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Study on the indenter shape of vibratory tactile sensor
振動型触覚センサの接触子形状に関する考察

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

1. Introduction

Various kinds of tactile sensors have been used for measuring the physical characteristics of an object [1-4]. Recently, various piezoelectric vibratory tactile sensors have been proposed for measuring the softness and hardness of an object [5-10]. They make use of the resonance frequency changes on resonators, which are induced when their vibrating indenters are brought into contact with an object. The rate of resonance frequency change depends on the acoustic impedance of an object that corresponds to the contact area of the indenter. We have previously proposed the sensitivity of the tactile sensor in terms of the frequency change for developing a systematic method of designing vibratory tactile sensors. However, the characteristics of tactile sensor are depend on the indenter shape of resonator. In this paper, the characteristics of tactile sensor with a different indenter shape are experimentally examined.

2. Structure of tactile sensor

Figure 1 shows the piezoelectric vibratory tactile sensor with a supporting structure for experiment. The supporting structure of tactile sensor was designed to reduce the vibration displacement at supporting area. The resonance frequency of $|\Delta f/f_0|$ at various conditions of supporting area was calculated with the finite element method using the analysis program of ANSYS ver.16. Here, $\Delta f/f_0$ is expressed as $\Delta f = f_{clamp} - f_{free}$, $f_0 = f_{free}$, where f_{clamp} is the resonance frequency under the clamping condition in the supporting area, and f_{free} is that under the free condition. $|\Delta f/f_0|$ was able to be reduced to 3ppm or less with the dimentions of supporting structure in Fig.1. The tactile sensor was fabricated from SUS304 stainless steel using an electric discharge machine. The indenter shape of the resonator was hemishere with a different radius of R=2.5, 2.0, 1.5, 1.0mm. Piezoelectric ceramic plate (Nepec6) was attached to the center of the longitudinal bar to drive the tactile sensor.

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 rebber pieces[11] of S2-S4 (AXIOM Co.) was 44mm in diameter and 10mm in thickness, and the material constants are shown in Table 1.

kudou@isenshu-u.ac.jp

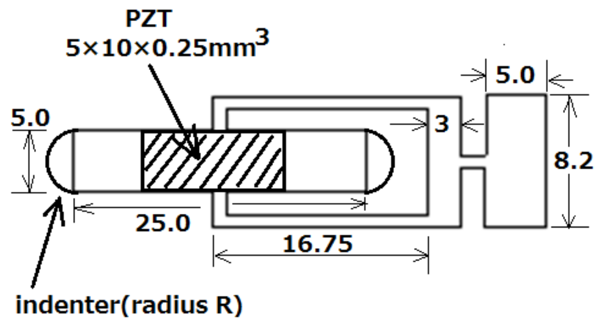

Fig.1.Construction of vibratory tactile sensor (unit:mm,thickness:5mm).

Table 1. Material constants of test rubber pieces.

Type	S2	S3	S4
Young's modulus (kPa)	68.5	130	217
Density ρ (kg/m^3)	1012	1048	1081

3. Experimental investigation
3.1 Experimental results for resonators

Table 2 shows the analytical and experimental characteristics for resonators. The measured resonant frequencies coincide with the calculated values with a difference of 1% or less. There are

Table 2. Characteristics of resonators.

(a) radius R=2.0mm

	f_{free} (kHz)	f_{clamp} (kHz)	Q_{free}	Q_{clamp}
Calculated value	94.865	94.865	—	—
Experimental value	95.276	95.291	2388	2123

(b) radius R=1.5mm

	f_{free} (kHz)	f_{clamp} (kHz)	Q_{free}	Q_{clamp}
Calculated value	97.792	97.792	—	—
Experimental value	98.576	98.558	2745	2635

considered to be due to the difference in material constants and the effect of piezoelectric ceramics attached to the resonators. Then, the quality factor Q_{clamp} for a clamp support is almost 10% less than Q_{free} on a soft support. These results indirectly show that the vibration analysis by finite element method is reasonable.

