A Large MEMS Scanning Mirror for Laser Printing Application

Yee-Chung Fu; Advanced Numicro Systems; Santa Clara, California

Abstract

A state-of-the-art electrostatic scanning mirror for laser beam printing application has been developed. The large optical scanning angle of the mirror is critical for reducing the linear scanning speed variation. The geometry of the mirror increases the printing resolution and decreases the mirror dynamic deformation. Its maximum optical scanning angle range is above 96 degrees. The diameter of the mirror is as large as 4.2mm and the scanning speed is 3,000 Hz which is equivalent to a hexagonal polygon mirror rotating at 60,000 RPM. The device, coupled with a low speed scanner, is able to print on both flat and curved surfaces. It enables fast printing speed, lowers power consumption and reduces printer size for traditional print media such as paper, labels and cans as well as other applications such as raster scan display for dynamic bill board advertising with an array of such mirrors.

Introduction

MEMS (micro-electro-mechanical systems) based micro scanning mirrors have been proposed to replace polygon mirror and traditional scanner in laser printer, barcode reader, and raster scanning laser display since 1990s. The MEMS micro scanning mirror has many advantages over the traditional polygon mirror, such as higher scanning speed, low power consumption, low noise, and smaller size. However, in the laser printing application most of the MEMS scanners do not meet certain performance or cost requirements such as large mirror size, large rotation angle, fast scanning speed and low mirror jitter/wobble. The parameter of the mirror diameter times the scanning angle is important because it directly related to the print resolution. Equation 1 shows the relationship between the print resolution and the mirror diameter and the scanning angle. Figure 1 also shows some of MEMS scanners performance comparison. It shows the performance of the ANS MEMS is superior to many other MEMS scanners in terms of the print resolution. Most of the comparison data are from Urey[1]. The data from Tsuboi[2] and Yoda[3] have been added to Figure 1 for updated comparison. The ANS MEMS scanner has been developed to meet all of the performance and cost requirements for laser printing application.

$$N \propto \frac{D\theta}{\lambda} \quad (1)$$

Where N is the optical resolution, θ is the rotation angle, D is the mirror diameter and λ is wavelength. This equation shows the optical resolution is proportional to the product of rotation angle and mirror diameter.

Device Design

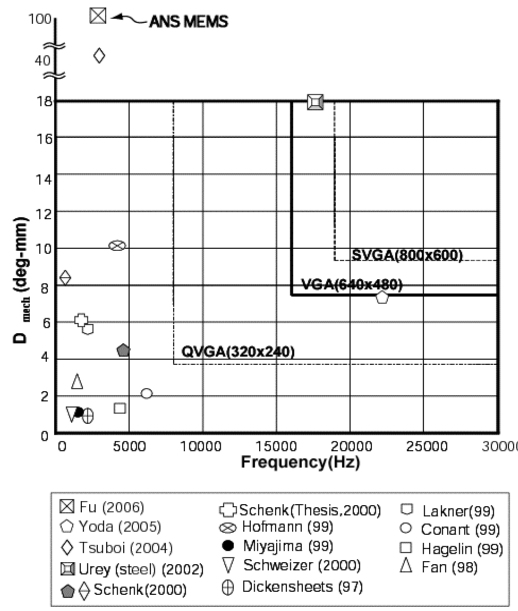

***Figure 1**. MEMS scanner performance comparisons; the value for ANS MEMS is above 100 deg-mm at 3,000 Hz; the value for Tsuboi's device[3] is 44.5 deg-mm at 3300 Hz. It shows ANS MEMS printing resolution is higher than other scanners*

Large driving force and large rotation angle are the two key requirements for the design. In order to obtain the large driving force and increase its rotation angle, the electrostatic comb drive has been designed to provide the driving force and the device is operated around its fundamental resonance frequency. In order to maintain the structural integrity, to improve its optical performance and to reduce its noise, the other structural resonant modes and frequencies have been simulated and carefully distanced from its fundamental frequency and its harmonics. The detailed structure has been designed based on the Finite Element simulation result.

Figure 2 shows the conceptual design of our scanning mirror. The mirror size is 4.2mm by 3.3mm. The mirror thickness is 200um. Thicker mirror will have less mirror dynamic deformation and better optical performance.

The hinge design is critical in our application. In order to support the large mirror structure and maintain the fundamental resonance frequency at 3000 Hz, the hinge has to be stiff. On the other hand, our target rotation angle is 96 degrees with sufficient overshoot margins. The hinge has to be supple so the hinge stress will not exceed the strength of silicon material during the large rotation operation and overshoot. This dilemma has been solved by implementing a design with multiple hinges on each side of the mirror. There is no special treatment or process step for making these hinges. This unique hinge design coupled with the electrostatic comb drive yields a new scanner which has pushed the forefront of the MEMS scanner performance.

