2P3-4

Proceedings of Symposium on Ultrasonic Electronics, Vol. 36 (2015)
5-7 November, 2015

The method of estimating density of the object using vibratory tactile sensor
振動型触覚センサを用いた対象物の密度推定の方法

Subaru Kudo (Ishinomaki Senshu Univ.)
工藤すばる（石巻専修大 理工）

1. Introduction

Various kinds of piezoelectric vibratory tactile sensors have been proposed for measuring the physical characteristics of an object. These tactile sensors have already been measured the softness and hardness of an object [1-5]. Recently, we have proposed the method on measuring the density of an object[6]. For estimating the density, it is necessary to obtain an accurate equivalent mass of tactile sensor. In this paper, the equivalent mass of tactile sensor is calculated with finite element method. Then, the method on measureing the density of an object is examined.

2. Estimation of equivalent mass

2.1 Analysis method

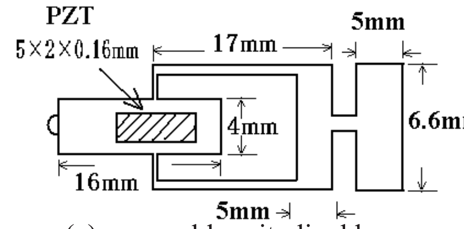
In general, the resonance angular frequency ω_0 of a resonator is shown by $\omega^2_0=s/m_0$. Here, m_0 and s are the equivalent mass and stiffness of the resonator, respectively. When the minute mass is attached to the vibrating tip of resonator, resonant frequency changes owing to an additional mass efect. In this case, the resonance angular frequency ω is approximately given by $\omega^2=s/(m_0+\Delta m)$, where Δm is an additional mass. Moreover, in the case of assuming that $1 \gg \Delta m/m_0$, the equivalent mass m_0 is expressed as

$$m_0 = \frac{f_0}{2} \cdot \frac{\Delta m}{\Delta f} \qquad , \qquad (1)$$

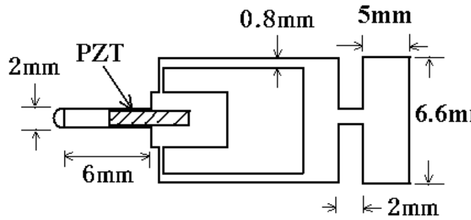
where $\Delta f\,(=f_0-f)$ is the resonance frequency change. This approximate equation means that the equivalent mass of resonator is proportional to $\Delta m/\Delta f$.

2.2 Calculated results of finite element analysis

In this study, the longitudinal bar type resonators shwn in Fig.1 were adopted as tactile sensors. The piezoelectric vibratory tactile sensors were fabricated from SUS304 stainless steel using an electric discharge machine. The sensor tip (SUJ-2) of the resonator was hemisheric with a radius R=1.0mm. Piezoelectric ceramic plates (Nepec6) were attached to the center of the longitudinal bar to drive the resonators. The equivalent masses of the resonators in Fig.1 were calculated using the finite element method. The analysis is performed using the finite element analysis program ANSYS ver.16. Figure 2 shows the calculated relationship between Δf and Δm. As the additional mass Δm is attached to the vibrating tip of resonator in Fig.1, the resonance frequency change Δf is calculated. The values of $\Delta m/\Delta f$ are given by 0.0053 for general longitudinal bar resonator and by 0.0023 for horn type resonator with carve fitting. Table 1 shows the characteristics of equivalent masses. The measured equivalent masses coincide with the calculated values obtained from eq.(1) and Fig.2.



(a) general longitudinal bar resonator



(b) horn type resonator

Fig.1. Construction of vibratory tactile sensor (thickness:2mm).

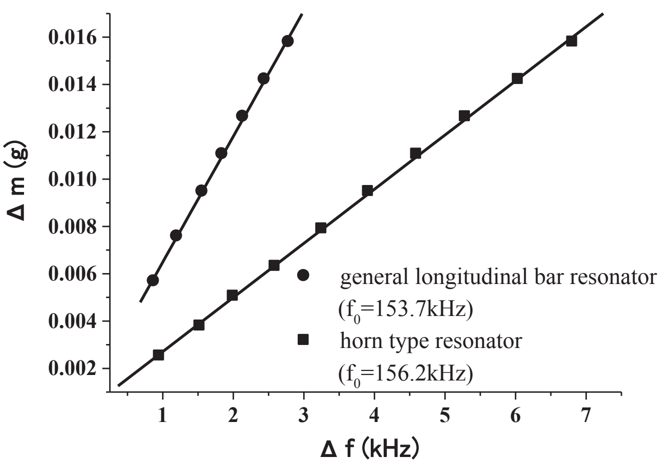


Fig.2. Calculated results of additional mass effect.

kudou@isenshu-u.ac.jp

Table 1. Characteristics of equivalent masses.

	Calculated value m_0 (g)	Experimental value m_0 (g)
Type (a)	0.41	0.40
Type (b)	0.18	0.15

3. Experimental investigation

3.1 Experimental method

To obtain the characteristics on tactile sensors, the resonators were placed in contact with test rubber pieces, and its resonance frequency was measured using impeadance analyzer (Agilent 4294A). The impressed load force was measured with an electric balance (A&D GF-3000). The size of the test rubber pieces of S1-S6 (AXIOM Co.) was 44mm in diameter and 10mm in thickness, and the measured material constants are shown in Table 2.

