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Construction of Three-Axis Acceleration Sensor Using a Cross-Coupled Vibrator
交差結合型振動子を用いた 3 軸加速度センサの構成

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1. Introduction

Recently, a small low-cost acceleration sensor with high sensitivity has been required for application to the attitude control and navigation systems of moving objects, such as vehicles. To develop such a sensor, the authors have studied an acceleration sensor utilizes the phenomenon that the resonance frequency of a bending vibrator changes by the axial force.[1-9)]

A new construction of the acceleration sensor using a cross-coupled vibrator is proposed here, and investigated experimentally. The sensor detects the acceleration from a change of vibration amplitude of the cross-coupled vibrator.

2. Structure of Sensor

Fig. 1 shows the structure of the three axis acceleration sensor using a cross-coupled vibrator. The four coupled vibrators are mechanically cross-coupled as shown in the figure. The cross-coupled vibrator is fixed to the frame at four ends, and the center portion of the vibrator is connected to mass at four points with a cross-coupled mass. Also the mass is fixed to the coupled vibrator with movable mechanism. This sensor structure detects the three accelerations along the x, y-and z-axes. The volume of the experimental sample is about $101 \times 101 \times 8$ mm^3. The vibration mode of the coupled vibrator is shown in **Fig. 2** shows the vibration mode of the bending vibrator, the displacements at the both ends are designed so as to become very small. The vibration mode of the y-axis is the same as x-axis. The experimental sample of the sensor is made from stainless steel (SUS304). The weight of a cross-coupled mass is 3.3 gram.

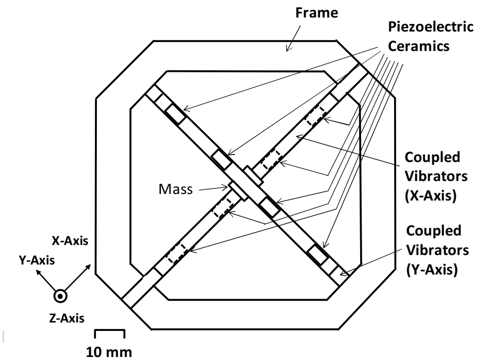


Fig. 1 Structure of sensor.

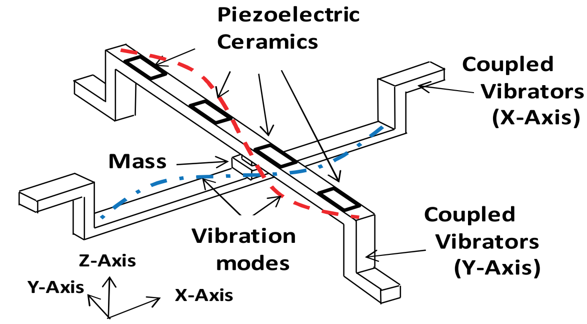
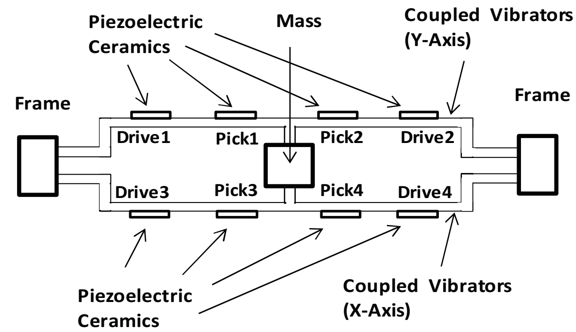
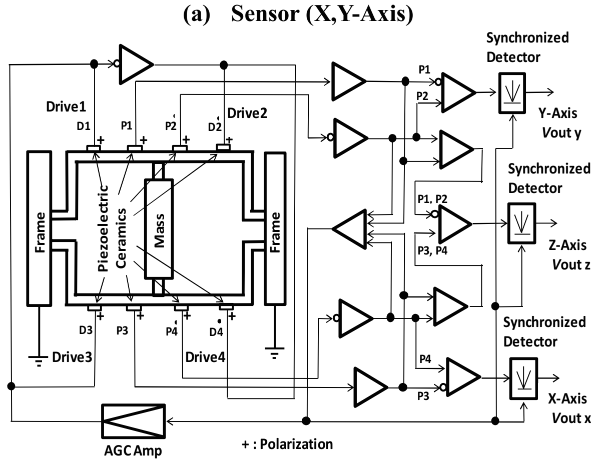


Fig. 2 Vibration modes of vibrator(X, Y-Axis).



