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A Study of Vibratory Tactile Sensor Using a Horn Type Longitudinal Bar Resonator
ホーン型縦振動子を用いた振動型触覚センサの一考察

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1. Introduction

Various kinds of tactile sensors have been used for measuring the physical characteristics of an object 1-4). Recently, the piezoelectric vibratory tactile sensors have been proposed for measuring the softness and hardness of an object 5-10). These tactile sensors utilize the longitudinal mode, flexural mode or edge mode vibration of the resonators. 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 these tactile sensors, the longitudinal bar type sensor has been the most studied, and the sensitivity of the resonance frequency change on the tactile sensor was investigated using the distributed constant circuit model of the resonator.

In this study, the tactile sensor using a horn type longitudinal bar resonator is considered for improving the sensitivity of the tactile sensor. First, the shape of the longitudinal bar resonator is studied for improving the sensitivity of the tactile sensor. The equivalent masses and equivalent mass coefficient of the horn type resonators are calculated using the finite element method. Then, the vibration displacement of the stepped horn type tactile sensor are analyzed for determine the structure which are not influenced by supporting conditons.

2. Sensitivity of tactile sensor

When the tactile sensor, which is driven in the longitudinal vibration mode, touches an object, the softness and hardness of the object are detected as changes in resonance frequencies. In the case of contacting with a softer object, the resonance frequency changes by an additional mass effect. In this case, the sensitivity of the frequency change ratio is appoximately expressed as 10)

$$\frac{\Delta f}{f_0} \cong -\frac{m_e}{2m_0} = -\frac{m_e}{2\delta M_0} \qquad (1)$$

, where $\Delta f = f - f_0$, δ (=m_0/M_0 ; m_0: equivalent mass, M_0:total mass) and m_e are the equivalent mass coefficient and an additional mass.

This approximate equation means that the sensitivity of tactile sensor is inversely proportional to the equivalent mass of the resonator. Then, the resonator with small δ is suitable for increasing the sensitivity.

3. Calculated results of the equivalent mass

To consider the effect on a shape of the bar resonator, the equivalent masses of the horn type resonators in Fig.1 are calculated using the finite element method. Table I shows the calculated results of the equivalent mass of the resonator in Fig.1(a). It is clarified that the equivalent mass m_0 and the equivalent mass coefficient δ are small as the width W2 of the sensor tip becomes smaller.

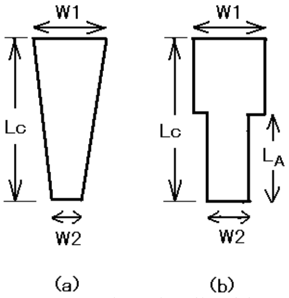

Fig.1 Horn type longitudinal bar resonator.

Table I. Calculated results of equivalent mass.
(Lc=16mm, W1=4mm, t=2mm, ρ =7900kg/m^3)

W2 (mm)	4.0	2.0	1.0
Equivalent mass m_0 (g)	0.494	0.262	0.158
Total mass M_0 (g)	1.011	0.758	0.632
Equivalent mass coefficient δ	0.49	0.35	0.25
Resonance frequency (kHz)	156.2	159.0	165.7

On the other hand, Figs. 2 and 3 show the calculated results of the equivalent mass and the eqivalent mass coefficent in Fig.1(b). The values of m_0 and δ become small when $L_A \fallingdotseq$ 6mm. From these calculated results, it became clear that there is a possibility to improve sensitivity by designing the shape of the longitudinal bar resonator.

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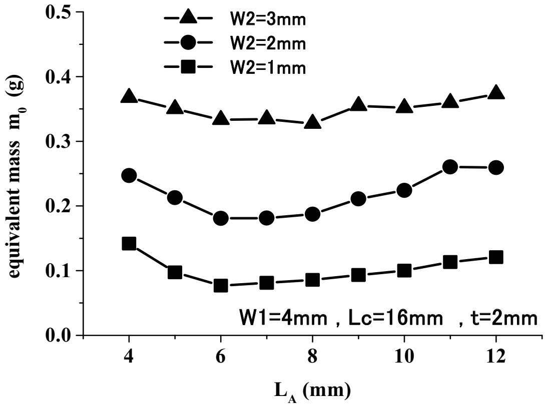

Fig.2 Calculated relationship between L_A and m_0.

