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Design and Properties of Piezoelectric Vibrator with Generating Function by FEM Analysis

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Abstract. Bimorph type piezoelectric vibrator with generating function is designed using Finite Element Method (FEM) and fabricated. Design of piezoelectric vibrator by FEM is focused at its length and the weight of added mass. Also, the vibration and charging properties of the fabricated piezoelectric vibrator are investigated. As the FEM analysis results, when the piezoelectric vibrator is the length of 18 mm and the additive weight of 0.3 g, its resonance frequency decrease to 150 Hz. Also, when input voltage of 20 V is applied, output voltage is 10.285 V in generating element. As the properties of piezoelectric vibrator fabricated, when input voltage is 20 V_{rms}, the acceleration of piezoelectric vibrator and output voltage are about 1.1 G and 10.18 V_{rms}, respectively. When gold capacitor of 0.0066 [F] is used as the load, the output voltage is about 3 [VDC] after 3600 [sec] driving time.

Keywords: vibration alarm, piezoelectric vibrator, generating function, FEM

1. Introduction

Use of such mobile telecommunication devices as pagers and mobile telephones is increasing markedly with the approach of a highly developed information society. For such telecommunication devices, a new soundless alarm is much in demand for silent notice of incoming calls and reducing the current consumption of a dry cell. At present, such a soundless alarm is composed of a DC motor having a non-coaxial rotor [1]. However, alarms using DC motor have some problems, for example, difficulty of further reduction thickness and high power consumption. These problems are resulted from a magnet and a coil component [2]. Accordingly, the devices using piezoelectric ceramics without a magnet and a coil component are studied. Bimorph type piezoelectric actuator of them is suitable as vibration motor. The properties of bimorph type piezoelectric actuator are low profile, low power consumption and no Electro-Magnetic Interference (EMI). Also, the generation function can be added in bimorph type piezoelectric actuator [3–5]. But the size of piezoelectric vibrator is too larger than DC motor in the previous studies because it is focused at generation properties as a function of physical dimension, and it can't use for mobile phone.

Accordingly, bimorph type piezoelectric actuator with generating function is optimally designed using Finite Element Method (FEM) and fabricated in this paper. Also, the vibration and charging performances of the fabricated piezoelectric vibrator are investigated.

2. Design and Construction of Piezoelectric Vibrator

ATILA 5.2.1 FEM software is used for the simulation of piezoelectric vibrator. The construction of piezoelectric vibrator with generating function is shown in Fig. 1. Bimorph type piezoelectric vibrator is composed of 2 sheets of piezoelectric ceramics that are poled to the same direction, an elastic sheet, and an additive mass to decrease the resonance frequency of piezoelectric vibrator. Each element is adhered by one component epoxy adhesive. One piezoelectric ceramic sheet is divided into 3 parts, 2 parts is used as vibration element

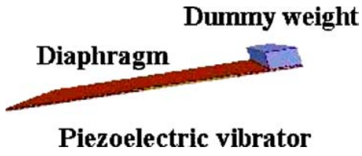

Fig. 1. Construction of piezoelectric vibrator.

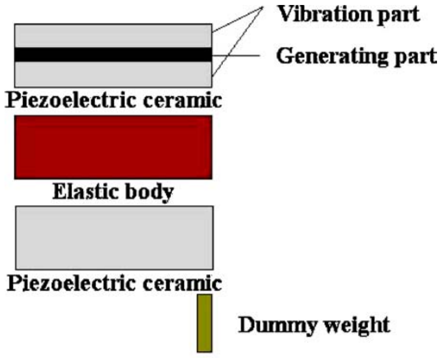

Fig. 2. Construction and role of piezoelectric ceramic sheet.

and the other is used as generating element as shown in Fig. 2. And the other sheet is just used as vibration element.

3. Fabrication of Piezoelectric Vibrator

Based on above simulation results, piezoelectric vibrator is fabricated. The composition of piezoelectric vibrator fabricated is PZT-based ternary piezoelectric ceramic system as following:

$$0.9PbZr_{0.5}Ti_{0.5}O_3 - 0.1PbNi_{1/3}Sb_{1/3}Nb_{1/3}O_3 \quad (1)$$

The piezoelectric and dielectric characteristics of piezoelectric ceramics are listed in Table 1. The piezoelectric ceramics for piezoelectric vibrator are needed characteristics such as high piezoelectric constant, electromechanical coupling coefficient and dielectric constant to make large displacement. Also, the mechanical quality factor must be low for the wide temperature range.

Table 1. Piezoelectric and dielectric properties of PZT-PNSN.