Table 2. Material constants of test rubber pieces.

Type	S1	S2	S3	S4	S5	S6
Young's modulus (kPa)	9	28	72	164	309	559
Density ρ (kg/m^3)	1011	1000	1072	1084	1096	1249

3.2 Experimental results

When the tactile sensors were brought into contact with a soft object, the resonance frequency of the resonator decreased as a result of an additional mass effect. As the load added to the test rubber pieces increased, the additional mass effect increased and the resonance frequency of the resonator decreased gradually. Figures 3 and 4 show the characteristics of additional mass m_L when the tactile sensors were brought into contact with the test rubber pieces. The additional masses were calculated using the experimental results of resonance frequency changes, the Young's modulus in Table 2 and the equivalent mass in Table 1. It is clarified that the similar characteristics of additional masses were obtained using the resonators with the different equivalent masses. The estimated values on density of each test pieces were shown in Fig.5. It is also indicated that the values of density in Table 2, which were measured by the mass and volume of test pieces. The estimated values of density are different form the experimental ones according to a specific test pieces. It is planned to examine the factor of difference in detail.

4. Conclusion

The equivalent mass of tactile sensor was calculated with finite element method. Then, the estimation on density of the test rubber pieces was studied using a vibratory tactile sensor with the different equivalent mass. It was investigated that the possibility for detecting the density of an object.

References

1. C.Kleesattel and G.M.L.Gladwell: Ultrasonics, p.175(1968).
2. S.Omata and Y.Terunuma:Sens.Actuat.,A35, pp.9-15 (1992).
3. H.Itoh,et al: Jpn.J.Appl.Phy.,Vol.38,No.5B,pp.3225-3227 (1999).
4. H.Watanabe,et al: Jpn.J.Appl.Phy.,Vol.44,No.6B, pp.4498-4500 (1999).
5. S.Kudo: Jpn.J.Appl.Phy.,Vol.49(07HD03) (2010).
6. S.Kudo:Pro.Sym. Ultra. Elec.,Vol.35,pp.283-284 (2014).

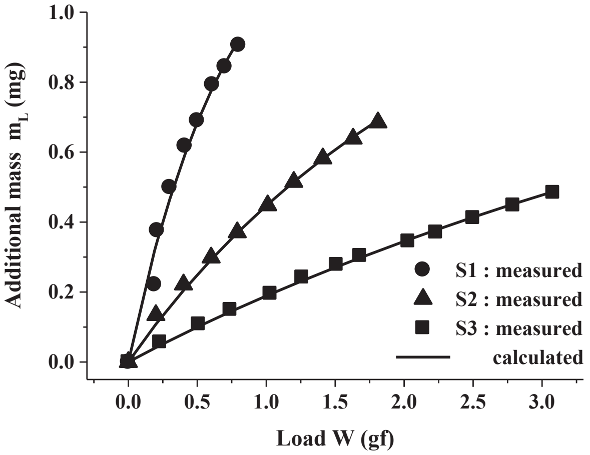


Fig.3.Characteristics of additional mass (1) for general longitudinal bar resonator.

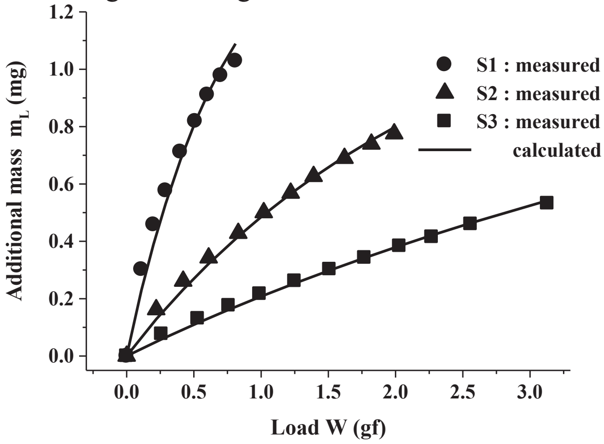


Fig.4. Characteristics of additional mass (2) for horn type resonator.

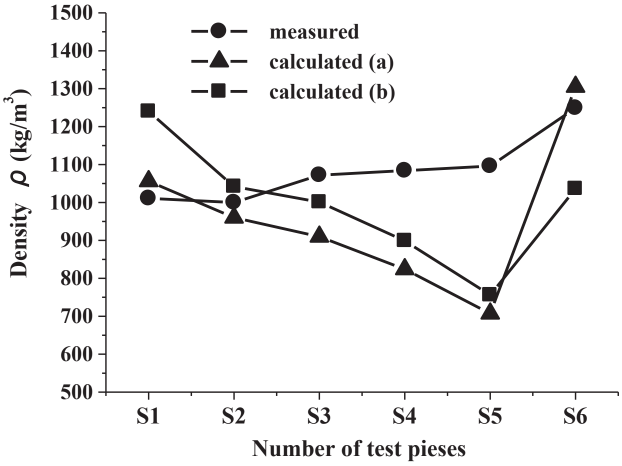


Fig.5. Characteristics of density.