

Energy Conversion According to Impact Loading on Piezoelectric Material

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ABSTRACT

This paper shows energy converting system. The energy converting system can convert uncontrollable random frequency into energy. For the efficiency, this system used the 33 mode piezoelectric materials. First, we did parametric analysis for prediction of the total stress and voltage. Parametric analysis is based on the theoretical model. And these parameters are a size/mass of piezoelectric material, velocity of impact material (ball), and electrostatic capacity. To transmit the impact to piezoelectric material, we conducted the 'bolldrop' test. The experiments were performed replacing the parameters. By changing parameters, we observed varying voltage potentials at the different conditions.

In the experiment, bolldrop test is experiment to measure the output voltage and converted energy for examine the correlation of input energy with converted energy. We could know input energy according to different piezoelectric material's characteristic. And the output voltage is not related with energy form, but proportionally increased by mechanical energy. When same energy is inputted, it checked that size and electrostatic capacity of piezoelectric among properties of piezoelectric changed energy quantity. It will predict possibility of optimal design of energy converting system though these experiment.

Keywords: Energy converting system, Piezoelectric material, Ubiquitous, Wireless sensor network

1 INTRODUCTION

In the ubiquitous era, many sensors are required in various purposes and fields. Therefore, configuring the network by currently wired sensor has a limit. In contrast, a wireless sensor has many advantages. Wireless sensor does not require wires. So it is not restricted about wiring, length/thickness of wire, location of sensors, etc. And wireless sensor is easy to install a network. Also related research has been actively done now.

Most of the sensors are active type with battery. But life time of battery has brought restrictions on the long-term use. In order to answer the growing need to provide remote power for systems isolated from hard-wired power and communication, there have been numerous approaches involved from wired to wireless sensor network power systems. The piezoelectric vibration energy harvesting system has been one of the hottest interests in energy harvesting and power supply for wireless sensor nodes. Piezoelectric harvest system is especially advantageous in

that it can exploit diverse forms of energy sources existing our daily activities and natural phenomena such as a wave, a sound wave, pulsation, impact etc. This paper shows energy converting system which uses the impact. We did parametric analysis. And we conducted the 'bolldrop' test.

2 DESIGN AND FABRICATION

2.1 Design

The important parts of piezoelectric material performance are piezoelectric material's shape, piezoelectric material's body condition, electric load, and circuit impedance, when the piezoelectric material is used to ignition or generator.

The impact is collision between the piezoelectric material and the hammer, so the impact is dynamic state. Therefore the impact is controlled by dynamic load, and the piezoelectric material gets dynamic stress. Dynamic stress is affected by acoustic impedance of hammer, impedance of piezoelectric material, and hammer's velocity. The impact is generated by collision between piezoelectric material and hammer. The stress which is generated in piezoelectric material can be calculated by one dimensional wave equation which is used to calculate collision stress. Using one dimensional wave equation, analytical modeling is equation (1), (2)

$$\frac{\partial^2 u}{\partial t^2} = \alpha^2 \frac{\partial^2 u}{\partial x^2} \quad (1)$$

$$v = \frac{\partial u}{\partial t}, \varepsilon = \frac{\partial u}{\partial x} \quad (2)$$

where u is the displacement of a mass, v is the velocity of a mass, ε is the strain and α is the velocity of compression wave. In this time, generated stress T_3 is

$$T_3 = \frac{z_h z_c A_h}{z_c A_c + z_h A_h} v_h \quad (3)$$

where T_3 is stress, v_h is velocity of the hammer, z_h is acoustic impedance of the hammer, z_c acoustic impedance of the piezoelectric material, A_h is area of the hammer, and A_c is area of the piezoelectric material.

