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Simplification of Structure of Frequency-Change-Type Three-Axis Acceleration Sensor
周波数変化型３軸加速度センサの構造の簡素化

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1. Introduction

In order to obtain motion information of moving objects such as automobiles, robots and structures such as buildings, it is required to develop a highly sensitive, highly stable and inexpensive acceleration sensor suitable for the MEMS structure. As such a sensor, some kinds of acceleration sensors were proposed that utilize the change in resonance frequency caused by the axial force in the transverse vibrator.[1)] Furthermore, it has been also proposed that the three-axis acceleration sensor of the frequency-change-type can be realized using the right-angled vibrator.[2, 3)] However, the three-axis sensor becomes highly sensitive, but it has a three-dimensional and complicated structure.[4)] Therefore, the structure must be simplified from the viewpoint of realizing the MEMS sensor.

Here, a new simplified configuration of the frequency-change-type three-axis acceleration sensor is proposed in which both of the two right-angled vibrators used are arranged only on the upper surface of the mass. The sensor is designed using the finite element method, and its characteristics are analyzed and compared with those of the sensor already proposed.

2. Structure of Three-Axis Acceleration Sensor

2.1 Structure of sensor

Fig. 1 shows a simplified structural example of the frequency-change-type three-axis acceleration sensor. The right-angled vibrator used is constituted by arranging two transverse vibrators in a plane at right angles. These transverse vibrators vibrate in the out-of-plane mode. The right-angle portion of the right-angled vibrator is connected to the surface of the divided mass through a spacer. Both ends of the right-angled vibrator are fixed to the frame, and each mass is also fixed to the frame using bent-type support bars at its two corners.

2.2 Operation mechanism of sensor

When the acceleration α_x or α_y in the x- or y-axis direction is applied, the two masses move in the same phase in each axis direction. As a result, the axial force is applied to the two transverse vibrators, and their resonance frequencies are changed. It is possible to estimate the applied acceleration from the resonance frequency change Δf_x or Δf_y. Also, when the acceleration α_z is applied in the z-axis direction, the two masses tilt in the opposite phase around the x axis as shown in **Fig. 2**. The frequency change Δf_z of the vibrator due to α_z is generated in the same vibrator as in the case of α_y. The signals detected piezoelectrically from the two vibrators arranged in the y-axis direction are separated into the signals due to α_z or α_y by means of their sum or differential detection after the *F-V* conversion.

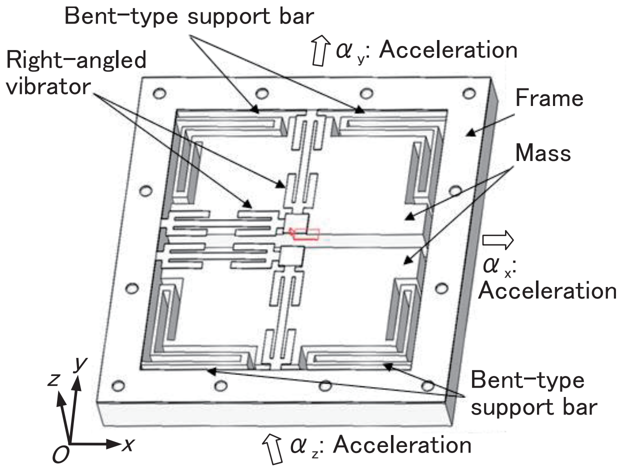

Fig. 1 New structure of three-axis acceleration sensor.

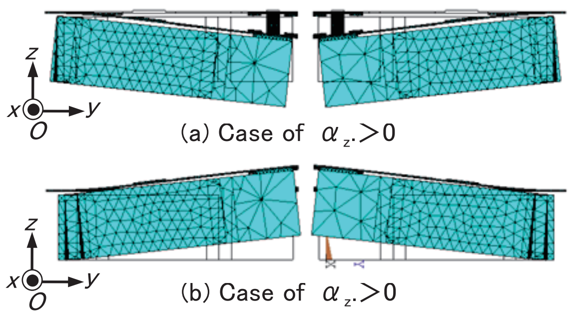

Fig. 2 Movement of mass due to acceleration α_z.

3. Design of Prototype Sensor

A small piezoelectric ceramic piece ($5\times2\times0.2$ mm^3) for driving is bonded to the upper surface of

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the central arm of each transverse vibrator. In this case, it is necessary to design so that coupling vibration does not occur between the two transverse vibrators constituting the right-angled vibrator. Therefore, the ratios between the maximum displacements u_{z0i} in the z-axis direction of the two transverse vibrators were analyzed with respect to the length ℓ_a of the short arm installed on both sides of both ends of the transverse vibrator, and the relationships were shown in **Fig.3**. Here, i (=1-4) is a number of the vibrator sequentially named counterclockwise from the transverse vibrator placed in the x-axis direction of the right-angled vibrator in the lower portion in Fig. 1. Also, f_{0i} is the resonance frequency of the i-th transverse vibrator. From the results of Fig. 3, the maximum displacement ratios become almost zero when ℓ_a=8.4 mm. Therefore, it was confirmed that it is possible to design so that coupling vibration is not excited even when the ceramic piece is bonded on one-side surface of the center arm of the vibrator.