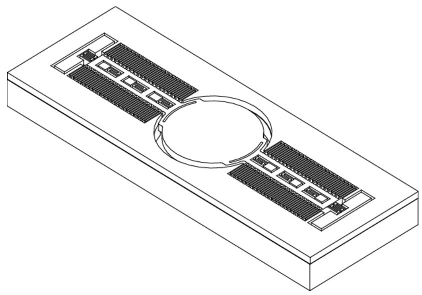

Figure 2. *The conceptual design of ANS MEMS scanner.*

Equation 2 shows the dynamic deformation as a function of the mirror diameter, the mirror thickness and the scanning frequency:

$$\delta \propto \frac{f^2 \theta D^5}{t^2} \qquad (2)$$

Where δ is the mirror dynamic deformation, f is the scanning frequency, θ is the rotation angle, D is the mirror diameter, and t is the mirror thickness. The mirror dynamic deformation increases drastically with the increase of mirror diameter. For a large diameter scanning mirror, the mirror thickness has to be increased significantly in order to reduce the dynamic deformation. Equation 1 and Equation 2 were simplified from the equations in Conant's paper[4].

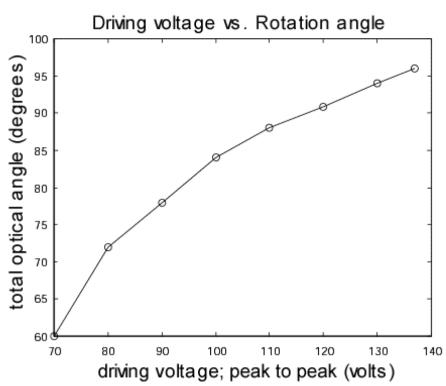

Figure 3. *Relationship between driving voltage and total rotation angle.*

Measurement and Simulation

Figure 3 shows the relationship between the driving voltage and the maximum scanning angle. The peak to peak AC driving voltage is operated from 0 to 140 Volts. Since our MEMS scanner is a electrostatic capacitive device, the driving current and power consumption are small compared with traditional scanners and polygon mirrors. The power consumption for the MEMS device is less than 16 mW. The total power consumption including our driving circuitry is less than 70 mW. One the other hand, a polygon mirror for laser printing application can consume up to 20 Watts. Figure 4 shows the testing setup for measuring the scanning angles.

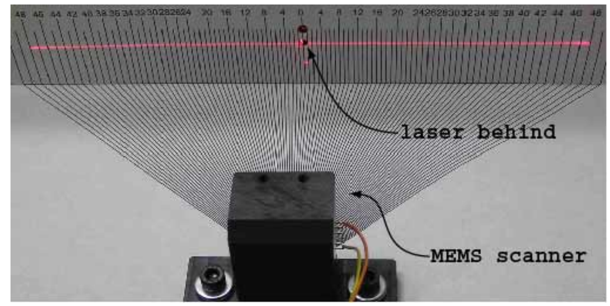

Figure 4. *The testing setup for measuring the scanning angle. It also shows the scanning angle is ± 48 degrees.*

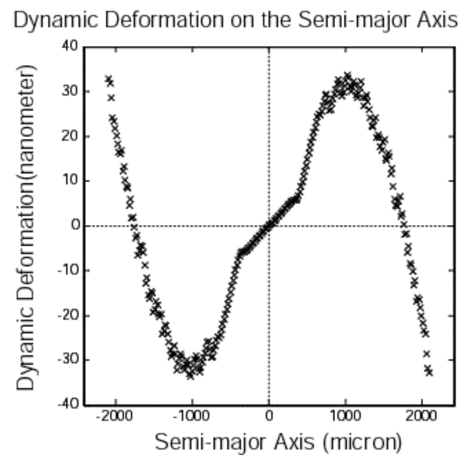

Figure 5. *Mirror dynamic deformation along its semi-major axis. The mirror size is 4.2mm by 3.3mm. The utilized rotation angle is ± 30 degrees*

Figure 5 shows the simulated result of the mirror dynamic deformation based on the finite element method. Since the mirror shape is elliptical, the dynamic deformation is calculated and plotted along the semi-major axis through the center of the mirror. Since the edges of the mirror on the semi-major axis have the greatest structural deformation, the greatest mirror dynamic deformation should be obtained on the semi-major axis. This is the reason the mirror dynamic deformation should be measured or calculated along semi-major axis. The mirror mass is also redistributed in a way to reduce the mirror dynamic deformation. The design of mirror mass distribution is based on the finite element simulation result. The redistributed mass will not add additional process step or increase the process time. Figure 5 shows the maximum mirror dynamic deformation at ± 30 degrees rotation angle is less than 80 nanometer which is smaller than one eighth of the wavelength of 780 nanometer for laser printing application. The utilized scanning angle, ± 30 degrees, is smaller than the maximum scanning angle of ± 48 degrees in order to obtain constant linear speed. Figure 6 explains the reason the utilized scanning angle should be smaller than the maximum scanning angle.