Stress occurs, converted energy equation is

$$W = \frac{V}{2} \varepsilon_{33}^T g_{33}^2 T_3^2 = \frac{V}{2} \varepsilon_{33}^T g_{33}^2 \left(\frac{z_h z_c A_h}{z_c A_c + z_h A_h} v_h \right)^2 \quad (4)$$

where V is volume of piezoelectric material, ε_{33}^T is electrostatic capacity of piezoelectric material, g_{33} is piezoelectric voltage coefficient, d_{33} is piezoelectric charge coefficient.

	Symbol	Unit	A type	B type
Length	L	mm	15 0.1	4.5 0.1
Diameter	D	mm	6.3 0.1	2 0.1
Permittivity	$\varepsilon_{33}^T / \varepsilon_0$	-	1800	1460
Piezoelectric charge coefficient	d_{33}	C/N	450 $\times 10^{-12}$	367 $\times 10^{-12}$
Piezoelectric voltage coefficient	g_{33}	Vm/N	27×10^{-3}	29.2×10^{-3}
Coupling factor	k_{33}	-	0.7	0.76

Table 1: Size and properties of 33mode cylindrical piezoelectric material

It was possible to find two important factors for converting energy from Equation (4). First, a magnitude of external force is important external factor for converting energy. Second, piezoelectric charge coefficient (d_{33}) and electrostatic capacity of piezoelectric material (ε_{33}^T) are important internal factor for converting energy.

Making a quite different value of acoustic impedance between the piezoelectric material and head which is top of piezoelectric material is efficient method for a transmission of external force with mechanical energy.

Typically, in the impact area, if the validly area of piezoelectric material are similar to validly area of head, stress equation can be expressed equation (3).

$$T = \frac{z_h z_c}{z_c + z_h} v_h \quad (5)$$

This case, a converted energy equation is equation (6).

$$W = \frac{V}{2} \varepsilon_{33}^T g_{33}^2 T_3^2 = \frac{V}{2} \varepsilon_{33}^T g_{33}^2 v_h^2 z_c^2 \left(\frac{1}{1+x} \right)^2 \quad (6)$$

In equation (6), x is acoustic impedance ratio (z_c / z_h). For design of efficient energy converting system, conditions of acoustic impedance between piezoelectric material and head must be satisfied with $z_c / z_h < 0.5$. But our condition is different from this, so we use steel for easy

manufacturing device. In this case, x is 0.74. And piezoelectric converting energy is $34v^2$ [mJ].

Next, a electrostatic capacity ε of piezoelectric material depends on the degree of freedom.

$$\varepsilon_{free}(1-k^2) = \varepsilon_{clamped} \quad (7)$$

k is coupling coefficient. Both ends of piezoelectric material were designed for set free end, because the electrostatic capacity is larger when the transformation occurs freely than opposite circumstance.

For another design parameter, the 33mode piezoelectric material is difficult to make electrode directly, because the direction of mechanical movement and the direction of electrode are same. Free end should be maintained for a large electric capacity. But there ware loss element of input energy, because the instable element of electrode from previous process. So, the copper plate was inserted between hard area and piezoelectric material for maintenance of free end.

Finally the electrode didn't occur contact-instability between the top and bottom. The copper plate was inserted between hart area and piezoelectric material to maintain free end of piezoelectric material.

2.2 Fabrication

The energy converting system which used piezoelectric material has three parts. Those are the energy converting part, the energy storage system, and regulated DC voltage part. We made the energy converting part considering design parameter. Figure 1 shows the energy converting part. And Figure 2 shows the circuit of the energy converting/storage and regulated DC voltage part.

