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# New Construction of Frequency-Change-Type Two-Axis Acceleration Sensor

周波数変化型２軸加速度センサの新構成

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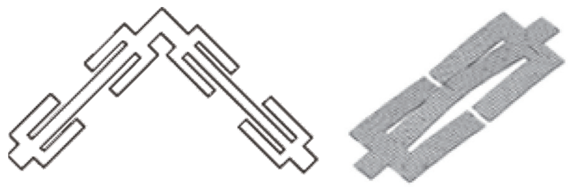
## 1. Introduction

The acceleration sensor suitable for a MEMS structure is required for application to the attitude control and navigation systems of moving objects such as a vehicle and a robot. As such a sensor, the authors have studied the frequency-change-type acceleration sensor that utilizes the phenomenon that the resonance frequency of a bending vibrator changes by axial force.[1-8] It is important for these sensors to become a simple structure with high sensitivity and also small cross-axis sensitivity. In the frequency-change-type two-axis acceleration sensor, the motion of mass must be designed so as to become linear along the direction of applied acceleration to reduce the cross-axis sensitivity.[9, 10] Therefore, the new construction of sensor which can conquer such a problem should be devised.

In this research, the frequency-change-type two-axis acceleration sensor using a new right-angled bending vibrator is proposed as one construction of the sensor which can conquer the problem mentioned above. And using finite element analysis, the sensor characteristics are clarified and the experimental sample of the sensor is produced.

## 2. Right-Angled Bending Vibrator and Acceleration Sensor

**Fig. 1** (a) shows the structure of the right-angled bending vibrator proposed here. In the right-angled vibrator, the two bending vibrators shown in Fig. 1(b) are connected so as to become a right-angled and flat structure. The first out-of-plane mode of vibrator is used here. As shown in Fig. 2, the center part of right-angled bending vibrator is connected to the center of gravity of mass with a symmetrical structure supported by four bent-type support bars with the same dimension. Under such construction, because a mass rotation of the sensor is suppressed, the cross-axis sensitivity becomes very small. The principle of operation of this two-axis acceleration sensor can be explained as follows. If acceleration is applied to mass, the generated force will act on two bending vibrators which constitute the right-angled vibrator as axial force. As the resonance frequencies of two bending vibrators change with axial force, acceleration can be estimated from the frequency change rate.



(a) Right-angled vibrator. (b) Bending vibrator.
Fig. 1 Construction of right-angled vibrator.

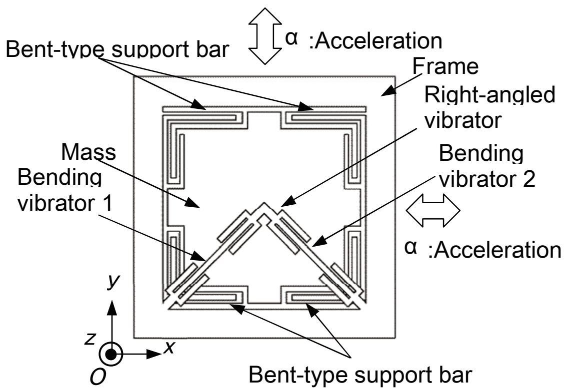
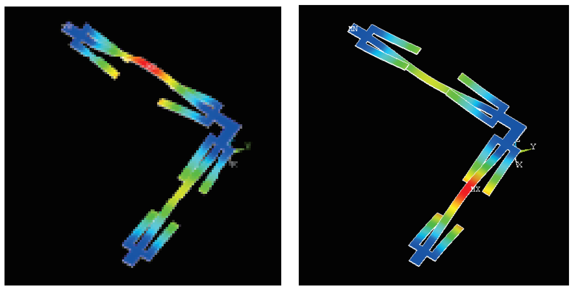



Fig. 2 Construction of one-axis mirror device.

## 3. Coupling Phenomenon of Right-Angled Vibrator

The two bending vibrators used for the right-angled bending vibrator are designed so that the vibration displacements of both ends become very small. When the finite element analysis of the right-angled vibrator was realized, there was a case that a coupling phenomenon shown in Fig. 3 was observed against expectation.

