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Improvement of temperature stability in MEMS differential resonant accelerometer by G-T correction

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Summary:

This paper presents a method for reducing temperature drift in MEMS differential resonant accelerometer (DRA). Conventionally, the difference in resonant frequency between two beams is utilized to eliminate the effect of temperature. However, the temperature coefficients of frequency (*TCf*) of the two beams do not match perfectly, resulting in temperature drift. G-T correction was performed to account for the difference in *TCf*. The measured Allan deviation was BI > 1 μG for the differential correction, and a highly accurate bias instability of BI < 500 nG was achieved by applying G-T correction.

Keywords: MEMS, accelerometer, DRA, TCf, G-T correction

Introduction

Highly accurate and wide dynamic range (navigation grade) accelerometers are needed for autonomous operation of airplanes and automobiles. These accelerometers must also be robust against disturbances such as temperature changes. MEMS differential resonant accelerometer (DRA) are being investigated for such applications. Here, we report a method for reducing temperature drift in DRA.

Design

The structure and operating principle of a DRA is shown in Fig. 1 [1]. The prototype MCU-based module (5 × 5 × 1 cm) and DRA electrodes are shown in Fig. 2 [2]. When the inertial force due to acceleration acts on the proof mass, it rotates around the pivot, causing tension and compression stresses to be generated in opposite directions in the two resonant beams. Consequently, the resonant frequency also changes in the opposite direction. However, both resonant frequencies decrease as the temperature increases, due mainly to the temperature dependence of Young's modulus of Si. These relationships are expressed by the following equation.

$$\begin{pmatrix} f_1 \\ f_2 \end{pmatrix} = \begin{pmatrix} SF_1 & TCf_1 \\ SF_2 & TCf_2 \end{pmatrix} \begin{pmatrix} G \\ T \end{pmatrix} + \begin{pmatrix} c_1 \\ c_2 \end{pmatrix} \quad (1)$$

Here, f_i is the resonant frequency (Hz), SF_i is the scale factor (Hz/G), TCf_i is the temperature coefficient of frequency (Hz/degC), c_i is the initial bias (Hz), G is the acceleration (G), T is the temperature (degC), and the subscript i is the difference between beam 1 and beam 2.

Because our DRA has a structure that is supported by only one anchor, the two beams are less affected by thermal stress. In addition, asymmetric double T-shaped electrodes are added at the maximum displacement position of the two beams in order to improve the capacitive sensitivity dC/dy and dynamic range.

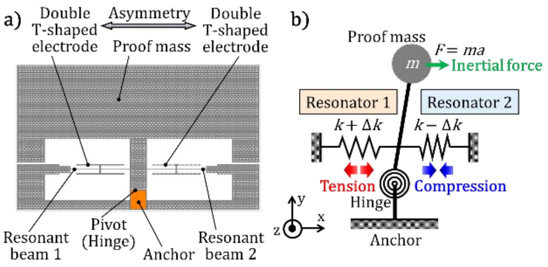

Fig. 1. (a) Structure of the MEMS DRA. (b) Concept of DRA acceleration measurement.

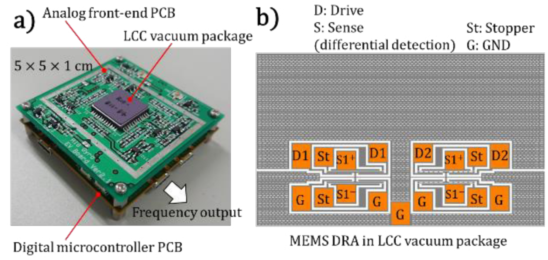

Fig. 2. (a) Photograph of the MCU-based DRA module. (b) Diagram of the MEMS DRA electrodes.

Correction methods

Differential correction

Conventionally, acceleration was measured by removing temperature dependence by taking the difference between the resonant frequencies of two beams, as in the following equation [3].

$$\Delta G = \frac{\Delta f_1 - \Delta f_2}{SF_1 - SF_2} \qquad (2)$$

Here, ΔG is the change in acceleration (G) and Δf_i is the change in resonant frequency (Hz).