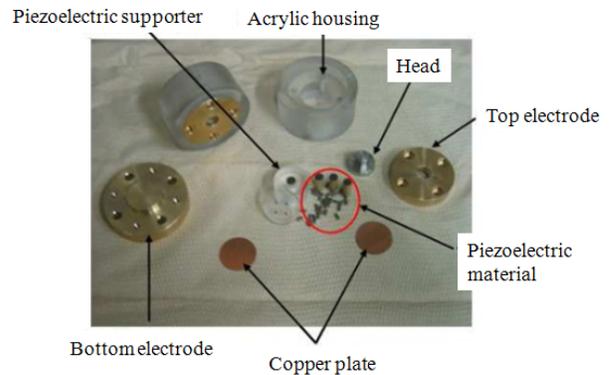


Figure 1: 33-mode piezoelectric energy converting part

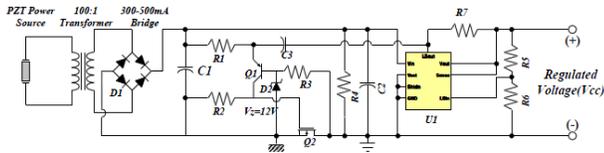


Figure 2: Circuit of the energy converting/storage and regulated DC voltage part

3 RESULT AND DISSCUSION

3.1 Bolldrop test

Bolldrop test is to see through changeable quantity of mechanical-energy in energy conversion system. Boll is dropped down with potential energy to energy transducer. And it makes stress on piezoelectric material by head. Figure 3 shows experimental equipment and others. Table 2 is experimental variable.

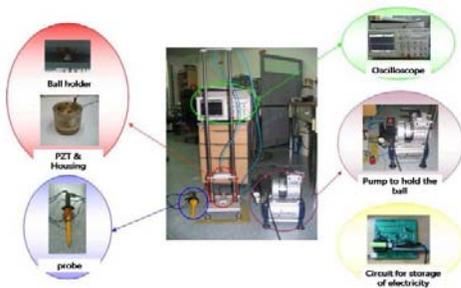


Figure 3: Generated Stress from piezoelectric material by ball drop

Parameter	Unit	Sort
Mass of boll	g	0.86, 2.7, 3.5, 4.08, 8.48, 11
High	cm	15, 20, 25, 30, 35, 40
Input energy	mJ	1.2~41

Table 1: Experiment parameter

Figure 4 is result of experiment Type A, B from the table 1. In case of identical piezoelectric material, output voltage is nearly proportionally increased by input energy. But we could know that different gradient of output voltage and input energy according to different piezoelectric material's characteristic. The output voltage is not related with energy form, but proportionally increased by mechanical energy. In other words, if energy level was same, height and weight of the ball does not matter.

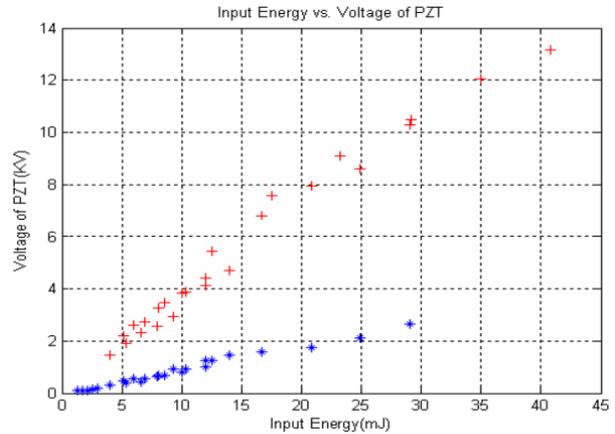


Figure 4: Voltage vs. input energy of piezoelectric material (+: A type, *: B type)

It is possible to calculate the output voltage of piezoelectric material for compare the result of experiment with result of analysis, if we know the stress what is occurred piezoelectric material when the boll is dropped down. And then we can get numerical converted energy by equation (8)

$$W = \frac{V}{2} \epsilon_{33}^T g_{33}^2 \left(\frac{m\sqrt{2gh}}{m+M} (1+e_*) \right)^2 \left(\frac{z_h z_c}{z_c + z_h} \right) \quad (8)$$

where m is mass of the boll, g is gravity acceleration, h is height of the boll, e_* is restitution coefficient between boll and head.

Figure 5 shows the output voltage and velocity of the head that compared theoretical result with experimental result when bolls were dropped down from different height.

