

Power generation characteristics of PZT piezoelectric ceramics using drop weight impact techniques: Effect of dimensional size

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Abstract

In this study the relation between the generated open circuit output voltages and the generated electrical energy of PZT piezoelectric ceramic body with applied impact mechanical energy are studied. The output voltages and the generated electrical energy of PZT piezoelectric ceramic body are increased with the increasing of the applied mechanical energy. Under the same impact mechanical energy, the output voltages and the generated electrical energy of the PZT piezoelectric ceramic body are depending on both the dimensional size and properties of the samples. The PZT piezoelectric ceramic body with greater (t/D^2) can produce a higher output voltage and higher generated electrical energy. With the same piezoelectric ceramic body size, under the same impact mechanical energy, the output voltage and the generated energy of soft type piezoelectric ceramic body is higher than that of hard type piezoelectric ceramic body, which is because the g_{33} and ϵ_{33}^T value of soft type piezoelectric ceramic body is higher than that of hard type piezoelectric ceramic body.

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1. Introduction

Piezoelectric ceramics are able to interchange electrical energy and mechanical motion or force. The power transfer phenomenon of PZT piezoelectric ceramics had been studied by many researchers. Umeda et al. [1] used a free-falling ball to impact a piezoelectric ceramic wafer attached to its underside, and developed an electrical equivalent model of the PZT transforming mechanical impact energy to electrical power. They also investigated the energy storage characteristics of the PZT with a bridge rectifier and a capacitor. Starnier [2] examines the energy available from leg motion of a human being and surveys other human motion sources of mechanical energy including blood pressure. Goldfarb et al. [3] presented a

linearized model of a PZT stack and analyzed the efficiency of it as a power generation device. It was shown that the maximum efficiency occurs in a low frequency region much lower than the structural resonance of the stack. The efficiency is also related to the amplitude of the input force due to hysteresis of the PZT. In addition to the force applied in the poling direction (d_{33} mode), Clark and Ramsay [4] have investigated and compared it with the transverse force (d_{31} mode) for a PZT generator. Their work showed that the d_{31} mode has a mechanical advantage in converting applied pressure to working stress for power generation. They concluded that a 1 cm^2 piezoelectric ceramic wafer can power MEMS device in the microwatt range. Kasyap et al. [5] formulated a lumped element model to represent the dynamic behavior of PZT in multiple energy domains using an equivalent circuit.

In this paper a comparison of two types of piezoelectric ceramics were experimentally investigated for use as energy transducers. The two types tested were the hard type PZT and the soft type PZT piezoelectric ceramic. The effect of

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Table 1
The dimension and capacitance of the samples used in this study.

Sample	1 (QB)	2 (KA)	3 (QB)	4 (QB)	5 (QB)	6 (QB)
Diameter (mm)	15	15	25	25	20	15
Thickness (mm)	0.9	0.9	1.24	2.07	1.24	2.07
D/t	16.67	16.67	20.16	12.08	16.13	7.25
t/D^2	0.004	0.004	0.001984	0.003312	0.0031	0.0092
Capacitance (nF)	2.628	3.564	5.402	3.196	3.402	1.047

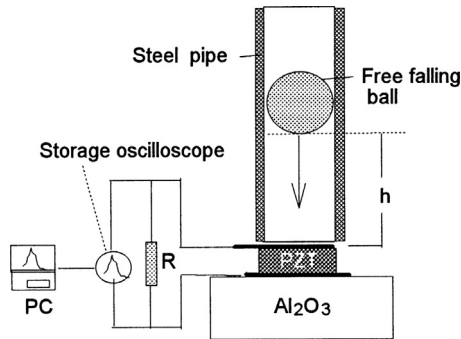


Fig. 1. Schematic drawing of the impact testing.

dimensional size on the output electrical characteristics of PZT piezoelectric ceramics using drop weight impact techniques was studied in this paper.

