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Experimental study on improvement of sound pressure characteristics of piezoelectric back buzzers

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1. Introduction

At the back buzzer (backup alarm devices) standard (SAE Recommended Practice: U.S.A.), Type B (107 dB), Type C (97 dB), Type D (87 dB) and Type E (77 dB) back buzzers can be mass produced, but the mass production of Type A (112 dB) back buzzers is still formidable.

In this report, we describe how by revising the piezoelectric back buzzer's construction and operating frequency, and by attaching an external horn, the experimental improvement of sound pressure was achieved, and mass production of a durable Type A back buzzer has become feasible.

2. Present status and improvement objectives

Even now, through the use of a Type B (107 dB) piezoelectric back buzzer, 112 dB sound pressure can be obtained. To achieve this, though, a Type B piezoelectric back buzzer emitting a sound of 107 dB at an operating voltage of 130 V_{p-p} must be operated at a voltage of 230 V_{p-p}. In this case, sound pressure of up to 116 dB was achieved. But by using this method, even though the durability time is 1,000~2,000 h at normal usage of a Type B back buzzer, the piezoelectric buzzer element split, the electrode connections separated frequently, and durability noticeably deteriorated. In addition, costs increase because a large power source must be used.

Therefore, we decided to study whether 112 dB sound pressure could be achieved without sacrificing durability by changing the structure of the current piezoelectric back buzzer, by changing aspects of the piezoelectric buzzer element and operating frequency, or by the use of an external horn.

We set the following development objectives:

- ① Sound pressure output above 112 dB.
- ② Operating voltage of 130 V_{p-p} (no increase in the capacity of the power supply).
- ③ Suppression as best as possible of frequencies above 2,800 Hz.

and the following durability objectives:

- ① Average temperature 500 h
- ② High temperature (74°C) 250 h (dehumidified/

dry condition)

- ③ Low temperature (−40°C) 250 h (dehumidified/dry condition)

3. Resonant frequency of piezoelectric back buzzer

We handled the resonant frequency of Helmholtz back buzzer resonator in the following way:

Figure 1 shows a cavity resonator of the buzzer. The diameter of the sound emission aperture (the short section) is represented by $2a$, the aperture length by t , the cavity's diameter by $2d$, and the height of the cavity by h . The approximate formula for the resonant frequency of the resonator becomes

$$f_r = \frac{ac}{2\pi d} \sqrt{\frac{1}{h(t + \xi \cdot a)}} \quad (1)$$

where

c : speed of sound in the air

$\xi \cdot a$: compensation term ($0.85 < \xi < 1.42$)

The value of the theoretical ξ that was introduced in the above equation, based on the approximate conditions, can be taken to vary between the values of 0.85 and 1.42.¹⁻⁴⁾

Therefore, in this research, the appropriate value of ξ is to be found through experimentation.

f_r changes in inverse proportion to d and the square root of h , and varies in proportion to the square root of $(a/(t + \xi \cdot a))$.

Fig. 1 Helmholtz resonance formation.

Fig. 2 Variation in the resonant frequency of the resonance formation vs. cavity height h where $a=9.5$ mm, $d=26.5$ mm, $t=7.1$ mm, $c=334$ m/s.

The resonator of the currently marketed Type B piezoelectric back buzzer has dimensions of $a=9.5$ mm, $d=26.5$ mm, $h=7.0$ mm and $t=7.1$ mm.

Figure 2 shows the calculated result of the movement of the resonant frequency when the height of the cavity h is varied from 6 mm to 1 mm for $\xi=0.8$, $=1.0$, $=1.2$, $=1.4$, $=1.6$, and $=1.8$. In this figure, when h becomes 1 mm, f_r reaches 2.5 times its original value.

In experiments to obtain the objective resonant frequency, adjustments were made by altering the cavity height h .

4. Exponential horn

To efficiently release sound from the piezoelectric back buzzer, we decided to attach an exponential horn.

The horn was designed as follows.

First, we set the objectives of minimum frequency emission at $f_1=2.0$ kHz and of cutoff frequency f_c at $f_c=f_1/2=1.0$ kHz.

Next, the opening curve of the horn $m=4\pi f_c/c$ was set at 0.0365.

The aperture's radius of $a_t=c/(\pi f_1)$ was set at 54.75 mm to rid reflection from the mouth of the horn.

The radius a' of the throat of the horn was set equal to the radius ($a=9.5$ mm) of the sound emission aperture of the resonator.

Accordingly the length of the horn $x=2(\log(a_t/a')/m)$ was set at 95.9 mm.

5. Trial and experimental study

For the experiment we ran a trial of the resonator and horn. We made it so that the piezoelectric element could slide inside the cover in a way that the height of the cavity of the resonator could change. Figure 3 shows one example of the experimental resonator.

In addition, the sound emission of the piezoelectric

Fig. 3 One example of experimental resonator.

back buzzer was at only one frequency, causing the resonant frequency of the piezoelectric element to coincide with the resonant frequency of the resonance formation. There was a need to align the frequency of the power source circuit with that frequency.

In the experiment, we used unimorph piezoelectric buzzer elements produced by Murata Mfg. Co., Ltd.

The following are the specifications of the piezoelectric buzzer elements we used in the experiment.

