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Characteristic Analysis of Frequency-Change-Type Two-Axis Acceleration Sensor Using Multiple Transverse Vibrators

複数の横振動子を用いた周波数変化型２軸加速度センサの特性解析

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1. Introduction

In the fields of automobiles, robots and observation of buildings, new acceleration sensors with high sensitivity and stability suitable for the MEMS structure are required in particular.[1)] As an example of such a sensor, frequency-change-type two-axis acceleration sensors have been proposed in which they utilize a change in the resonance frequency of a transverse vibrator due to axial force.[2-4)] In particular, a flat-type high-sensitivity vibrator has been newly proposed. In the vibrator, vibration displacements at both ends are considerably reduced, then the structure which hardly affected by fixing is realized. As a two-axis acceleration sensor using this vibrator, a prototype structure has been proposed in which the two vibrators are respectively arranged in the same-shaped space symmetrically provided at 45 degrees from the horizontal axis by cutting off a part of the mass used.[2)] However, as long as the sensor structure in which the vibrators are introduced by partially cutting off the mass, it is inevitable that the sensitivity of the sensor will be lowered by this decrease of the mass due to the cutting, Therefore, it was necessary to develop a new structure in which the rotational motion of the mass did not easily occur from the beginning, as achieving high sensitivity by effectively utilizing all of the mass without cutting. As a constitution of such a sensor, a two-axis acceleration sensor using a right-angled or a cross-type vibrator in which multiple transverse vibrators are arranged in a plane has been proposed.[3,4)] It was also clarified that these multiple vibrators should be aware of the design because mechanical coupling vibrations occur between the transverse vibrators. In addition, these sensors have never been studied in a unified manner from a design standpoint.

Here, the frequency-change-type two-axis acceleration sensors using a right-angled and a cross-type vibrators are newly proposed to improve the disadvantages of the previously proposed two-axis sensor. Moreover, the design method and the supplemented characteristics of these sensors are clarified using the finite element method.

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2. Structure of Two-Axis Acceleration Sensor

Fig. 1 shows the structures of a frequency-change-type two-axis acceleration sensor using multiple transverse vibrators. These vibrators used are constructed by connecting two and four transverse vibrators, respectively. As an example for explanation of operation principle of them, the sensor using the right-angled vibrator is treated here. One end of each transverse vibrator is fixed to a frame, and the other end is connected together to a central part and connected to the center of gravity on the upper surface of mass through a spacer with the same area as the center part. The mass is fixed to the frame at its four corners using bent-type support bars. The force generated in the mass by the

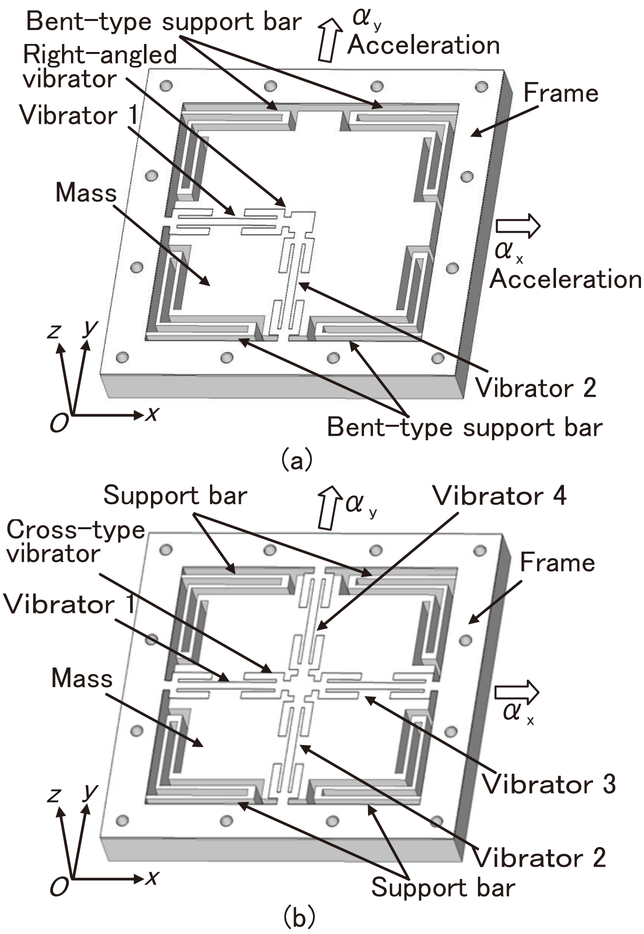

Fig. 1 Structures of sensor using multiple transverse vibrators. (a) Case of right-angled vibrator. (b) Case of cross-type vibrator.

acceleration α applied to the sensor acts as an axial force of tension or compression on the transverse vibrator arranged in the two axial directions, and increases or decreases the resonance frequency of each vibrator. The applied acceleration can be estimated from the change amount of the frequency.