Kp [%]	Qm	$\varepsilon^T_{33}/\varepsilon_0$	d_{33} [pC/N]	T_C [°C]
63	360	2000	470	290

The piezoelectric ceramic sheets are adhered with thin elastic material by epoxy adhesive and lead is used as dummy weight.

Also, the resonance frequency of the fabricated piezoelectric vibrators is measured by impedance analyzer (HP 4194A).

4. Results and Discussion

4.1. Resonance Frequency Characteristics

Change of resonance frequency as a function of length of elastic element is shown in Fig. 3. The length of piezoelectric ceramic is fixed to 12 mm. As shown in Fig. 3, as the length of elastic element increases, the resonance frequency of piezoelectric vibrator decreases linearly. Also, measured value is slightly low, compared with simulation value. Because epoxy adhesive is acted as dummy weight when ceramic sheets are adhered with elastic body by epoxy adhesive.

When the length of elastic element is 22 mm, the resonance frequency decreases to 100 Hz, but the length of piezoelectric vibrator is so large that it is not practical. So, in order to decrease the resonance frequency, the length of piezoelectric vibrator is fixed to 18 mm and the additive mass is added in the edge element of piezoelectric vibrator.

Figure 4 shows the relation of the additive mass and the resonance frequency. The length of piezoelectric ceramics and elastic element are 12 mm and 18 mm, respectively. As the weight of the additive mass

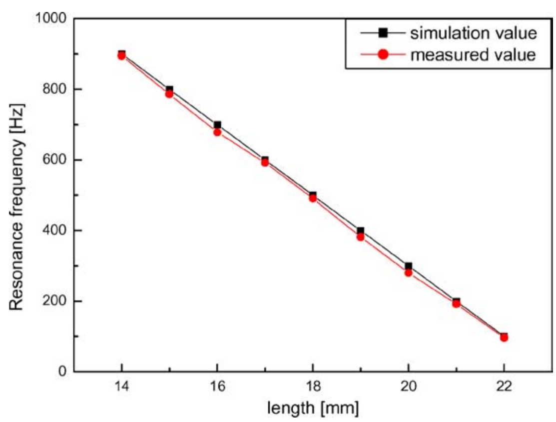

Fig. 3. Change of resonance frequency as a function of the length of elastic element.

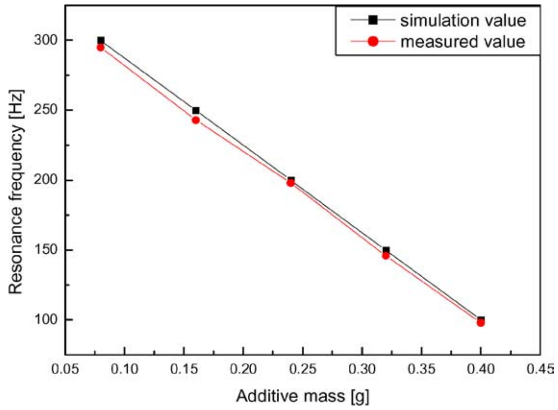

Fig. 4. Change of resonance frequency as a function of additive mass.

increases, the resonance frequency of piezoelectric vibrator decreases linearly. Measured value is slightly lower than simulation value in the case of additive mass. It can be explained by the same reason in the case of length. When the weight of the additive mass is 0.3 g, the resonance frequency is about 150 Hz of which the human feels the vibration sensitive.

From these results, the optimal physical dimension of piezoelectric vibrator is decided; the length of piezoelectric vibrator and the weight of the additive mass are 18 mm and 0.3 g, respectively.

4.2. *Vibration Properties*

Measured result of piezoelectric vibrator is shown in Fig. 5.

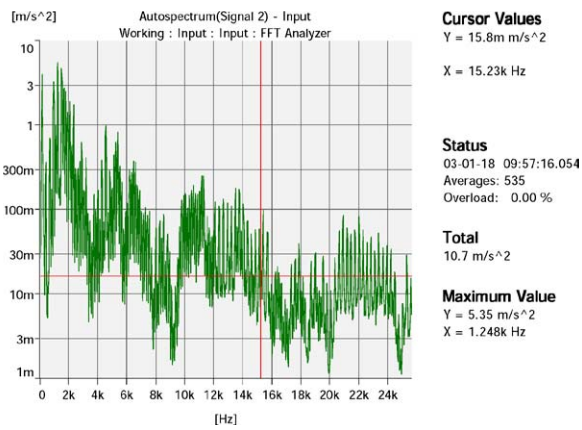

Fig. 5. Acceleration G of piezoelectric vibrator.