Element 7BB55-2-4

Resonant Frequency of Element $2,700 \pm 300$ Hz

Measurements of elements:

Resonance board (metal board=brass) 55 mmφ

Diameter of ceramics 25 mmφ

Thickness 0.2 mm

(The resonant frequency of the elements is given according to the Murata approved figure.)

We took measurements at an echoless chamber at Yamaguchi Electric Ind., Co., Ltd., having prepared the distance above ground at 1 m 20 cm, and the distance from the microphone at 1 m 20 cm. A driving voltage to the piezoelectric buzzer elements was 132 V_{p-p}.

We measured the frequency characteristic and the sound pressure with an A characteristic while changing the height of the cavity h from 22 mm to 1 mm. The sound pressure varied inversely with the height of the cavity and exceeded an objective sound pressure of 112 dB at $h=2$ mm where the frequency characteristic showed that the main composition of the sound pressure was 2,600~2,700 Hz. At $h=1$ mm, another resonance as large as the resonance of 2,600~2,700 Hz appeared at around 5,000 Hz. So, the height of the cavity h should be 2 mm in order to suppress frequencies over 2,800 Hz as recommended by SAE Practice.

Figure 4 shows the characteristic frequency of the piezoelectric back buzzer when the cavity's height is 2 mm. Figure 4(a) is the frequency with the horn at-

Fig. 4 Frequency characteristics of sound pressure with the cavity height $h=2$ mm (Piezo-electric buzzer element 7BB55-2-4).

Fig. 5 Frequency characteristics of sound pressure with the cavity height $h=7$ mm (Piezo-electric buzzer element 7BB55-2-4).

tached, and Fig. 4(b) is the frequency without a horn. Figure 5 shows the characteristic frequency when the cavity's height is 7 mm.

Similar to the above, Fig. 5(a) shows the case with the horn attached, and 5(b) shows the case without the horn. In both of the experiments for Figs. 4 and 5, the fixed values for the resonator other than h are $d=26.5$ mm, $a=9.5$ mm, and $t=7.1$ mm.

Among these figures, Fig. 5(b) corresponds to the operating conditions of current piezoelectric back buzzers. From Fig. 4(b), it is apparent that by changing the height of the cavity by 2 mm, the sound pressure for frequencies from 2.5 kHz to 2.7 kHz is improved by 10 dB. In addition, it is apparent from Fig. 4(a) that the sound pressure is improved 8 dB by the introduction of an exponential horn, for a total improve-

Table 1 Results of continuous durability experiment (normal temperature).

Frequency range	Evaluated items	Beginning value 9/11, 8:00	Durability time		
			216 h 9/20, 8:00	501 h 10/03, 15:00	638 h 10/09, 8:00
2,500 Hz Region	Sound pressure (dB)	112	113	114	114
	Frequency (Hz)	2,505	2,502	2,513	2,502
	Electric current (mA)	100	106	80	82
2,550 Hz Region	Sound pressure (dB)	113	115	113	114
	Frequency (Hz)	2,543	2,551	2,552	2,549
	Electric current (mA)	98	101	78	78
2,600 Hz Region	Sound pressure (dB)	113	112	111	111
	Frequency (Hz)	2,604	2,601	2,599	2,606
	Electric current (mA)	94	95	78	78
2,650 Hz Region	Sound pressure (dB)	112	112	111	111
	Frequency (Hz)	2,642	2,654	2,650	2,649
	Electric current (mA)	96	91	78	78
Conditions of experiment: continuous operation (normal humidity durability experiment)					
Measurement distance: between article and microphone 1 m 20 cm distance 1 m 20 cm above ground					
YEC Akita Factory, echoless chamber					
Piezoelectric element: 7BB-55-2-4 (Murata)					

ment of 18 dB.

Estimating the resonant frequency versus the height of the cavity from the frequency characteristic measured, we estimated ξ to be about 1.8.

6. Durability experiments

The durability experiments were carried out with the following objectives:

- Normal temperature 500 h
- High temperature (74°C) 250 h (dehumidified/dry condition)
- Low temperature (−40°C) 250 h (dehumidified/dry condition)

First, as shown by the results at normal temperature in Table 1, the durability experiment was carried out with one sample. A time of 638 h was achieved at normal temperature.

Next, we increased the samples to ten, and carried out the durability experiment for high and low temperatures at the driving frequency of 2,650 Hz. In the high temperature experiment, 250 h were achieved at an average sound pressure of 111~113 dB. Also, during the low temperature experiment, in two out of the ten samples, the electrodes peeled off after 210 h. The rest cleared 250 h.

7. Conclusion

The relationship between the resonant frequency of the resonance formation of piezoelectric buzzers, the resonant frequency of individual piezoelectric buzzer elements, and driving frequencies was reviewed experi-

mentally, with all three frequencies encountering virtually identical conditions. In addition, without any reduction in durability, 112 dB sound pressure was achieved with 132 V_{p-p}, almost equal to the conventional driving voltage, by means of the use of an exponential horn. Also, the value of ξ was estimated to be about 1.8 in these experiments.

In the continuous operation durability tests, under normal temperatures, 638 h of continuous operation were achieved. In the high temperature test (74°C), 250 h were cleared at 111~113 dB of sound pressure. In the low temperature tests (−40°C), two samples' electrodes peeled off at 210 h, but the rest cleared 250 h of continuous operation, virtually achieving the objective.

Through this research, we believe that the foundation has been laid for the manufacture of Type A (112 dB) piezoelectric back buzzers.

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