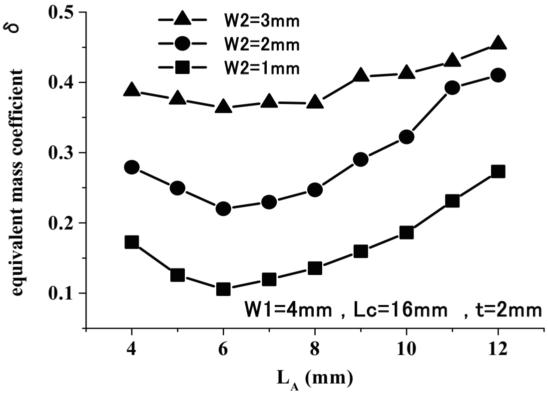

Fig.3 Calculated relationship between L_A and δ .

4. Calculated results of vibration displacement

The stepped horn type resonator in Fig.1(b) with L_A=6mm and W2=2mm is adopted as a new tactile sensor. Figure 4 shows the elevation and plane views of the tactile sensor with a supporting structure. To reduce the vibration displacement at the supporting point Ps in Fig.4, the vibration displacement analysis is performed while changing the arm width Wa and base length L_b. Figures 5 and 6 show the results of calculating the resonance frequency change $|\Delta f/f_0|$ by the supporting condition. In these figurers, the values of $\Delta f/f_0$ is expressed as $\Delta f=f_{clamp}-f_{free}$, $f_0= f_{free}$, where f_{clamp} is the resonance frequency for the clamping condition on the supporting area, and f_{free} is that of the free condition. From these results, it is clarified that the value of $|\Delta f/f_0|$ is very small, 10ppm or less, when Wa=0.8mm and $L_b \geqq 4.0$mm, and there is a little influence from the supporting condition.

5. Conclusion

The tactile sensor using a horn type longitudinal bar resonator was studied in this paper. This work was partially supported by a Grant-in-Aid for Scientific Research C2(No.19560426) from the Japan Society for the Promotion of Science, and a Grant from Ishinomaki Senshu University.

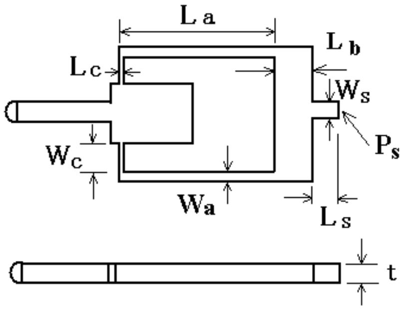

Fig.4 Stepped horn type tactile sensor
(Lc=5mm, La=12mm, Wc=0.5mm, Ws=1mm, Ls=2mm, t=2mm).

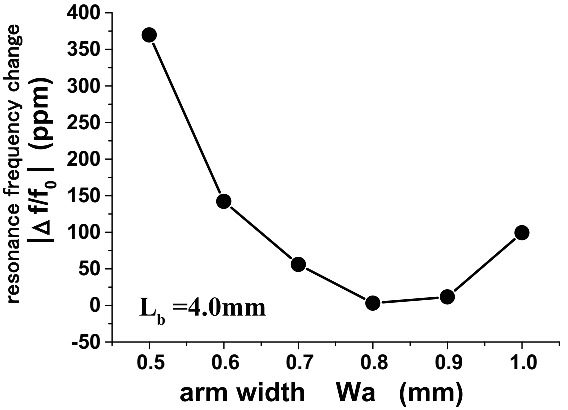

Fig.5 Calculated resonance frequency change (I).

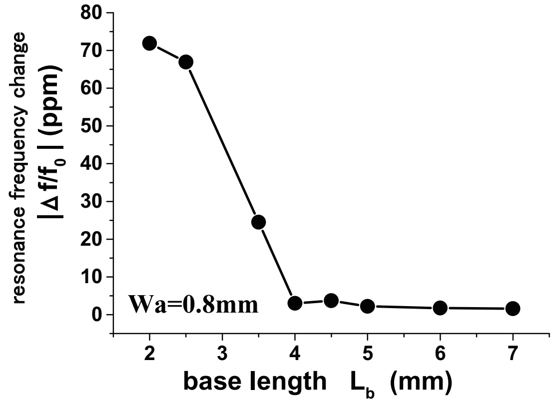

Fig.6 Calculated resonance frequency change (II).

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