Therefore, the side-arm length of bending vibrator was adjusted so that the phenomenon might not appear. As shown in Fig. 4, the two vibrators do



(a) $f_{01}$ (b) $f_{02}$
Fig. 3 Coupling phenomenon of right-angled vibrator.

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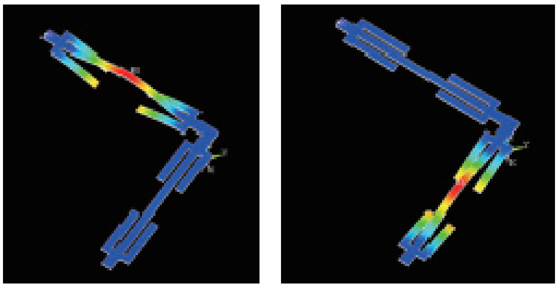
not couple in this case.



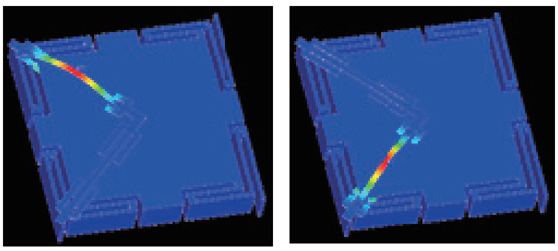
(a) $f_{01}$ (b) $f_{02}$

Fig. 4 Right-angled vibrator with no coupling phenomenon.

**4. Construction of Two-Axis Sensor**

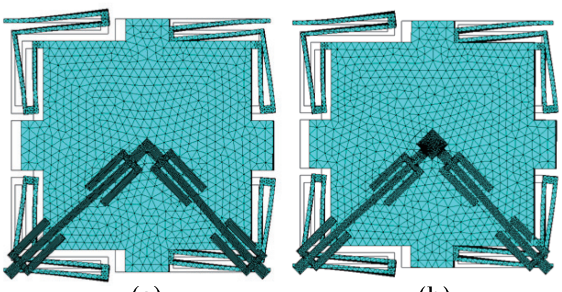
Fig. 5 shows the analyzed mode of vibration of the sensor. The center part of the right-angled vibrator is connected to the center of gravity of the mass, a coupling phenomenon between the two bending vibrators is not observed and each vibrator vibrates independently. When the acceleration along the x and y axis directions is applied to the sensor, the frequency change rates become linear against applied acceleration. It was confirmed that the vibrators did not couple even when acceleration was applied. Moreover, the motion of mass of the sensor becomes in parallel to the direction of applied acceleration as shown in Fig. 6 and then the influence of cross-axis sensitivity becomes very small. The sensor is made of stainless steel (SUS304), the external dimensions are about $90 \times 90 \times 10.8$ mm$^3$.

Fig. 7 shows the top view of the two-axis sensor of trial production. Small piezoelectric ceramics ($5 \times 2 \times 0.2$ mm$^3$) are bonded for driving.



(a) $f_{01}$ (b) $f_{02}$

Fig. 5 Vibration modes of acceleration sensor.



(a) (b)

Fig. 6 Calculated motion of mass to the x-axis direction.

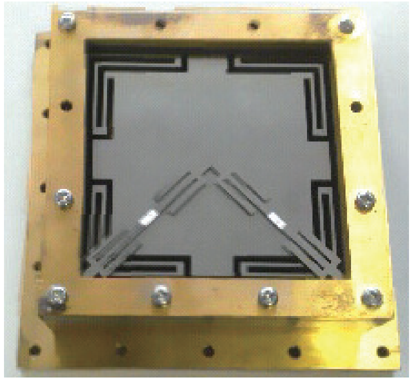


Fig. 7 Example of sensor of trial production.

The support unit is made of brass and the sensor is fixed to the unit.

**5. Conclusions**

The new construction of the frequency-change-type two-axis acceleration sensor was proposed here. The right-angled vibrator was newly developed to reduce the cross-axis sensitivity caused by a rotation of mass of the sensor. The design method for the sensor using the right-angled bending vibrator was investigated utilizing the finite-element analysis. As a result, it was clarified that a flat and simple construction of the sensor with high sensitivity is realized.

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