(a) Sensor (X,Y-Axis)



(b) Circuit

Fig. 3 Driving and detecting methods of sensor.

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3. Driving and detecting methods of Sensor

Fig 3(a) shows a cross section of the sensor. Four small piezoelectric ceramics ($3\times7\times0.1$ mm^3) are bonded on the long arms of the coupled vibrator, and electrically connected for driving and detecting the vibrator as shown in **Fig. 3(b)**. The vibrator is driven with the constant amplitude using an AGC amplifier, and the output signals are detected differentially. The inverse phase is transcribed in the spot point. The sensor output is obtained using a synchronized detector.

4. Sensor Characteristics

The experimental sample of the sensor is shown in **Fig. 4**. The measured values of resonance frequency and quality factor are about 1123Hz and 150, respectively. The sensor characteristics are measured using the gravitational field, and the acceleration is changed by rotating the sensor around the axis along the length of the vibrator. The measured characteristics are shown in **Fig. 5**. The drive voltage is 1V rms then. When the acceleration along the x,y-axis is applied to the sensor relationship between the acceleration value and the output voltage $V_{out\ x,y,z}$ becomes linear as shown in **Fig. 5(a),(b),(c)**. Here, V_{out} x shows the differential voltage between $V_{pick(3)}$ and $V_{pick(4)}$, which are the output voltages at the terminals Pick(3) and Pick(4) in **Fig. 3(b)**. V_{out} y shows the differential voltage between $V_{pick(1)}$ and $V_{pick(2)}$, which are the output voltages at the terminals Pick(1) and Pick(2) in **Fig. 3(b)**. V_{out} z shows the differential voltage between $V_{pick(1,\ 2)}$ and $V_{pick(3,\ 4)}$, which are the output voltages at the terminals Pick(1, 2) and Pick(3, 4) in **Fig. 3(b)**. **Fig. 5(a),(b),(c)** shows the characteristic in the case of the acceleration applied along the x, y-axis and z-axes. The sensitivity of 0.78mV/m/s^2(x,y-axis), 1.35mV/m/s^2(z-axes) and the linearity of 0.88～1.00% were realized experimentally. Also the

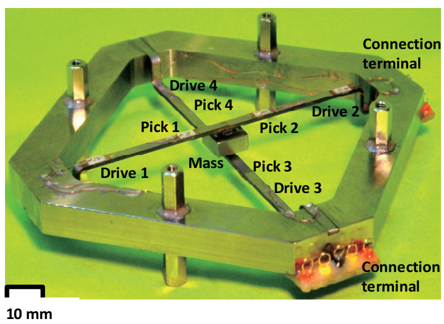


Fig. 4 Experimental sample of sensor.

sensitivity of 1.05mv/m/s^2(x, y-axis) and 1.8mv/m/s^2(z-axes) was simulated by the finite-element analysis, when the sensor was constructed from a silicon single-crystal and piezoelectric then films, and designed so as to have the volume of $4\times4\times0.5$mm^3.

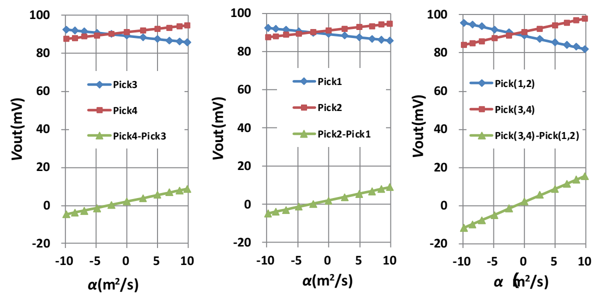
5. Conclusions

A new construction of the three-axis acceleration sensor using a cross-coupled bending vibrator was proposed, and the sensor characteristics were measured experimentally. The obtained results are summarized as follows.

(1) The acceleration sensor can be realized using the change in the vibration amplitude of the vibrator.

(2) The sensitivity of 0.78mV/m/s^2(x, y-axis) and 1.35mv/m/s^2(z-axes) is realized using the experimental sample of the sensor.

(3) The linearity of 0.88～1.00% is also realized using the differential detection of the coupled vibrator.



(a) X-Axis (b) Y-Axis (c) Z-Axis

Fig. 5 Measured characteristic of acceleration-output voltage.

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