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Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 501-502
8-10 November, 2011

Fundamental Study on Hardness Measurement Using Piezoelectric Bimorph Resonator
圧電バイモルフ振動子を用いた硬さ測定に関する一考察

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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. In this study, a new construction of hardness measurment is investigated by using a piezoelectric bimorph resonator. A possibility for detecting the hardness of an object is studied with the experimental results and the equivalent circuits analysis.

2. Structure of tactile sensor and equivalent circuits

Figure 1 shows the construction of 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 tip of the bimorph resonator was hemispheric with a radius R=1.0mm.

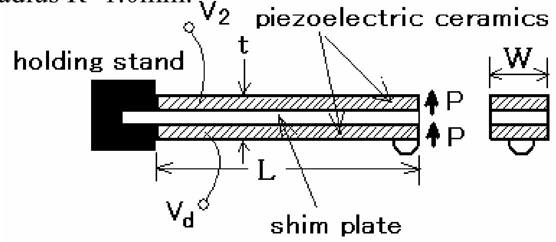


Fig.1. Construction of hardness measurment using piezoelectric bimorph.

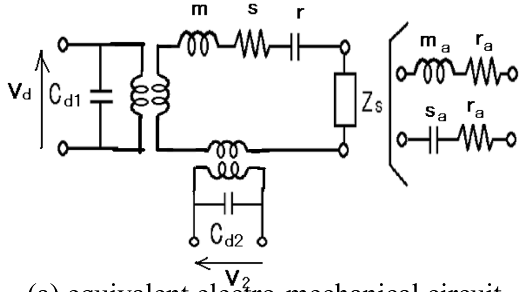
To measure the hardness of an object, the bimorph resonators were placed in contact with standard rubber test pieces 6). The amplitude and the phase of output voltage were measured using the phase locked amplifier. The impressed load force was measured with an electric balance. The size of the test pieces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

Table I. Material constants of test pieces.

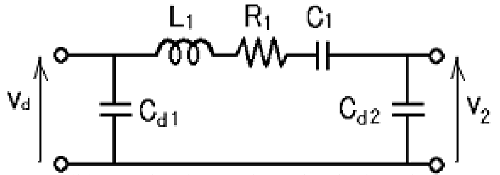
Type	S4	S5	S6
Young's modulus **(MPa)**	**0.216**	**0.386**	**0.653**
Density **(kg/m^3)**	**1045**	**1175**	**1210**

The bimorph resonator is driven by constant voltage of V_d and constant driving frequency of f_d. When the tip of a resonator 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. The contact impedance was calculated by the experimental results of the amplitude and phase of output voltage.

Figure 2(a) and (b) show the equivalent circuit of the bimorph resonator. The characteristics of the contact impedance can be analyzed by using this equivalent circuit. Then, Table II shows the equivalent circuit constants obtaind by the experiments.



(a) equivalent electro-mechanical circuit.



(b) equivalent electrical circuit.

Fig.2. Equivalent circuit of piezoelectric bimorph resonator.

3. Equivalent circuit analysis

3.1 Characteristics for first vibration mode

For measuring the softness and hardness of test pieces, the contact impedance was calculated using the equivalent circuits in Fig.2 with experimental characteristics of output voltage 7). The bimorph resonator was driven by constant driving voltage of V_d=500mV and constant driving frequency of f_d= f_0=447Hz. When the resonator tip was contacted to the

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Table II. Equivalent circuit constants.

	First mode	Second mode
Resonance frequency f_0	446.8(Hz)	2.483(kHz)
Electrical inductance L1	159.1(H)	43.4(H)
Electrical capacitance C1	797.7(pF)	94.72(pF)
Electrical resistance R1	7.33(kΩ)	6.51(kΩ)
Quality factor Q	90	104
Dumped capacitance Cd1	62.3(nF)	62.3(nF)
Dumped capacitance Cd2	62.0(nF)	62.0(nF)
Force factor A	$0.118(g/H)^{1/2}$	$0.215(g/H)^{1/2}$

test piece, the amplitude and phase of the output voltage of V_2 changed rapidly. Figure 3 shows the calculated results for the contact impedance of C1 using the first vibration mode. The equivalent capacitance of C1 gradually decreased as the load added to test piece increased. It is thought that the contact stiffness on the tip of bimorph resonator was increased by contacting with the test pieces. The characteristics between the load and the amount of decrease of C1 show the tendency that the amount of decrease for the hard test piece S6 is larger than those of the soft test pieces S4 and S5. This reason is to be thought that the contact stiffness of the harder test pieces is larger than those of the soft test pieces on the same load. On the otherhand, Fig.4 shows the characteristics between the load and the difference of equivalent resistance. The amount of resisitance change is expressed as Δ R1(=R_L-R1), where R_L is the equivalent resistance when a load is applied and R1 is the resisitance with no load. When the load added to the test piece increased, ΔR1 gradually increaed.