Acceleration G of piezoelectric vibrator depends on driving frequency, applied voltage and the weight of housing of which the piezoelectric vibrator is attached. To measure the acceleration G, the piezoelectric vibrator is attached at the housing of 100 g weight that is the mean weight of general mobile phone. And the acceleration sensors are attached at the top and the side of housing. The acceleration G of piezoelectric vibrator is directly measured by accelerometer. From the results, the acceleration G is 1.1 G in the top of housing and 0.85 G in the side. The reason that the acceleration G in the top of housing is larger than in the side is because the piezoelectric vibrator is vertically vibrated. In practice, acceleration G of silent alarm using DC motor is more than 0.8 G and is usually 1 G. Accordingly, the piezoelectric vibrator fabricated can apply to silent alarm.

4.3. *Charging Properties*

Change of output voltage according to applied frequency is shown in Fig. 6. The piezoelectric vibrator is 18 mm long and 0.3 g weight, and input voltage is 20 [V]. The load is opened. As applied frequency increases, output voltage shows the typical resonance curve. When applied frequency is 150 [Hz], maximum output voltage is 10.285 [V].

The voltage generated in generating element is rectified by full-bridge rectifier and charged in gold capacitor of 0.0066 [F] (seiiko co.). The voltage across the gold capacitor is measured by differential voltage probe as a function of charging time.

When the load is 1 MΩ, the output voltage waveform across the generating element is shown in Fig. 7.

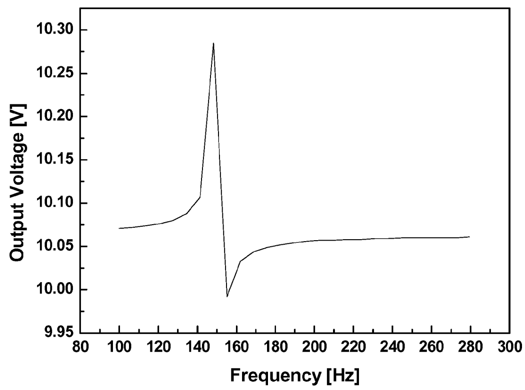

Fig. 6. Output voltage according to applied frequency.

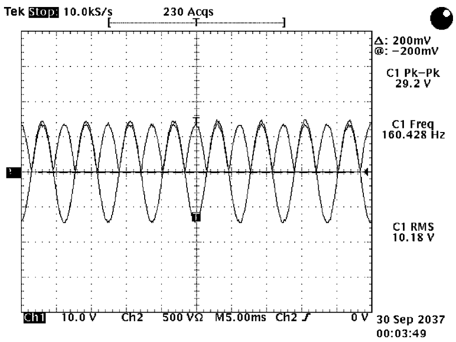

Fig. 7. Output voltage waveform in front and behind of rectifier.

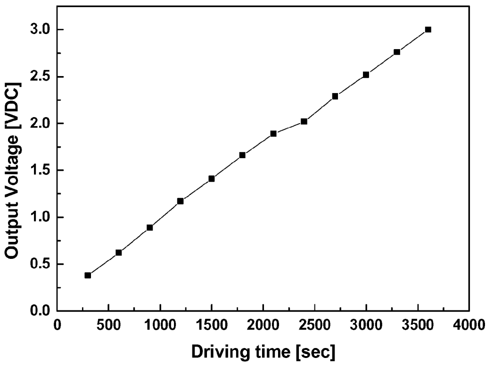

Fig. 8. Change of output voltage across the gold capacitor as a function of driving time.

Input voltage and frequency are 20 V_{rms} and 150 Hz, respectively. Output voltage is sinusoidal and about 10.18 V_{rms} in front of full-bridge rectifier. These results are nearly the same in FEM analysis.

The change of output voltage across the gold capacitor as a function of driving time is shown in Fig. 8. Input voltage and frequency are 20 V_{rms} and 150 Hz, and gold capacitor of 0.0066 [F] is used as the load. As shown in Fig. 8, as the driving time increases, the output voltage also increases. After the driving time is 3600 [sec], the output voltage is about 3 VDC. The charging time is so long that it has the problem in practical. But it is considered that this generating function is usable for other application that small rechargeable battery is used.

5. Conclusions

In this paper, the piezoelectric vibrator with generating function is proposed and simulated as a function of its length and added weight by FEM. From simulation results, the piezoelectric vibrator is fabricated and its vibration and generating property is measured. As a result, the generating function has the problem that the charging time is so long in practical. But it is considered that this generating function is usable for other application that small rechargeable battery is used. Its size and vibration property is better than that of DC motor. But when the battery voltage of mobile phone is considered, its input voltage is high. To decrease the input voltage of piezoelectric vibrator, the multi-layer structure must be studied.

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