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Two-dimensional optical scanning of a piezoelectric cantilever actuator

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Abstract A piezoelectric optical scanning cantilever structure with two-dimensional scanning angles was reported. The theoretical and experimental studies on the structure were carried out. By using finite element method, the effect of the materials and the structure size on the theoretical results were concluded, and a favorable two-dimensional piezoelectric optical scanning structure with a single cantilever was obtained. A two-dimensional piezoelectric optical scanning specimen was fabricated. It was found that a 0.282° bending scanning angle at 1056 Hz and a 0.12° torsional scanning angle at 4612 Hz were obtained under the forcing voltage of 5 V (o–p).

Keywords Two-dimensional optical scanning structure · Structural optimization · Scanning frequency · Forcing voltage · Scanning angle · Flatness of the reflecting mirror

1 Introduction

Optical scanning system has been widely investigated for its applications in many important optical instruments, including scanners, printers, displays, projectors, bar code reading, remote measurements of dimensions, etc.

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There are many types of the optical scanning system, such as mechanical, electromagnetic, electrostatic, piezoelectric, acousticoptical, electrooptical types and polygon-mirror type. The electromagnetic and electrostatic types of optical scanning structures have been researched for a long time and already widely used in the optical scanning [1–3]. However, because of the driving theories of the electromagnetic and electrostatic types, the scanning structure vibrates obviously when working and the electromagnetic radiation come out.

The piezoelectric type of optical scanning structure with much advantage has been reported recently [4–7]. The piezoelectric optical scanning structure has a simple structure, quick response, good stability and anti-interference, which are basic demand for optical scanner.

The piezoelectric cantilever structure reported in this paper has been in possession of all the advantaged features mentioned above. A more important feature is that the piezoelectric structure could be easily developed into two-dimensional optical scanning systems, which makes more sense in practice.

2 Design and analysis

A piezoelectric optical scanning structure with a cantilever and two-dimensional scanning angles has been designed. As shown in Fig. 1(a), the two dimensional optical scanning structure is composed of two pieces of z-axial polarized piezoelectric ceramics and an elastic cantilever. When the in-phase alternative current stimulating signals are applied on the electrodes, top of both piezoelectric ceramics, the structure produces a bending vibration, as shown in Fig. 1(b). When the anti-phase alternative current stimulating signals are applied on the ceramics, as shown in

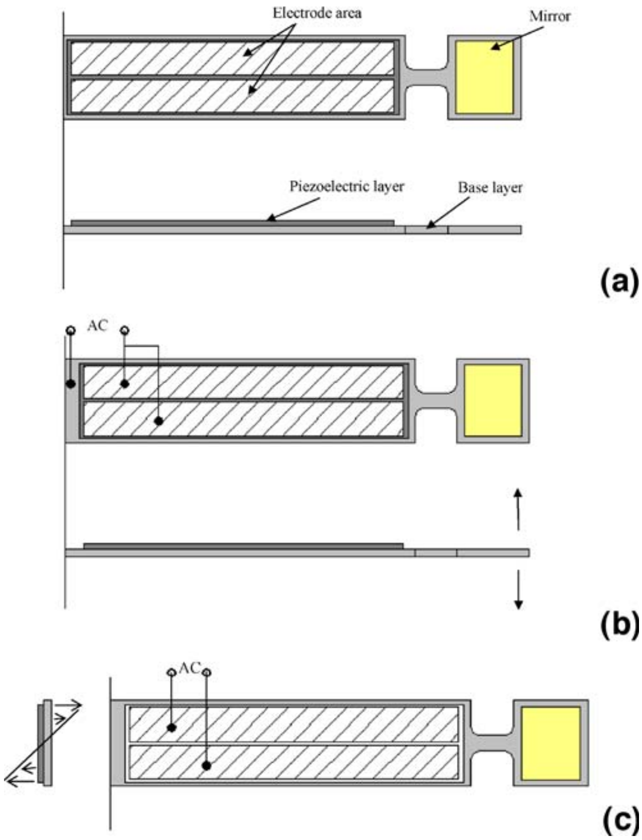

Fig. 1 (**a**) Schematic plot of the reported piezoelectric two-dimensional optical scanning structure, (**b**) schematic plot of the bending vibration, and (**c**) schematic plot of the torsional vibration

Fig. 1(c), the structure produces a torsional vibration correspondingly.

