2P3-1

Reduction of the Coupling Vibration Between the Bending Vibrators of the Frequency-Change-Type Two-Axis Acceleration Sensor
周波数変化型２軸加速度センサにおける横振動子間の結合振動の低減化

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1. Introduction

The acceleration sensor suitable for 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 author has studied the frequency-change-type acceleration sensor utilizing the phenomenon that the resonance frequency of a flat-type bending vibrator changes by axial force. [1, 2] When the coupling vibration exists between two or more vibrators used for the two-axis sensor, the resonance frequency of each vibrator is not able to control independently.

Here, in the two-axis acceleration sensor consisting of four bending vibrators, the method of reducing the coupling vibration is investigated using the finite-element analysis.

2. Structure of Two-Axis Acceleration Sensor

2.1 Structure of sensor

The structure of the metal frequency-change-type two-axis sensor is shown in **Fig. 1**. A cross-type vibrator used consists of four bending vibrators with out-of-plane mode. One end of each vibrator is connected together to the center of gravity of the mass, and the other end is fixed to the frame. The mass is also fixed to the frame through four bent-type support bars. When acceleration α_x or α_y is applied to the x or y axis direction, the axial force to each vibrator is generated by the mass, and so the resonance frequency of each vibrator is changed by this force. Acceleration can be estimated from the frequency change.

2.2 Vibration modes of vibrator

Each vibrator of the cross-type vibrator of **Fig. 1** is designed so as to vibrate independently at almost equal resonance frequency. **Fig. 2** shows the calculated vibration modes of two vibrators arranged along the x axis direction. The vibrators are vibrating independently at the nearly equal frequencies, f_{01} and f_{03}, and the coupling vibration is not observed. Moreover, the two vibrators along the y axis direction vibrate independently at the resonance frequencies, f_{02} and f_{04}. In addition, the coupling vibration between the vibrators arranged along the two axis directions at right angles is not observed in this case. In order to design each vibrator so that the coupling vibration does not generate, the length of the short arm is adjusted in advance to make the displacement u_z of both ends minimum. As a result, the displacement is extremely reduced by about 10^{-4} to the displacement u_{z0} at the center of the central arm of the vibrator. [1)]

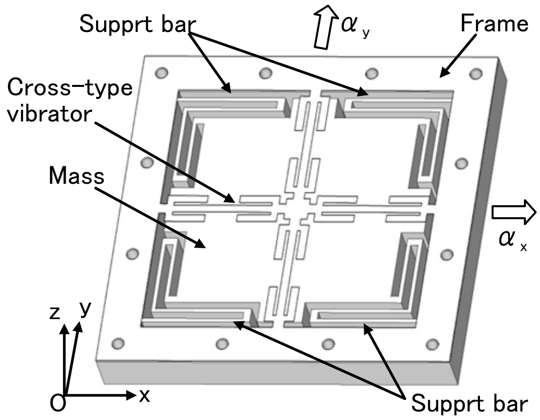
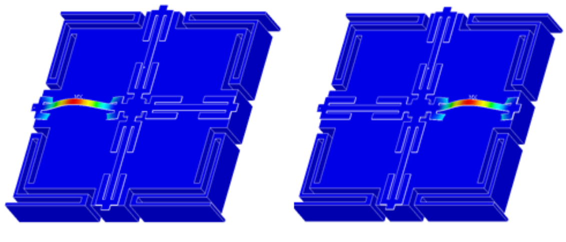


Fig. 1 Structure of two-axis acceleration sensor.


(a) f_{01}=1560.30Hz (b) f_{03}=1560.33Hz
Fig. 2 Vibration modes of vibrator in the case of no adhesion of ceramics.

The displacement ratios at the center of the central arm of two vibrators arranged along each axis direction, u_{z03}/u_{z01} (u_{z01}/u_{z03}) and u_{z04}/u_{z02} (u_{z02}/u_{z04}) are calculated as **Fig. 3** when the length ℓ_a of the short arm is changed. From the result, the ratios become almost zero in a certain range of the

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length ℓ_a. Accordingly the design for not generating the coupling vibration became possible.

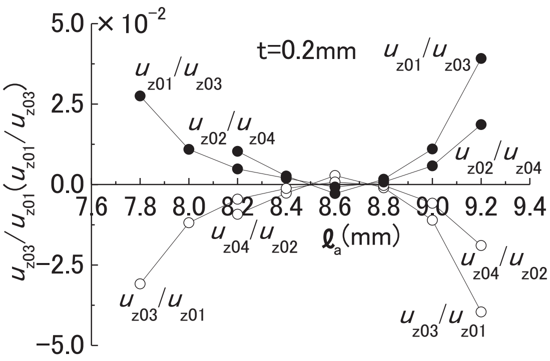
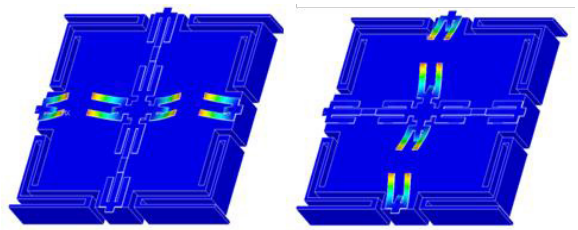


Fig. 3 Displacement ratios to arm length ℓ_a in the case of no adhesion of ceramics.

