3P3-23
Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 521-522
18-20 November, 2009

Experimental Study of Frequency-Change-Type Two-Axis Acceleration Sensor

周波数変化型２軸加速度センサの実験的検討

Sumio Sugawara and Yu Kajiwara† (Ishinomaki Senshu Univ.)
菅原澄夫，梶原　優†（石巻専修大 理工）

1. Introduction

A low-cost multi-axis acceleration sensor with high sensitivity is required for applcation to the attitude control and navigation systems of moving objects. As such a sensor, the authors have studied one- and two-axis acceleration sensors using the phemonenon that the resonance frequency of a bending vibrator changes with axial force.[1-5] The characteristics of the two-axis sensor espetially are not inspected experimentally.

In this paper, the characteristics of the two-axis acceleration sensor are analyzed using the finite-element method, and then inspected experimentally.

2. Structures of Two-Axis Sensor

The structure of two-axis acceleration sensor is shown in Fig. 1. The sensor is composed of two 45°-arranged bending vibrators, a mass, support bars, and a frame. One end of the vibrator is fixed at the frame, and the other end is connected to the mass. Also, the mass is connected to the frame by support bars. The axial force F ($=M\alpha$), which is the product of the mass M and the acceleration α, is applied to the end of the vibrator by the mass. The resonance frequency f_0 of the vibrator is changed by the force F. As the force F is changed by the acceleration α, α is estimated from the frequency change Δf ($=f_0'-f_0$), where f_0' is the resonance frequency in the case of applying the acceleration α. The out-of plane modes of the bending vibrator are shown in Fig. 2, the first mode of vibration is used here.

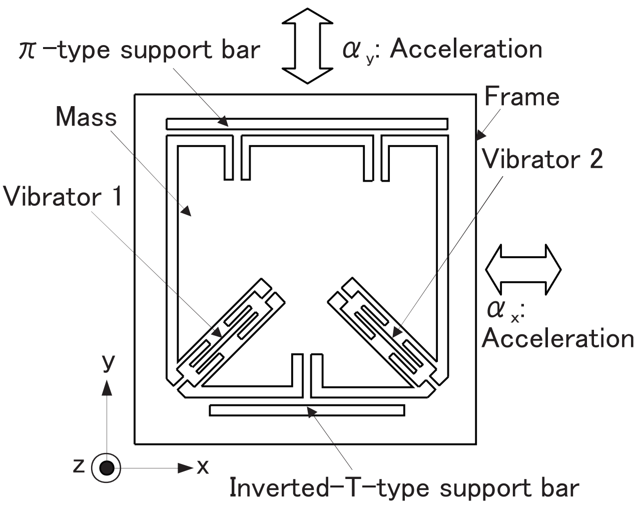

Fig. 1. Structure of two-axis acceleration sensor.

The frequency changes Δf of the two-axis sensor by the forces F_x and F_y, which are caused by the accelerations along the x- and y-axes, are listed in Table Ⅰ. The acceleration α can be determined from the sign of Δf, and the magnitude is estimated from that of Δf. Fig. 3 shows a more sensitive structure of the two-axis sensor using bent support bars.

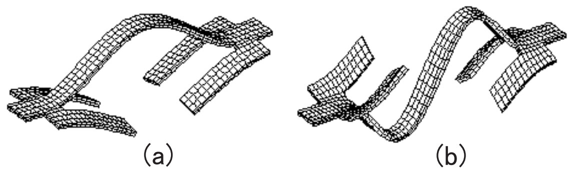

Fig. 2. Vibration modes of bending vibrator. (a) First mode, (b) Second mode.

Table Ⅰ. Frequency changes Δf of vibrators.

	Vibrator 1	Vibrator 2
$F_x>0$	$\Delta f>0$	$\Delta f<0$
$F_x<0$	$\Delta f<0$	$\Delta f>0$
$F_y>0$	$\Delta f>0$	$\Delta f>0$
$F_y<0$	$\Delta f<0$	$\Delta f<0$

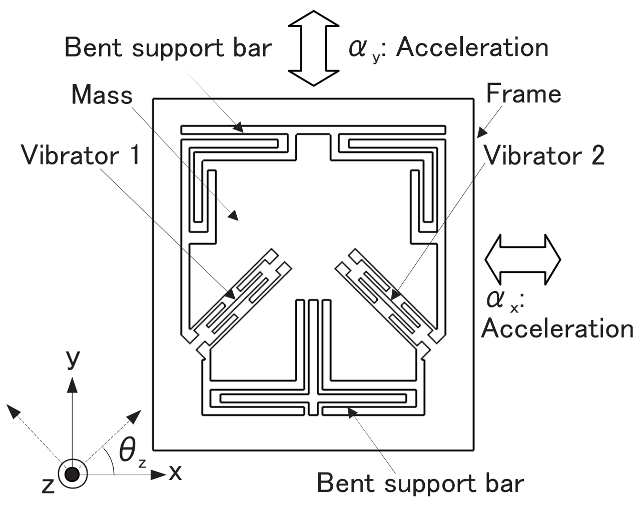

Fig. 3. More sensitive structure of two-axis sensor.

E-mail address: ssumio@isenshu-u.ac.jp

3. Sensor Characteristics

The sensor of Fig. 3 is made of stainless steel (SUS304), and driven by small piezoelectric ceramics bonded on the central arm of the vibrator. The length and thickness of the vibrator are 31 and 0.2 mm, respectively. The volume of the sensor is approximately $90\times95.8\times10.2$ mm^3, and almost equal to the one of Fig. 1. The details on the dimensions are omitted here. The calculated resonance frequencies f_{01} and f_{02} of vibrators 1 and 2 are f_{01}=1788.2 and f_{02}=1787.2Hz, respectively.