2. Experimental processes

The PZT piezoelectric ceramics used in this study were supplied by Eleceram Technology Co., Ltd., Taiwan. Two kinds of ceramics body were used in this study, one was hard type with the coded QB, and the other was soft type with the coded KA. The compositions of both types were in the vicinity of the MPB of PZT system in the tetragonal range. The hard QB was doped with MnO_2 and Sb_2O_3 , and it presented a free dielectric constant ϵ_{33}^T (1 kHz)=1140, a dielectric dissipation factor D (1 kHz)=0.3%, a piezoelectric voltage constant $g_{33}=19.8 \times 10^{-3}$ Vm/N, a planar electromechanical coupling factor $k_p=0.65$, a thickness electromechanical coupling factor $k_{33}=0.69$, a mechanical quality factor $Q_m=1650$, a Curie temperature $T_C=315$ °C and a bulk density $\rho=7.95$ g/cm³. The soft KA was doped with Nb_2O_5 and Sb_2O_3 , and it presented a free dielectric constant ϵ_{33}^T (1 kHz)=2100, a dielectric dissipation factor D (1 kHz)=1.5%, a piezoelectric voltage constant $g_{33}=24 \times 10^{-3}$ Vm/N, a planar electromechanical coupling factor $k_p=0.70$, a thickness electromechanical coupling factor $k_{33}=0.72$, a mechanical quality factor $Q_m=65$, a Curie temperature $T_C=325$ °C and a bulk density $\rho=7.90$ g/cm³. The disc-shaped samples with different diameter and thickness were used in this study, as shown in Table 1.

The electrical output performance of PZT specimens during applying mechanical compressive stress was measured using drop weight impact techniques, in a way as shown in Fig. 1. A steel ball (38.6 mm in diameter, 16.5 g in weight) was

dropped from a height from 5 to 50 mm, through a steel guide pipe, thereby applying an impact to the test PZT specimen. The electrical response of PZT specimens to applied stress was displayed on a digital storage memory oscilloscope (Agilent MSO-X 3054A) with an input resistance R of $10^7 \Omega$, which was connected to a personal computer (PC) for data acquisition and analysis.

3. Results and discussions

The relation between applied mechanical stress and the generated open circuit output voltage of PZT piezoelectric ceramic can be expressed as[6]

$$V = g_{33}tT_3 = \frac{g_{33}tF_3}{A} = \frac{4g_{33}tF_3}{\pi D^2} = \frac{4g_{33}F_3}{\pi} \left(\frac{t}{D^2} \right) \quad (1)$$

in which g_{33} is the piezoelectric voltage constant of the PZT piezoelectric ceramics, A is the surface area of the sample, t is the thickness of the sample, D is the diameter of the sample, F_3 is the applied mechanical force and T_3 is the applied mechanical stress.

The piezoelectric ceramic body also is the dielectric, with the generated open circuit voltage and measured capacitance, the generated electrical energy E_E stored in the piezoelectric ceramic can be calculated using a simple equation as

$$E_E = CV^2 \quad (2)$$

when substituted capacitance C with

$$C = \epsilon_o \epsilon_{33}^T \frac{A}{t} = \epsilon_o \epsilon_{33}^T \frac{\pi D^2}{4t} \quad (3)$$

and generated open circuit output voltage V with Eq. (1), the Eq. (2) can be rewritten as

$$E_E = \epsilon_o \epsilon_{33}^T g_{33}^2 F_3^2 \left(\frac{4t}{\pi D^2} \right) \quad (4)$$

From Eqs. (1) and (4), it is found when the piezoelectric ceramics material and the applied mechanical stress or applied mechanical energy is the same, the generated open circuit output voltage and the generated electrical energy were dependent on the (t/D^2) ratio of the piezoelectric ceramic body, the piezoelectric ceramics body with higher (t/D^2) ratio can produce larger generated open circuit output voltage and larger generated electrical energy.

Fig. 2 shows the relation between applied mechanical energy and the generated open circuit output voltage of the

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