G-T Correction

However, the *TCf* of the two resonant beams differed, and temperature drift occurred if only the differential was used. Therefore, we solved (1) assuming that *SF* and *TCf* are linearly independent and orthogonal, as in the following equation.

$$\Delta G = \frac{TCf_2 \cdot \Delta f_1 - TCf_1 \cdot \Delta f_2}{SF_1 \cdot TCf_2 - SF_2 \cdot TCf_1} \qquad (3)$$

Experiment results

Measurements of SF and TCf

The results of *SF* and *TCf* measurements for the prototype DRA are shown in Figs.3 and 4, respectively. *SF* and *TCF* of two resonant beams were SF_1 = 14.2 Hz/G, SF_2 = −16.2 Hz/G, and TCf_1 = −0.63 Hz/degC, TCf_2 = −0.77 Hz/degC.

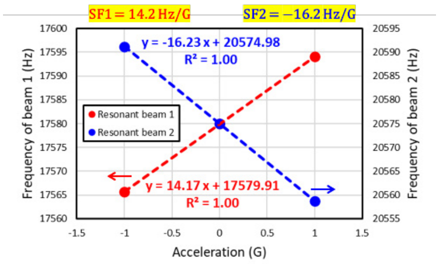

Fig. 3. SF measurement results for the DRA.

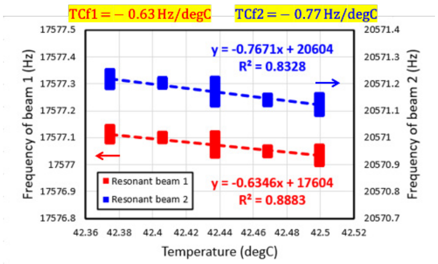

Fig. 4. TCf measurement results for the DRA.

Measurement of Allan deviation

DRA noise (velocity random walk (VRW)) is reduced in inverse proportion to the drive voltage Vac, as shown in the following equation.

$$\mathrm{VRW} \propto \frac{1}{V_{dc} \cdot V_{ac} \cdot \dfrac{dC}{dy}_{drive} \cdot SF} \qquad (4)$$

Here, V_{dc} and V_{ac} are the DC and AC voltages of the drive, respectively, and dC/dy_{drive} is the capacitive sensitivity of the drive electrodes.

We varied Vac from 5 to 25 mV and measured the Allan deviation. The results obtained by differential correction are shown in Fig. 5. VRW was decreased by the drive voltage Vac. However, due to the effect of temperature drift, it bottomed out at about tBI = 20 s, and BI became 1.0 μG at Vac = 25 mV. The result obtained by G-T correction is shown in Fig. 6. Due to the effect of reduced temperature drift, the Allan deviation continued to decrease by −1/2 power, and finally BI became 430 nG at Vac = 25 mV.

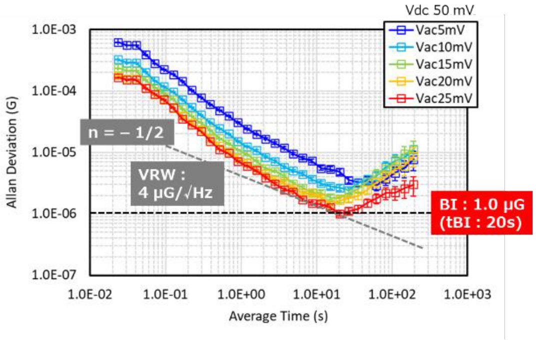

Fig. 5. Allan deviation of a DRA with differential correction.

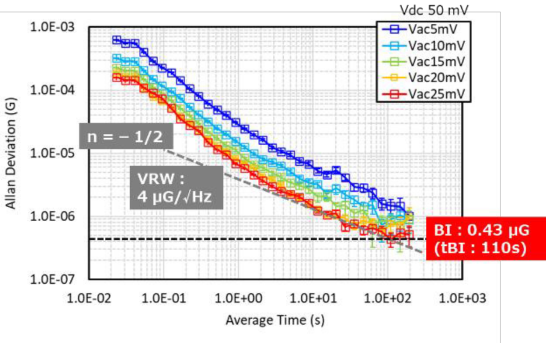

Fig. 6. Allan deviation of a DRA with G-T correction.

Conclusions

To improve the capacitive sensitivity dC/dy, double T-shaped electrodes were added. The effect of temperature drift in the DRA was reduced by applying G-T correction. As a result, a highly accurate bias instability of BI < 500 nG was achieved.

References

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