3.2 Experimental results for tactile sensors

When the tactile sensors were brought into contact with a softer object, the resonance frequency of the resonator decreased as a result of an additional mass effect. Figure 2(a) and 2(b) show the experimental results for the tactile sensor with a longitudinal resonator, where R=2.0mm and resonance frequency f_0=95.291kHz. When the load added to test pieces increased, the resonance frequencies of the resonator gradually decreased as in Fig.2(a). The amount of decrease of resonance frequency is expressed as Δf (=f_L-f_0), where f_L is the resonance frequency when a load is applied and f_0 is the resonance frequency with no load. The characteristics between the load and Δf show the tendency that the amount of decrease for the soft test piece S2 is larger than the hard test pieces S3 and S4. Figure 2(b) shows the relative quality factor of tactile sensor. The relative quality factor is expressed as Q/Q_0, where Q is the quality factor when a load is applied and Q_0 is the quality factor with no load. The quality factors of tactile sensor also decreased to the load force.

Figure 3 shows the characteristics of tactile sensors with different indenter shape. When the radius of indenter is large such as R=2.5mm and 2.0mm, the frequency change of Δf could be large as utilizing the resonator with large indenter radius. This reason is that the contact area on the same load is large as for the resonator with large indenter radius. Then, when the radius of indenter is small such as R=1.5mm and 1.0mm, Δf could be almost the same value. It is thought that all the areas of resonator tip come in contact with the object.

4. Conclusion

The characteristics of tactile sensors with different indenter shape were experimentally examined. The difference of characteristics was discussed from the viewpoint of indenter shape. It is scheduled to clarify the relation between resolution and indenter shape.

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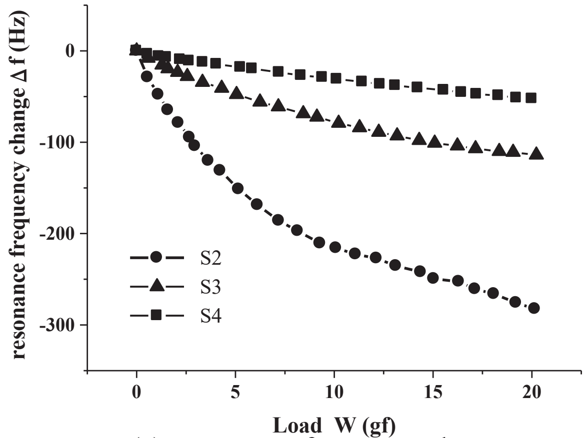
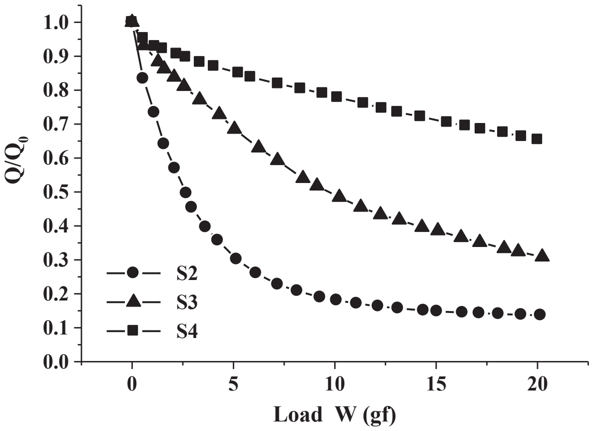


(a) resonance frequency change



(b) quality factor change

Fig.2. Experimental characteristics of tactile sensor(R=2.0mm, f_0=95.291kHz, V_d=0.5V_{rms}).

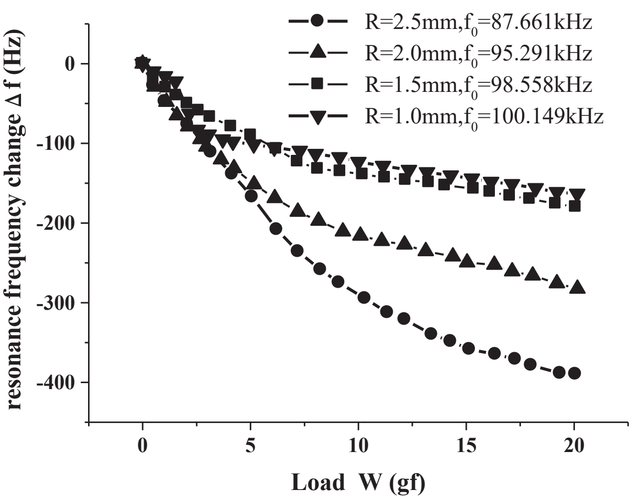


Fig.3. Characteristics of tactile sensor with different indenter shape(test piece:S2, V_d=0.5V_{rms}).