3.2 Characteristics for second vibration mode

Figure 5 shows the experimental results for the contact impedance of C1 using the second vibration mode. The bimorph resonator was driven by V_d=500mV and f_d=f_0=2.483kHz. When the load added to the test piece increased, the value of C1 gradually decreased. The characteristics showed a similar result using a first vibration mode in Fig.3. However, the difference of hardness was not so clarified from the characteristics of equivalent capacitance C1 in second vibration mode. The equivalent resistance change also showed the simlar characteristics in Fig.4.

4. Conclusion

The hardness measurement using a bimorph resonator was studied in this paper. It was examined that the possibility for detecting the hardness of an object by bimorph resonator. 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.

References

[1] H.Itoh, et al : Jpn.J.Appl.Phys **38** (1999) 3225.

[2] H.Watanabe : Jpn.J.Appl.Phys **40** (2001) 3704.

[3] Y.Murayama and S.Omata:IEEE Trans. Ultra. Fero. & Freq. Cont. **52**(2005)434.

[4] S.Kudo:JSME-C,**49**(2006)675.

[5] S.Kudo:Jpn.J.Appl.Phys, **46**(2007)4704.

[6] S.Kudo, et al: Ultrason. Technol., 16,3(2004) 94[in Japanese].

[7] S.Kudo:Proc.Symp.Ultrason.Electro.**31**(2010)87.

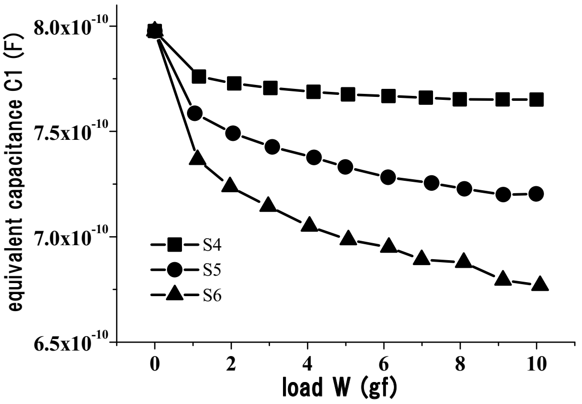

Fig.3. Calucuated relationships between W and C1 using first vibration mode.

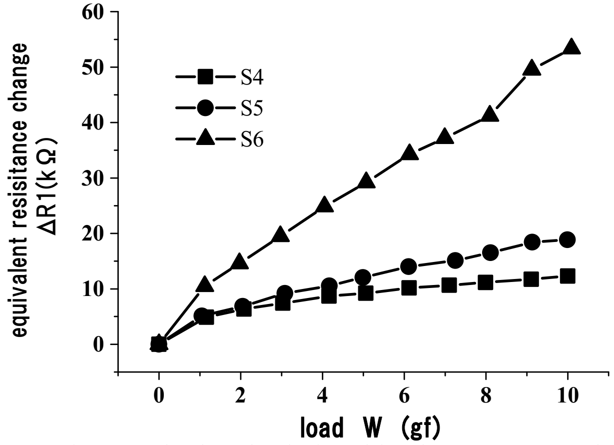

Fig.4. Calculated relationships between W and ΔR1 using first vibration mode.

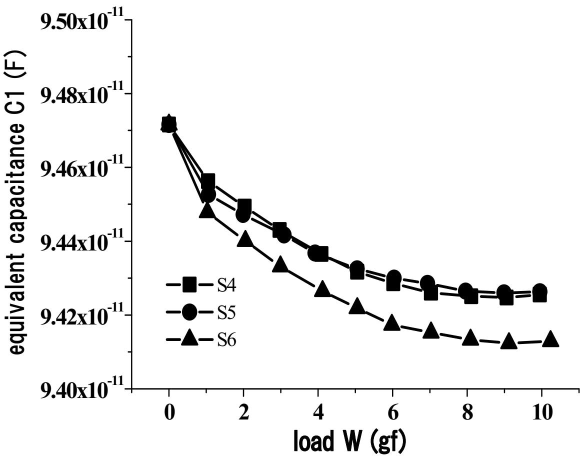

Fig.5. Calculated relationships between W and C1 using second vibration mode.