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Research on voltage sensitivity of vibration accelerometer based on cymbal transducer

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Abstract The cymbal piezocomposite transducer was used as the sensitive element of a new type of vibration accelerometer. In this paper voltage sensitivity, S_v, of the accelerometer was researched. Voltage sensitivity, S_v, as a function of operation frequency, *f*, and voltage sensitivity as a function of preinstalled mass, *M*, was analyzed. The dimensions of cymbal transducer effecting on voltage sensitivity were also discussed. The experimental results are shown that the voltage sensitivity of this new kind of accelerometer is more 30 times than that of conventional piezoelectric vibration accelerometer which sensitive element is PZT-5A disk.

Keywords Cymbal piezocomposite transducer · Vibration accelerometer · Voltage sensitivity

1 Introduction

Vibration acceleration sensor is widely used in various vibration measurements. And the accelerometer which has the characters of small volume and high sensitivity is more widely used. Piezoelectric ceramic and crystal are the important sensitive element of accelerometer. Voltage sensitivity, S_v, is a significant parameter which is used to estimate accelerometer's characteristic. For piezoelectric ceramics and crystal, high sensitivity accelerometer is big and weighty. The improvement of the component of piezoelectric material is used to enhance the transducer's sensitivity, such as PZN2PT crystal [1]. But its piezoelectric constant does not rise obviously. People also alter the configuration of the transducer to improve the sensitivity, take the piezoelectric monolithic multilayer [2] for instance, which sensitivity increase greatly but their fabricating process usually is complex. Cymbal transducer is composed of a poled piezoelectric ceramic disk sandwiched between two cymbalshaped mental endcaps [3], shown in Fig. 1. Its effective piezoelectric coefficient is more 40 times than that of piezoelectric ceramic disk. Cymbal transducer is small and light, and the fabrication process is simple. Otherwise, cymbal transducer is different from other kinds of flextensional transducers' flexural mental electrode [4, 5] which has an even area on top of the brass foil to load preinstalled mass.

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2 Theoretics basic

Vibration acceleration sensor is fixed tightly on the vibrated object and it vibrates with the object, as well as the preinstalled mass *M*. Then the mass produces an inertia force which absolute value is F=Ma and operates on the piezoelectric ceramics disk. The electric charge which is proportional to the force that produced on both sides of the disk surface as a result of piezoelectric effect [6].

$$q = d_{33}F = \mathrm{Ma} \tag{1}$$

Where d_{33} is longitudinal piezoelectric constant, *M* is preinstalled mass. It can be seen from Equation 1 that the electric charge is proportional to d_{33} and *M*.

Cymbal transducer's elastic coefficient k_y is an invariable value in the rang of elasticity. During the vibration process, the stress which is formed on the cymbal transducer is:

$$F = k_y \Delta x \tag{2}$$

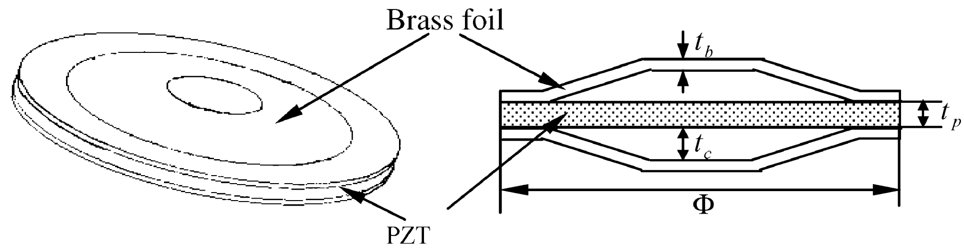

Fig. 1 Schematic structure of the cymbal transducer

where Δx is the deformation displacement of cymbal transducer. Then the electric charge can be expressed as:

$$q = d_{33}^{e} k_y \Delta x = d_{33}^{e} \mathrm{Ma} \tag{3}$$

where d_{33}^{e} is cymbal transducer's effective piezoelectric constant. The voltage sensitivity of the accelerometer which sense organ is cymbal transducer can be described as the following equation:

$$S_v = \frac{U}{a} = \frac{qA}{C_0 a} = \frac{d_{33}^{e}\mathrm{MA}}{C_0} \tag{4}$$

Where C_0 is transducer's nature capacity of cymbal transducer's sense organ, A is the amplification coefficient of signal processing circuit.