3. Characteristic Analysis of Sensor with Right-Angled Vibrator

A method of considerably reducing coupling phenomenon was studied by adjusting the length ℓ_a of the short arm equipped on both sides of both ends of each transverse vibrator. **Fig. 2** shows the ratio u_{z02}/u_{z01} or u_{z01}/u_{z02} of the maximum displacement u_{z01} or u_{z02} in the z-axis direction at the center of the central arm of the vibrator with respect to the arm length ℓ_a of the vibrator 1 or 2. The analysis results when the thickness of the vibrator is t=0.2mm have already been reported. However, the results at thicknesses other than t=0.2mm have not been clarified, and its clarification has been desired. From the results in Fig. 2, it became clear that the values of u_{z02}/u_{z01} and u_{z01}/u_{z02} become almost zero at the same time when the arm length ℓ_a=8.7mm and the value of the arm length ℓ_a becomes almost the same even if the thickness t changes. At the time, one of the two vibration amplitudes disappears in each coupling vibration, and each vibrator independently vibrates at almost the same resonance frequency. By observing the vibration modes analyzed at the short arm length clarified here, it was confirmed that, even in the structure in which two transverse vibrators are mechanically connected, the coupling vibration phenomenon hardly occurs and such a sensor design is also possible. A small piezoelectric ceramic piece (5×2×0.2 mm^3) for driving is bonded to the upper surface of the central arm of each vibrator. **Fig. 3** shows the sensor sensitivity on the x-axis direction to the thickness t of the vibrator. Measured values agree almost with the calculated ones.

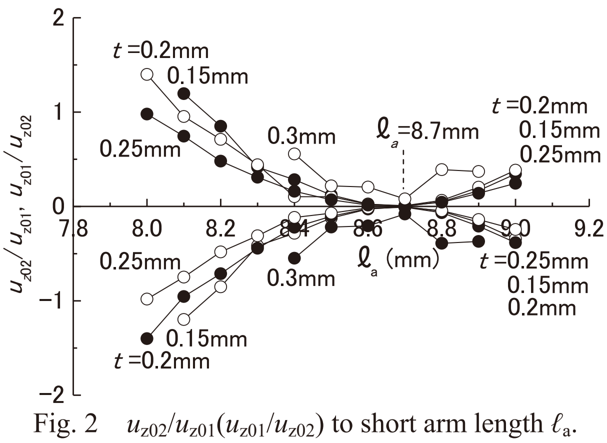

Fig. 2 $u_{z02}/u_{z01}(u_{z01}/u_{z02})$ to short arm length ℓ_a.

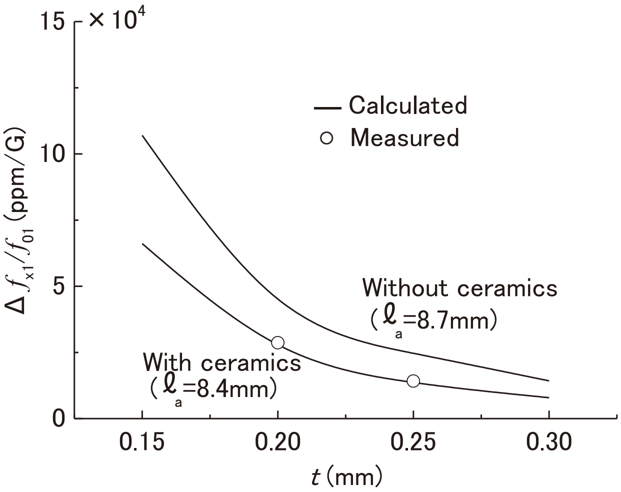

Fig. 3 Sensitivity of sensor using right-angled vi rator.

4. Characteristic Analysis of Sensor with Cross-Type Vibrator

A cross-type vibrator can be roughly as a structure in which two right-angled vibrators are arranged in a cross shape, or four vibrators are arranged in cross shape in a plane. As a result, a structure in which two transeverse vibrators are arranged in each of the x- and y-axis directions is realized. Therefore, it becomes possible to differentially detect the electrical signals from each of the two vibrators. Then, a frequency-change-type two-axis acceleration sensor capable of canceling out the temperature characteristic of the vibrator in each axis direction should be realized. This is the greatest merit of using the cross-type vibrator. The design method and characteristics of this sensor structure are basically the same as in Chapter 3, so they are omitted here.

5. Conclusions

To improve the disadvantages of the previously proposed frequency-change-type two-axis sensor, a new sensor structure using a right-angled or cross-type vibrator consisting of multiple transverse vibrators was newly proposed here, and the design method and supplemented characteristics of these sensors were clarified using the finite element method. These sensor structures are characterized in that the cross-sensitivity of the sensor can be considerably reduced because the vibrator can be connected to the center of gravity of the mass.

References

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