An original design of the structure has been made out, which has a reflecting mirror of 5×5 mm, a gemel with 0.2 mm in width and 2 mm in length, a cantilever with 8 mm in width, 23 mm in length and 0.2 mm in thickness, two piezoelectric ceramics with 0.3 mm in thickness, 3.4 mm in width and 22.2 mm in length. The bending and torsional vibration modes have been calculated by the finite element method (FEM), and the mode shapes are plotted as shown in Fig. 2. The third bending mode and the first torsional mode are designed to use in the two-dimensional optical scanning.

An optimization analysis has been made by the FEM from the original design. To improve the performance of the scanner, the optimization rule is defined as to obtain a higher response frequency, a larger vibration angle, and fine consistent performance in two dimensions.

Focusing on the response frequency and vibration angle, the parameters such as the materials property, the size of the structure are analyzed.

The response frequencies of the vibration modes could be higher when the cantilever is made of the materials with

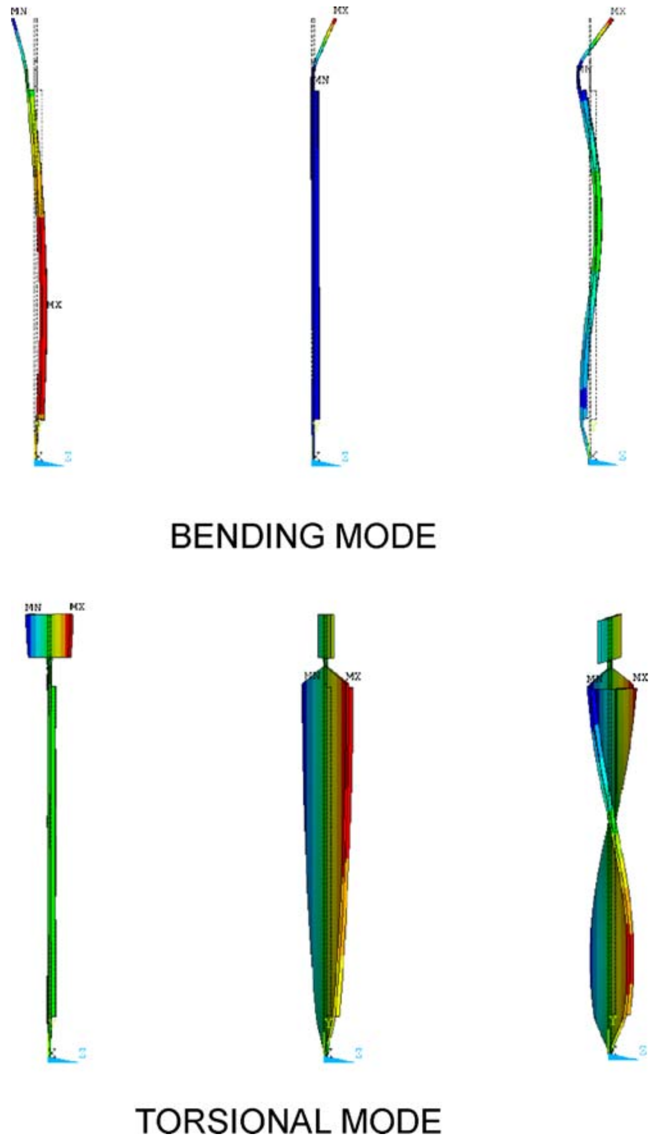

Fig. 2 Vibration modes shapes calculated by FEM

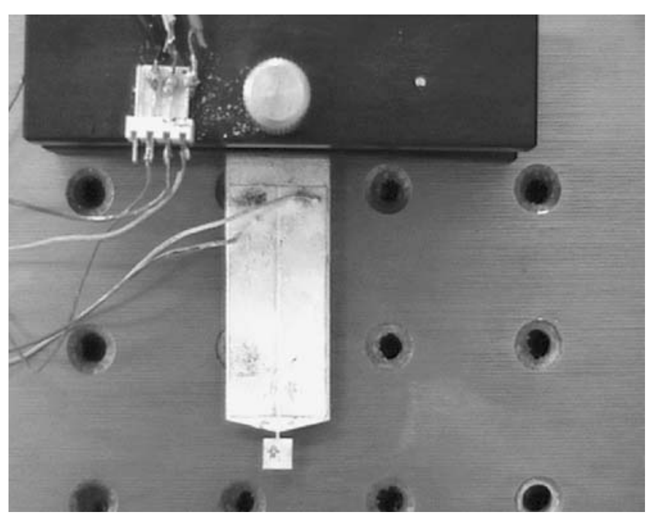

Fig. 3 Piezoelectric two-dimensional optical scanning structure specimen

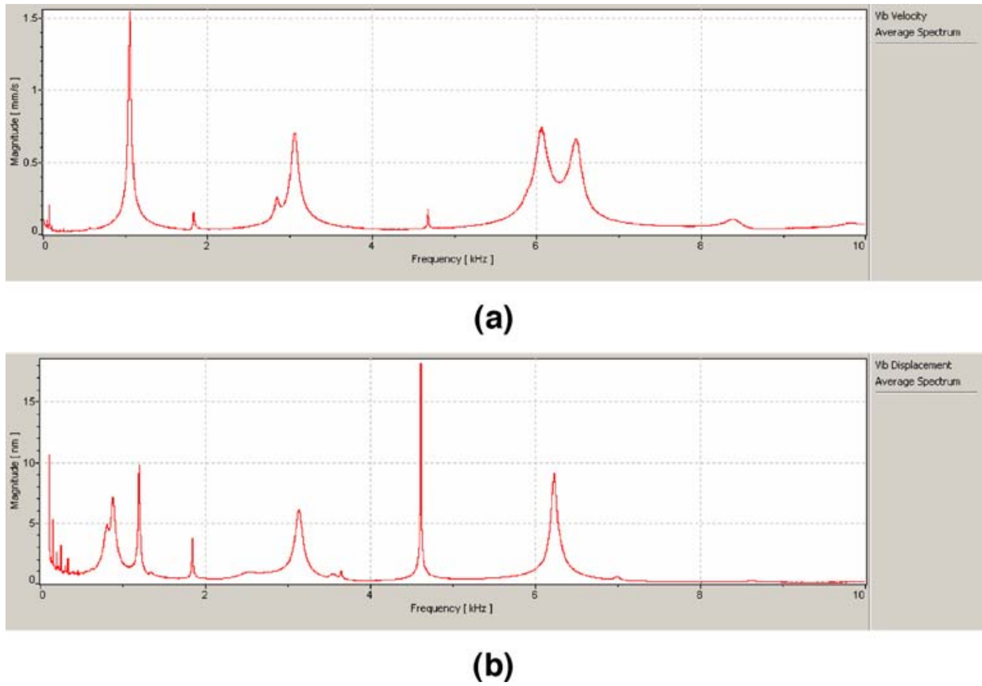

Fig. 4 Frequency spectrums measured by the vibrometer under the forcing voltage of 5V (o–p); (**a**) bending modes, (**b**) torsional modes

higher Young's Modulus and lower density, by which we can shift the response frequencies using different materials.

The mirror is the assembly which makes the laser beam reflected to accomplish the optical scanning. It is found that the larger mirror size could make the vibration angle larger in the bending modes, but smaller in the torsional modes. The size of 4 mm×4 mm is chosen considering about both the response frequency and vibration angle. The flatness of the mirror was analyzed at the same time. The mirror is more flat in the lower response frequency vibration mode.