3. Coupling Vibration of Bending Vibrator

3.1 Effect of piezo-electric ceramics

In order to measure the sensor characteristics, a small thin piezo-electric ceramic plate (5x2x0.2mm^3) adheres to the upper surface of the center of the central arm of the vibrator designed so as not to generate the coupling vibration. The vibration modes are calculated as **Fig. 4**. The two vibrators arranged along each axis direction result in the coupling vibration respectively. **Fig. 5** shows the calculated result of the displacement ratios in this case. The arm length ℓ_a must be adjusted so that the ratios become a minimum value. However, the values do not become zero. This leads to the result of generating the coupling vibration.



(a) f_{01}=1555.48Hz (b) f_{03}=1556.01Hz

Fig. 4 Vibration modes of vibrator in the case of ceramics adhered to upper surface.

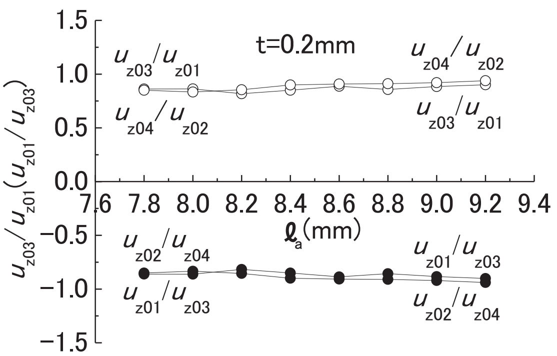
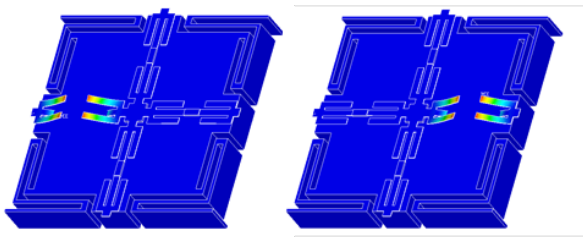


Fig. 5 Displacement ratios to arm length ℓ_a in the case of ceramics adhered to upper surface.

3.2 More reduction of coupling vibration

Asymmetry along the thickness direction by adhering of the ceramics may become the cause of generating of the coupling vibration. For this reason, the ceramics with the same dimensions were also adhered to the lower surface of the central arm. The modes of vibration were calculated as **Fig. 6**. The coupling vibration of **Fig. 4** is not observed in this case. The vibrators are vibrating independently at the nearly equal frequencies. The displacement ratios are calculated as shown in **Fig. 7.** The ratios of Fig. 5 are reduced remarkably. The ceramics of the lower surface may be replaced with the same material as the vibrator.



(a) f_{01}=1428.57Hz (b) f_{03}=1428..61Hz

Fig. 6 Vibration modes of vibrator in the case of ceramics adhered to upper and lower surfaces.

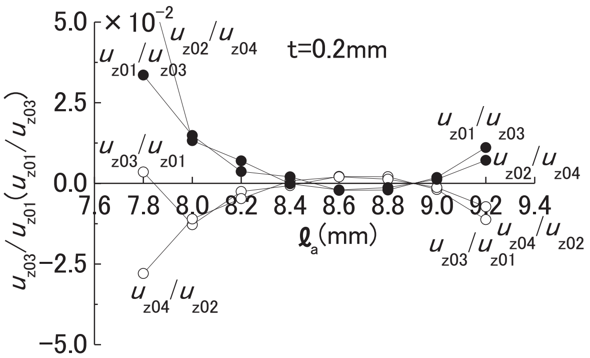


Fig. 7 Displacement ratios to arm length ℓ_a in the case of ceramics adhered to upper and lower surfaces.

4. Conclusions

The method of reducing the coupling vibration between the vibrators of the cross-type vibrator used in the frequency-change-type two-axis acceleration sensor was investigated by the finite-element analysis. As a result, it became clear that there is a limit in the method of reducing the coupling vibration by adjusting the length of the short arm. Moreover, remarkable reduction was obtained by taking into consideration symmetry along the thickness direction of vibrator.

References

1) S. Sugawara, J. Takahashi, and Y. Tomikawa: Jpn. J. Appl. Phys., **41** (2002) 3433.
2) S. Sugawara, K. Omori, and K. Takahashi: Proc. 35th Symp. Ultrasonic Electronics, 2014, p. 273.