Figs 4(a) and 4(b) show the sensor characteristics of $\alpha - \Delta f/f_0$. The broken lines show the calculated characteristics without piezoelectric ceramics, and the solid lines show the calculated ones with piezoelectric ceramics. The experimental characteristics agree with the calculated ones with piezoelectric ceramics.

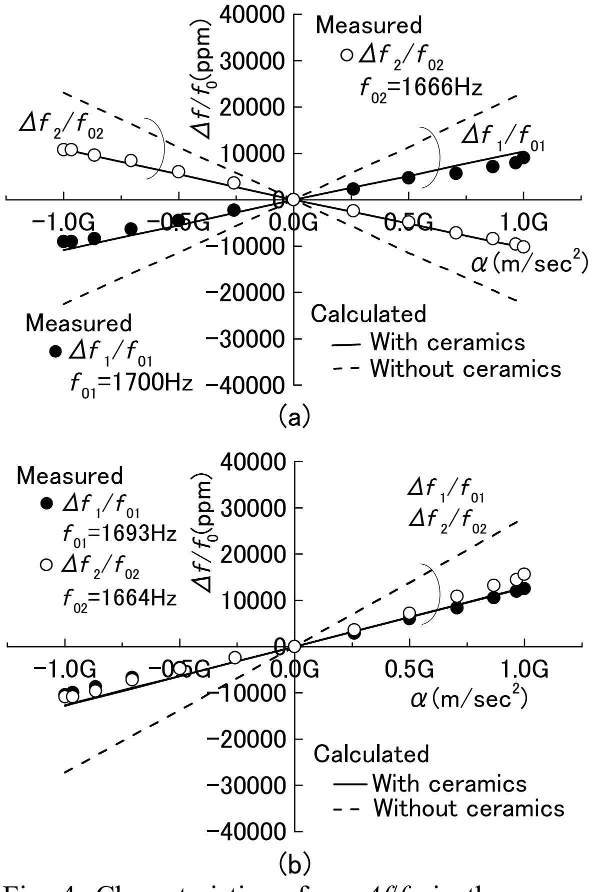

Fig. 4. Characteristics of $\alpha - \Delta f/f_0$ in the case of θ_z=0°. (a) α along the *x*-axis, (b) α along the *y*-axis.

To realize high-sensitivity, the sensor of Fig. 3 was rotated -45 ° around the z-axis. The characteristics under this condition are shown in Fig. 5. The calculated characteristics agree with the experimental ones. The frequency changes, $\Delta f_2/f_{02}$ in Fig. 5(a) and $\Delta f_1/f_{01}$ in Fig. 5(b), appear slightly, therefore must be adjusted to become zero.

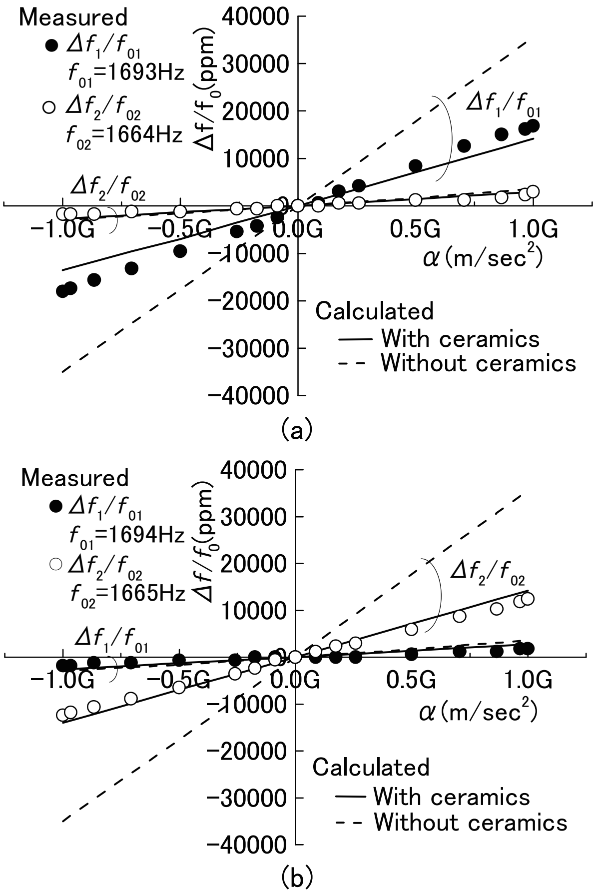

Fig. 5. Characteristics of $\alpha - \Delta f/f_0$ in the case of θ_z=-45°. (a) α along the *x*-axis, (b) α along the *y*-axis.

4. Conclusions

The characteristics of the frequency-change two-axis acceleration sensor were analyzed using the finite-element method, and compared with the measured ones. The experimental characteristics agree with the calculated ones with piezoelectric ceramics. The calculated values decrease to approximately half of the ones without piezoelectric ceramics.

Acknowledgment

This work was partially supported by a Grant-in-Aid for Scientific Research (No. 19560047) from the Japan Society for the Promotion of Science.

References

1. J. Takahashi, S. Sugawara, and J. Terada: Jpn. J. Appl. Phys. **42** (2003) 3124.
2. J Takahashi and S. Sugawara: Jpn. J. Appl. Phys. **43** (2004) 3035.
3. S. Sugawara and J. Terada: Proc. Symp. Ultrason. Electron., 2004, p. 185[in Japanese].
4. S. Sugawara, H. Suzuki and T. Saito: Jpn. J. Appl. Phys. **46** (2007) 4652.
5. S. Sugawara and J. Koike: Jpn. J. Appl. Phys. **47** (2008) 6578.