The gemel connecting with the cantilever and the mirror greatly affects the response frequency and vibration angle in torsional modes. It is found that a higher response frequency and a larger vibration angle could be obtained with a wider and shorter gemel. There is a tight relationship between the size of the cantilever and the vibration modes obviously, especially the torsional modes. The calculation using the FEM indicates that a longer and wider cantilever could produce a higher response frequency and a larger vibration angle. The response frequency increases with increase of the thickness, while the maximum value of the vibration angle was achieved with the thickness 2 mm. The size of the ceramics also influences the response frequency and the vibration angle. It is found that the response frequency increases with increase of the thickness of ceramics, while the vibration angle decreases.

The optimized structure could be obtained following the optimization rule by the analysis. It is composed of a reflecting mirror of 4×4 mm, a gemel with 0.5 mm in width and 1 mm in length, a cantilever with 10 mm in width, 27 mm in length and 0.2 mm in thickness, two piezoelectric ceramics with 0.2 mm in thickness, 4.4 mm in width and 24.2 mm in length. It could produce a bending scanning angle at 2643 Hz and a torsional scanning angle at 5835 Hz under the forcing voltage of 60 V (o–p).

3 Experiment and results

In order to demonstrate the concepts proposed in this paper, a two-dimensional piezoelectric optical scanning specimen is fabricated. It has a reflecting mirror of 5×5 mm, a gemel

Table 1 The calculated and measured results of the specimen under the forcing voltage of 5 V (o–p).

Vibration mode (b for bending, t for torsional)	1st b	2nd b	3rd b	1st t	2nd t	3rd t
Calculated response frequency (Hz)	1164	2093	3561	909	3162	5582
Measured response frequency (Hz)	1056	1834	3059	878	3138	4612
Calculated vibration angle (°)	1.97	0.42	0.41	0.239	0.065	0.221
Measured vibration angle (°)	0.282	0.079	0.12	0.011	0.017	0.128

with 0.5 mm in width and 1 mm in length, a cantilever with 17.8 mm in width, 41.06 mm in length and 0.3 mm in thickness, two piezoelectric ceramics with 0.54 mm in thickness, the distance between the border of the cantilever and the ceramics and the ceramics themselves is 0.4 mm, as shown in Fig. 3. According to the fabrication process, the size of the specimen is larger than the optimized one.

The experimental results, including resonant frequency, mode shapes, velocity, displacement, etc. are measured using the Polytec 300-F Vibrometer, in which the velocity and displacement measurement of the piezoelectric cantilever is carried out using a modified Mach–Zehnder interferometer. And its maximum scanning frequency is 1.5 MHz, measuring range between 5 and 1000 mm/(s/V), maximum velocity ±10 m/s, displacement resolution 2 nm. To avoid any disturbance from around environments, the whole optical system and the piezoelectric cantilever are placed on the vibration isolated table. Various input voltages of the piezoelectric cantilever are generated by HP3325B Function Generator to stimulate the prototype as well as a reference input signal of the controller.

The specimen is measured under the in-phase and anti-phase alternative current stimulating signals, according to the schematic plot shown in Fig. 1(b) and (c). The frequency spectrums are shown in Fig. 4. Comparison between the experimental results and the theoretical calculation is shown in Table 1.

There are little variation between the response frequencies from the calculation and the experimental results, while the measured vibration angles are lower than the calculated. One possible reason is that the materials used in the specimen are not as ideal as that in the FEM calculation, and the joints on each assembly are not ideal strong as that in the calculation.

The specimen produced a 0.282° bending scanning angle at 1056 Hz and a 0.12° torsional scanning angle at 4612 Hz under the forcing voltage of 5 V (o–p).

4 Conclusion

A cantilever piezoelectric optical scanning structure with two-dimensional scanning angles was reported. The effect of the materials and the size of the structure in theory was concluded using the FEM. A favorable two-dimensional piezoelectric optical scanning structure with a single cantilever was obtained by the optimizing analysis.

A two-dimensional piezoelectric optical scanning specimen was fabricated. It could produce a 0.282° bending scanning angle at 1056 Hz and a 0.12° torsional scanning angle at 4612 Hz under the forcing voltage of 5 V (o–p).

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