Two results are similar to each other. Figure 6 shows quantities of converted energy from mechanical input energy.

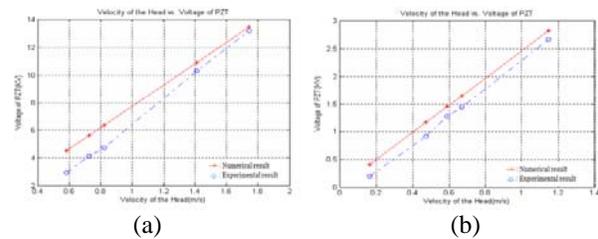


Figure 5 : Velocity of the head vs. voltage of PZT (a) : A type, (b) : B type

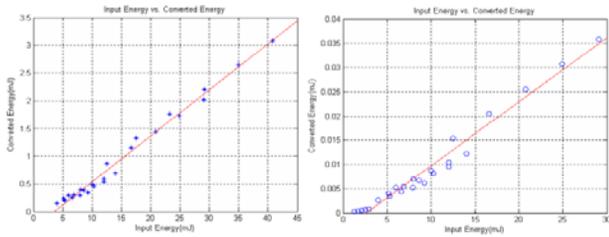


Figure 6 : Input energy vs. converted energy (a) : A type, (b) : B type

The gradient is converting efficiency at Figure 6. Type A is 8%, type B is 0.1%. Energy converting system is affected by piezoelectric material's volume and permittivity. That's why each efficiency of type A and B are different.

In summary, bolldrop test is experiment to measure the output voltage and converted energy for examine the correlation of input energy with converted energy.

3.2 Using air pressure vibrator

It is an experiment that measuring of a quantity of charging about converting continuously input mechanical energy into electric energy in a storage of the circuit. Figure 7 shows an energy converting system and the device of measurement in experiment. While it sustains 1bar using the air pressure pump, the experiment was performed; to input impact to converting system using air pressure pump. Input energy is about 5.5mJ each a hitting; impact is 50~58 times per a second and displacement of hammer is 6mm. This experiment is performed; the number of piezoelectric, it changed 1,3,5,8 using Type B piezoelectric. Also electrostatic capacity was changed. And Capacitor used a 100uF.

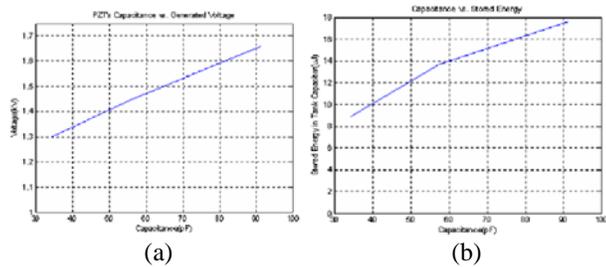


Figure 7: (a) Capacitance vs. voltage of piezoelectric material (b) Capacitance vs. stored energy

It is similar to bolldrop test for generating voltage depending on input energy. Increasing of the number of piezoelectric or that of electrostatic capacity is that increasing of generating energy and stored energy. Also, the more increase electrostatic capacity and volume of piezoelectric, the more increase generating voltage during same putting energy.

4 CONCLUSION

We did parametric analysis for prediction of the total stress and voltage. Next, we did bolldrop test which is to see through changeable quantity of mechanical-energy in energy conversion system. Bolldrop test is experiment to measure the output voltage and converted energy for examine the correlation of input energy with converted energy. The theoretical result and experimental result are similar to each other. In the experiment, output voltage of identical piezoelectric material is nearly proportionally increased by input energy. But we could know that different gradient of output voltage and input energy according to different piezoelectric material's characteristic.

The energy converting system is affected by piezoelectric material's volume and permittivity. When same energy is inputted, it checked that size and electrostatic capacity of piezoelectric among properties of piezoelectric changed energy quantity. It will predict possibility of optimal design of energy converting system though these experiment.

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