3 Experimental procedure

The sketch of the vibration testing system for voltage sensitivity of vibration acceleration sensor is shown in Fig. 2. The sensor was fixed on the vibration table. The testing circuit mainly consists of signal amplifier circuit which amplified the output charge and a low pass filter which was used to filter high frequency noise. Oscillator displayed the output voltage values.

4 Results and discussion

Figure 3 shows two type of acceleration sensors' voltage sensitivity S_v as a function of working frequency f. Their dimensions of sensitive element, cymbal transducer, are Φ= 12 mm, t_b=0.3 mm, t_c=0.3 mm, t_p=0.5 mm and Φ=16 mm, t_b=0.2 mm, t_c=0.5 mm, t_p=0.5 mm. Their resonance frequencies, f_0, are 37.66 kHz and 22.64 kHz separately. When the workingfrequency of vibration table was 0–2.5 kHz<$0.22f_0$, acceleration was a=9.8 m/s^2, these two sensors' voltage sensitivity, S_v, is expressed by the following Fig. 3.

From this figure, their frequency response curves obtained from this experimental is plain and the error within 5%.

From Equation 4 we can conclude that voltage sensitivity can be improved by increasing the preinstalled mass M. Two types of cymbal transducer which dimensions were Φ=12 mm, t_c=0.3 mm, t_b=0.25 mm and Φ=12 mm, were used in prestress experimentation. The experimental results described this relationship is shown in Fig. 4:

We can conclude from the figure that the output voltage sensitivity is linear with the preinstalled mass, M, and increases with it. Whereas when the mass was added to a certain value, voltage sensitivity S_v will not be linear with M, but trend to a stable value. The thinner the brass foil the narrower the linear range. As we know that cymbal transducer's elastic constant k_y is an invariable value within its elastic region. It can be seen from Equation 4 that S_v is proportional to M. When preinstalled mass, M, is out of the elastic region the cymbal will lose elasticity and k_y will not be an invariable value.

Brass foil thickness of cymbal transducer has an influence on cymbal transducer's effective piezoelectric constant. In this research, cymbal transducers which t_b are 0.15, 0.2, 0.25, 0.3 and 0.38 mm, Φ=12 mm, t_c=0.3 mm, t_p=0.5 mm were used to accelerometer's sensitive element. The working frequency of vibration table was 500 Hz, the acceleration was 1 G. Their experimental and calculated results of voltage sensitivities, S_v, as a function of brass foil thickness is expressed in Fig. 5:

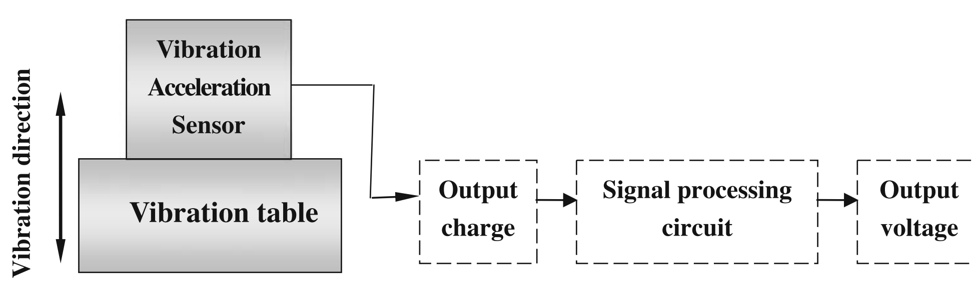

Fig. 2 Vibration testing system

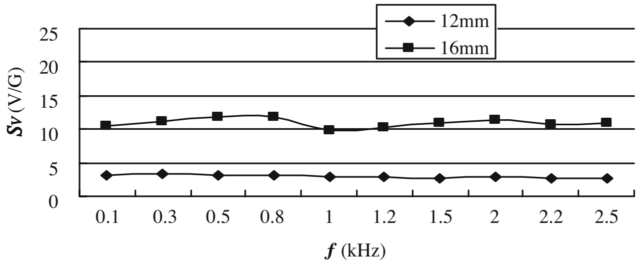

Fig. 3 S_v as a function of frequency, f

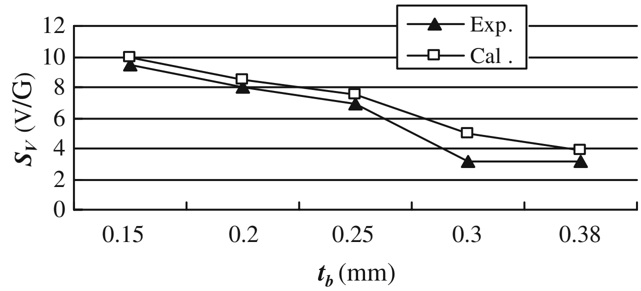

Fig. 5 S_v as a function of brass foil thickness, t_b

From Fig. 5 we can see that the thicker the brass foil, the lower the voltage sensitivity of this vibration acceleration sensor. With the thickness of brass foil increasing, the cymbal's effective piezoelectric constant, d_{33}^{e}, is decreased. It can be deduced from Equation 3 that the voltage sensitivity of the vibration sensor decreased also. And the experimental results and calculated results agree very well.

If the vibration sensor's sensitive element was PZT-5A disk, which diameter was 12 mm, thickness was 0.5 mm, its voltage sensitivity is 0.28 V/G. Comparing with hereinbefore voltage sensitivities, our new type of accelerometer is 33.6 times than the later one.

The depth of cymbal transducer's brass foil cavity as a function of vibration voltage sensitivity, S_v, is shown in Table 1. The cymbal transducer's piezoelectric phase is PZT-8 and its thickness is 0.5 mm and diameter is 12 mm. The brass foil thickness of cymbal transducer is 0.25 mm, and the depth of brass foil cavity, t_c, is 0.3, 0.4, 0.5 and 0.6 mm, separately.

From the table we can see that when t_c<0.5 mm, vibration sensor's voltage sensitivity, S_v, is increasing with the depth of brass foil cavity. When t_c>0.5 mm, S_v decreased. The reason is that the effective piezoelectric constant, d_{33}^{e}, is increased when t_c<0.5 mm and decreased when t_c>0.5 mm. The experimental results and the calculated results agree well.

From the above experimentations, we can see that the experimental results are not same with the calculated results. The error mainly origin from the signal processing circuit which theoretic value and actual value of amplification coefficient is different and the actual circuit will be influenced by environment temperature. The difference of every vibration acceleration sensor based on cymbal transducer's fabrication process will cause error too.

5 Conclusion

The goal of this study was to investigate a new type of vibration accelerometer sensor's resonance frequency and voltage sensitivity characteristics which sensitive element is cymbal transducer and the influence on these characteristics caused by configuration parameter of cymbal transducer. The resonance frequency of this new type of accelerometer is plain within the range of working frequency. S_v is proportional to preinstalled mass, M, in the elastic region of cymbal and it will trend to an invariable value. The thinner the cymbal's brass foil, the high the new type of the accelerometer's S_v. With the increasing of the depth of cymbal's brass foil cavity, voltage sensitivity values grow at first, then decrease. The S_v of this vibration accelerometer used cymbal as sensitive element is more 30 times than that which sensitive element is PZT-5A.

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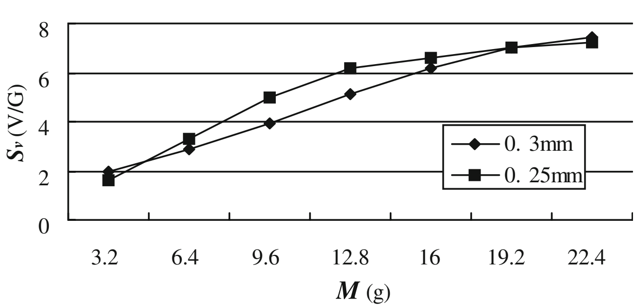

Fig. 4 S_v as a function of preinstalled, M

Table 1 Experimental results and calculated results of voltage sensitivity.

Results	Values			
t_p (mm)	0.3	0.4	0.5	0.6
d_v (V/G)				
Exp. results	3.72	4.70	4.80	3.63
Cal. results	4.31	4.70	5.09	3.72

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