturize the scanning system. A hybrid assembled 5 x 4 matrix of 2D beam steering MEMS mirrors was realized for optical alignment of multiple optical channels within a fluorescence sensor for parallel measurements in a microfluidic diagnostic device for fast practical sorting and diagnostic of a blood sample. Therefore, 2D ResoLin MEMS scanner were combined with wet-etched mesa-structured counter electrodes underneath the inner mirror to enable a static 2D tilt of ≥ ±2° using electrostatic actuation. In [2] a 2D beam steering MEMS with 6 x 8 mm² mirror aperture was presented using electromagnetic actuation instead of common electrostatic drives. Four permanent NdFeB magnets with 1 mm diameter and high are mounted on the backside of the gimbal mounted 75 µm thick silicon mirror plate. The magnetic forces were generated by stationary electromagnetic coils placed underneath the moving magnets forming a reluctance drive. For higher drive efficiency also variants with magnetic flux-guiding material (FGM) were used. In [4] we investigated several alternative driving principles for 2D beam steering mirrors to enhance scan dynamics and mirror aperture simultaneously (enabling higher optical resolution and laser power). We now present a new 2D qs MEMS scanner with improved position dynamics enabling non-resonant scan frequencies of up to 1 kHz). The design goal of the new 2D beam steering mirror was a static tilt angle (≥ 5°) of ≥ 3 mm mirror aperture with an eigen-frequency ≥ 1000Hz for high dynamic (adaptive) scanning.

4. EXPERIMENTAL RESULTS

The quasi-static 2D tilt characteristic of the electromagnetic 2D beam steering mirror with 6x8mm² aperture is shown in fig. 3. The mechanical quasi-static tilt angle was limited to ± 3.3° for 300mA driving current. The use of electromagnetic drives with FGM showed two effects (i) increase of qs-tilt by 1.5x and (b) reduction of eigen-frequency from 244 (238) Hz to 188 (172) Hz due to a magnetic spring softening effect. The frequency response curve of a new designed 2D MEMS vector scanner with 1.3 kHz eigen-frequency, 3mm aperture and about ± 5° qs mech. tilt angle is shown in fig. 4. The flat response curve is obvious up to 1000 Hz, which demonstrates the potential for a high dynamic 2D MEMS vector scanner.

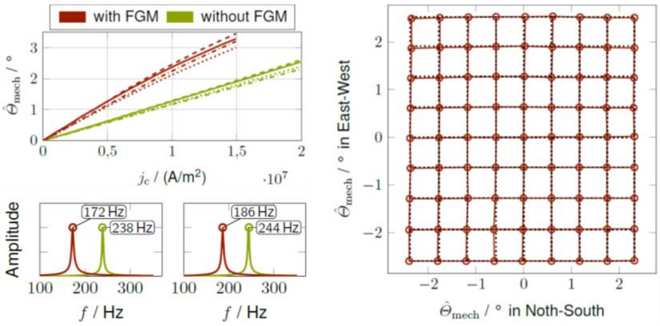


Fig. 3. Exp. results of electro-magnetic actuated 2D vector MEMS scanning mirror: (left) qs-static tilt and frequency response with / w.o. FGM, (right) 2D quasi-static deflection.

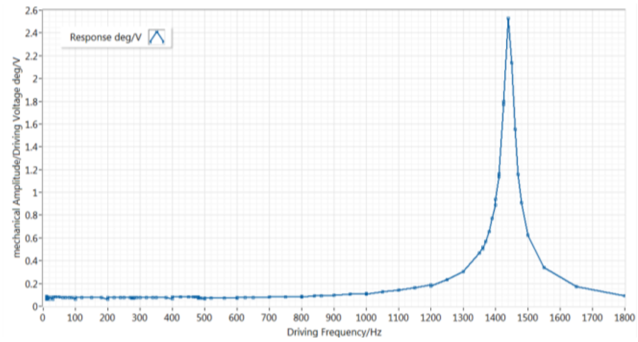


Fig. 4. Flat frequency response of new MEMS vector scanner

5. CONCLUSIONS

2D MEMS raster scanning mirrors are best suited for fast scanning laser imaging systems (e.g. for ophthalmological or endoscopic diagnostics), if large scan angles and high scanning speed with periodic scan trajectories are required. 2D vectorial scanning mirrors are more flexible due to adaptive beam steering. They are a core component for future miniaturization of diagnostic or therapeutic medical laser instruments, e.g. in ophthalmology for OCT based retina imaging based diagnostics or laser photocoagulation (LPC) eye-surgery techniques for treatment of eye diseases, e.g. diabetic retinopathy. Flatness based closed loop position control was successfully implemented sofar for electrostatic driven MEMS scanner using a jerk-limited trajectory design.

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