

Fundamental Study on Vibratory Tactile Sensor Using Piezoelectric Bimorph Resonator

圧電バイモルフ振動子を用いた振動型触覚センサの基礎検討

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1. Introduction

Various kinds of tactile sensors have been used for measuring the physical characteristics of an object. Recently, the piezoelectric vibratory tactile sensors have been proposed for measuring the softness and hardness of an object (1-5). They make use of changes in the resonance frequencies of the resonators, which are induced when their vibrating sections are brought into contact with an object. Therefore, these tactile sensors are driven by self-oscillating method. In this study, a new construction of tactile sensor is investigated by using a piezoelectric bimorph resonator. A possibility for detecting the hardness of an object is studied with the piezoelectric bimorph resonator.

2. Structure of tactile sensor

Figure 1 shows the construction of a tactile sensor used as a piezoelectric bimorph resonator. Piezoelectric bimorph plate (FDK Co.) was attached to the holding stand. The size of the bimorph plate was 60mm in length, 20mm in width and 0.55mm in thickness. The sensor tip of the bimorph resonator was hemispheric with a radius $R=1.0\text{mm}$.

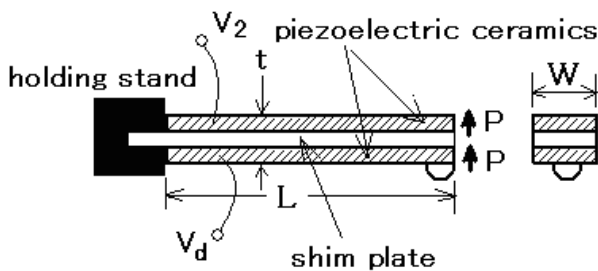


Fig.1. Construction of vibratory tactile sensor using piezoelectric bimorph.

The bimorph resonator is driven by constant voltage of V_d and constant driving frequency of f_d . When the tip of a tactile sensor is contacted with an object, the resonance frequency and quality factor of the resonator change. Then, the amplitude and the phase of output voltage V_2 will be changed. Figure 2 shows the equivalent circuit of the tactile sensor. The characteristics of the tactile sensor can

be analyzed by using this equivalent circuit.

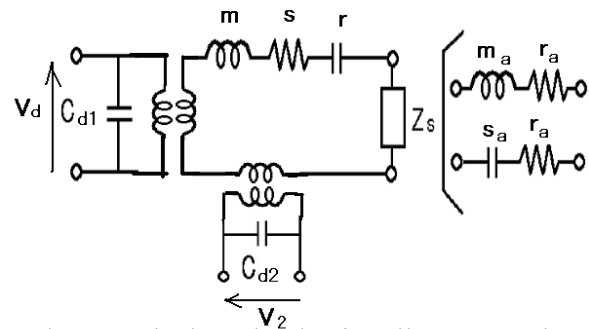


Fig.2. Equivalent circuit of tactile sensor using piezoelectric bimorph.

3. Experimental results

To obtain the characteristics on tactile sensors, the bimorph resonators were placed in contact with standard rubber test pieces (6). The amplitude and the phase of output voltage were measured using the phase locked amplifier. The impressed load force was measured with an electric balance. The size of the test pieces of S4-S6 (AXIOM Co.) was 44mm in diameter and 10mm in thickness, and the material constants are shown in Table 1.

Table 1. Material constants of test pieces.

Type	S4	S5	S6
Young's modulus (MPa)	0.216	0.386	0.653
Density (kg/m^3)	1045	1175	1210

3.1 Characteristics for first vibration mode

Figures 3 and 4 show the experimental results for the tactile sensor with the first vibration mode. The bimorph tactile sensor was driven by driving voltage of $V_d=500\text{mV}$ and driving frequency of $f_d=f_0=445\text{Hz}$. When the sensor tip was contacted to the test piece, the amplitude of the output voltage of V_2 decreased rapidly as in Fig.3. Then, as the load added to test piece increased, the amplitude of V_2 gradually decreased. It is thought that the resonance frequency of the tactile sensor was changed and the quality factor was decreased by contacting with the test pieces. The characteristics between the load and the amount of decrease of V_2 show the tendency that the amount of decrease for the soft test piece S4 is smaller than that of the hard test pieces S5 and S6. This reason is to be thought that the amount of

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decrease of Q value for the soft test piece S4 is smaller than that of the hard test pieces S5 and S6 in case of contacting with the test pieces. On the other hand, Fig.4 shows the characteristics between the load and the phase difference of output voltage. The amount of phase difference is expressed as $\Delta\phi (= \phi_L - \phi_0)$, where ϕ_L is the phase of output voltage V_2 when a load is applied and ϕ_0 is the phase of V_2 with no load.