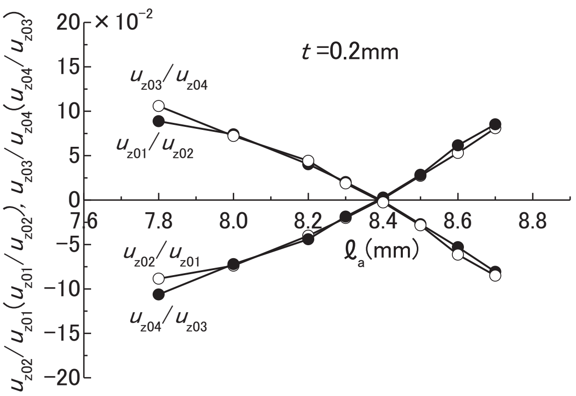

Fig. 3 Analyzed relationships of maximum displacement ratios to short arm length of transverse vibrator.

4. Sensor Characteristics

4.1 Characteristics of sensor designed

The external dimensions of the acceleration sensor designed are relatively large 100×90×10.7 mm^3 for ease of handling. The sensor characteristics are analyzed and shown in **Fig. 4**. The solid lines show the case where the influence of the bonded ceramics is not taken into account, and the broken lines show the case where the influence is taken into account. By bonding the ceramics, the sensitivity was decreased by about 39% in this case.

4.2 Comparison of sensitivity

In the frequency-change-type three-axis sensor, it has been necessary to increase the frequency change rates (sensitivities) $\Delta f_{2z}/f_{02}$ and $\Delta f_{3z}/f_{03}$ due to the acceleration α_z particularly in the z-axis direction. As a method of increasing the sensitivities, the method of sandwiching the mass with the two right-angled vibrators was proposed.[4] It became clear that the sensor proposed here has almost the same high sensitivity as this. **Fig. 5** shows the comparison results of the characteristics in the z-axis directions of these sensors.

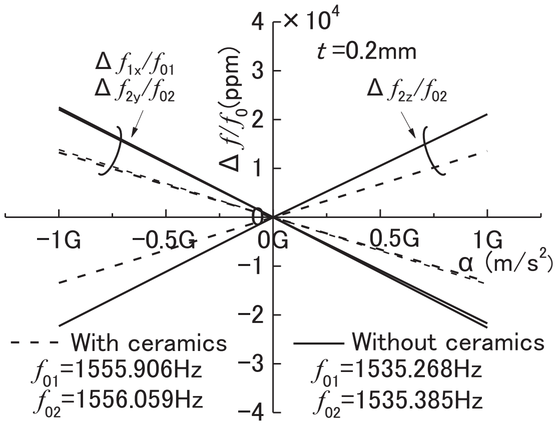

Fig. 4 Analyzed characteristics of sensor.

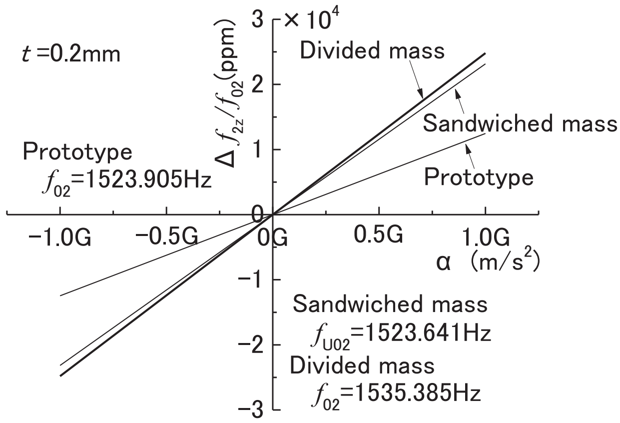

Fig. 5 Comparison of sensor sensitivity.

5. Conclusions

A new simplified frequency-change-type three-axis acceleration sensor suitable for the MEMS structure was proposed and its characteristics were analyzed by the finite element method. As a result, it was clarified that simplification and high sensitivity of the sensor structure can be realized by arranging all the vibrators only on the upper surface of the mass without using the mass sandwiched with the vibrators as in the past. From now on, the sensor characteristics will be experimentally verified.

References

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