Discussion

Equations 3 and 4 show the linear scanning speed of a polygon mirror and a resonant MEMS scanner as a function of scanning angle. The assumption is that the scanned line is straight and the laser beam direction is normal to the straight line when the laser beam is in its neutral position ($\theta = 0$).

$$V = \frac{L\omega}{[\cos(\theta)]^2} \tag{3}$$

$$\omega = 2\pi\theta_{\max} f \cos[\sin^{-1}(\frac{\theta}{\theta_{\max}})] \tag{4}$$

Where V is linear velocity, L is the normal distance from laser to the projected line, ω is the angular velocity, f scanning frequency, θ is the rotation angle which is variable, $\theta_{\max}$ is the maximum scanning angle which is a constant. The angular speed of a polygon mirror is constant. Equation 4 is utilized for calculating the angular speed of a resonant scanner only.

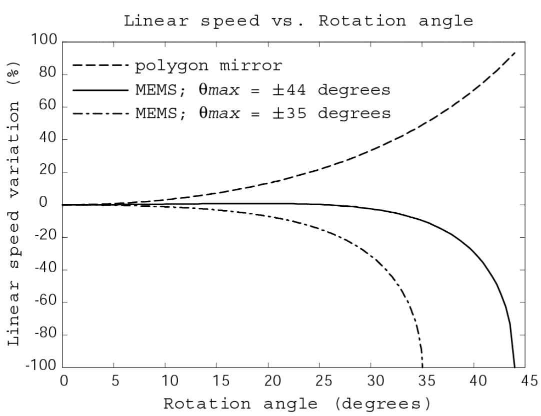

***Figure 6**. Relationship between rotation angle and linear speed variation without lens correction*

Figure 6 shows our MEMS scanner is capable of maintaining near constant speed within $\pm$28 degrees of scanning angle if its maximum scanning angle is set at $\pm$44 degrees. The slight speed variation within $\pm$28 degrees is $\pm$1% in this case. Figure 6 also shows the linear speed variation of a traditional polygon mirror and a conventional MEMS scanner with maximum scanning of $\pm$35 degrees. In both cases, the speed variations are larger than 20% when the utilized scanning angle is set at 28 degrees. Figure 6 demonstrates that even the required scanning angle for laser printing is less than $\pm$30 degrees, the MEMS scanner must be able to scan an angle much larger than $\pm$30 degrees in order to provide constant linear speed profile for printing application. ANS's MEMS is capable of scanning $\pm$48 degrees. It will enable a much larger utilized scanning angle, reduce the module size, and simplify the optical lens design and assembly. Figure 6 was obtained by implementing Equation 3 and Equation 4.

Laser Marking

Figure 7 shows a setup for laser marking or laser display. The uniaxial MEMS scanner has been coupled with low speed scanner in order to project a raster scanned image on a surface. A traditional galvanometer is utilized as the low speed scanner. The mirror size has to be large enough in order to withstand the high laser power for laser marking application. For bill board advertising application, an array of lasers and/or an array of MEMS scanners can be implemented to provide a high resolution image. A low speed MEMS scanner has been designed to replace the galvanometer for the next engineering build. A bi-axial scanner has also been designed to replace two uniaxial scanners for laser display and laser marking applications for future development.

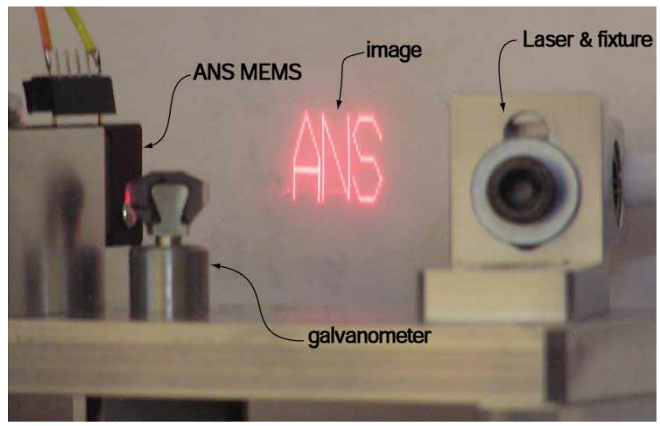

***Figure 7**. The set up for laser display and/or laser marking*

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Author Biography

Yee-Chung Fu received his BS and MS in Engineering from the National Taiwan University and his PhD in Mechanical Engineering from Stanford University in 1996. He has extensive experience in designing and processing various optical MEMS devices.