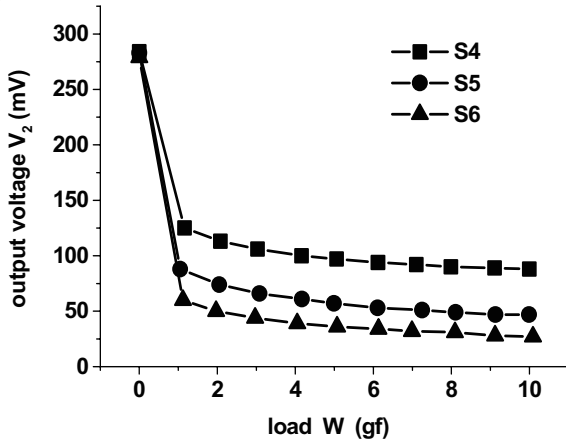


Fig.3. Measured characteristics between W and V_2 using first vibration mode.

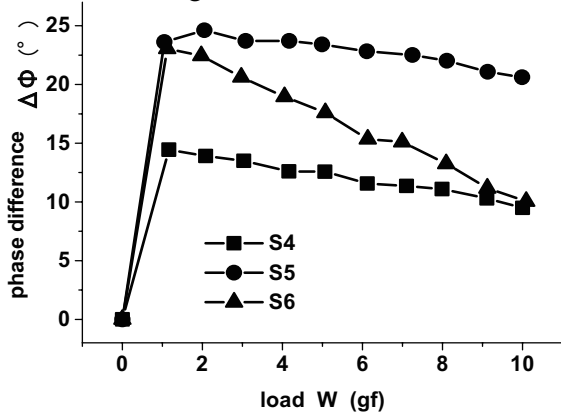


Fig.4. Measured characteristics between W and $\Delta\phi$ using first vibration mode ($\phi_0 = 134^\circ$).

When the sensor tip was contacted to the test piece, the phase of V_2 increased rapidly as in Fig.4. Then, as the load added to the test piece increased, the phase of V_2 gradually decreased. The difference of hardness was not so clarified from the experimental results of phase difference.

3.2 Characteristics for second vibration mode

Figure 5 and 6 show the experimental results for the tactile sensor with the second vibration mode. The bimorph type tactile sensor was driven by $V_d=500\text{mV}$ and $f_d=f_0=2.481\text{kHz}$. When the load added to the test piece increased, the amplitude of V_2 gradually decreased as shown in Fig.5. The amplitude of V_2 is smaller than that in the case of using the first vibration mode because the force factor in second vibration mode is smaller than that

in the first vibration mode. Figure 6 shows the characteristics between the load and the phase difference of V_2 . When the sensor tip was contacted to the test piece, the phase of V_2 gradually increased. It is difficult to measure the hardness of an object only from the experimental results of the phase difference.

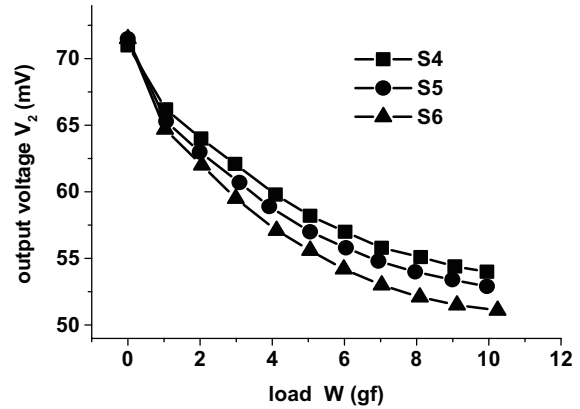


Fig.5. Measured characteristics between W and V_2 using second vibration mode.

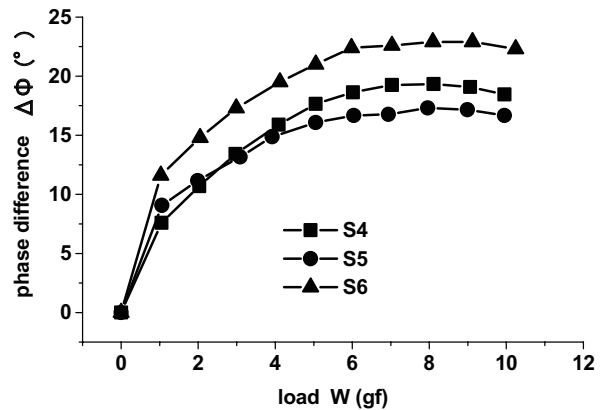


Fig.6. Measured characteristics between W and $\Delta\phi$ using second vibration mode ($\phi_0 = 103^\circ$).

4. Conclusion

The bimorph type tactile sensor was studied in this paper. It was examined that the possibility for detecting the hardness of an object by bimorph type tactile sensor. This work was partially supported by a Grant-in-Aid for Scientific Research B(No. 21360106) from the Japan Society for the Promotion of Science.

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