GENERATING ELECTRICITY USING PIEZOELECTRIC MATERIAL

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ABSTRACT. *This paper discusses the use of piezoelectric material to generate electricity. This includes the basic theoretical modelling of the electrical power generation mechanisms and optimization of the piezo-host system. It is shown that with proper configuration, a single piezo-film can generate enough electrical density that can be stored in a rechargeable battery for later usage.*

KEYWORDS. Piezoelectric effects, Renewable energy, Vibration, Euler-Bernoulli, Power generator.

INTRODUCTION

The recent fluctuations on the price of petroleum have affected worldwide economics which has forced an increased in the price of other items including food. Some even linked the recent collapse of few financial institutions in countries such US and the UK to the recent increased in this price. This shows that we are too dependent to petroleum as a source of electrical power. Besides, petroleum as a source of electrical energy has contributed to severe air pollution problem. Therefore, an alternative method to produced electricity has to be put in place.

Among other solutions which can be explored are nuclear and hydroelectric power generators. However, these options require huge financial capability to run and to maintain. Besides, not many countries are “allowed” to use nuclear power generator due to world political scenario. Thus, photovoltaic cells and wind turbines have been the popular choices and these renewable energy sources are gaining more attention. However, they are expensive and not affordable to many countries to acquire them. As a consequence, other possible energy sources must again be explored.

One of the promising options is by using piezoelectric material or PZT. PZT can be used as a mechanism to transfer ambient vibrations into electrical energy. This energy can be stored and used to power up electrical and electronics devices. With the recent advancement in micro scale devices, PZT power generation can provide a conventional alternative to traditional power sources used to operate certain types of sensors/actuators, telemetry, and MEMS devices. Umeda *et al.* (1996) for example successfully developed an equivalent electrical model of the PZT transforming mechanical impact energy to electrical power.

Similarly, Kymissis *et al.* (1998) examined the application of a piezo film in addition to the ceramic to provide power to light up bulbs in a shoe, entirely from walking motion. Kimura's US Patent (Kimura 1998) centred on the vibration of a small plate, harnessed to provide a rectified voltage signal to run a small transmitter fixed to migratory birds for the purpose of transmitting their identification code and location. Other works by Clark & Ramsay (2000), Goldfarb *et al.* (1999) and Elvin *et al.* (2000; 2001) indicated similar possibility.

The application of piezoelectric as a power generator can be extended to operate daily low power electrical appliances such as tuner, light bulb, mobile phone and so on. The aim of this paper is to develop the piezoelectric material as a power generator for these applications.

THEORETICAL DEVELOPMENT AND SIMULATION

There are two theoretical models normally used to predict the power output from piezoelectric film attached to a beam namely pin-force and Euler-Bernoulli methods (Eggborn, 2003). Their main difference is the way to model the interaction between host structure and the piezo-film. The predicted voltage outputs for pin-force and Euler-Bernoulli are, respectively

$$V = \frac{6 g_{31} M}{b t_b (3 - \varphi)} \tag{1}$$

$$V = -\frac{6 g_{31} M \varphi (1 + T)}{b t_a (1 + \varphi^2 T^2 + 2\varphi(2 + 3T + 2T^2))} \tag{2}$$

where g_{31}, M, b, t_b, φ and T are the voltage constant of the piezo-film, moment of the beam, the width of the piezo-film, thickness of the beam, strain ratio between the beam and piezo, and the stress on the beam, respectively. The predicted voltage outputs show different pattern as shown in Figure 1.

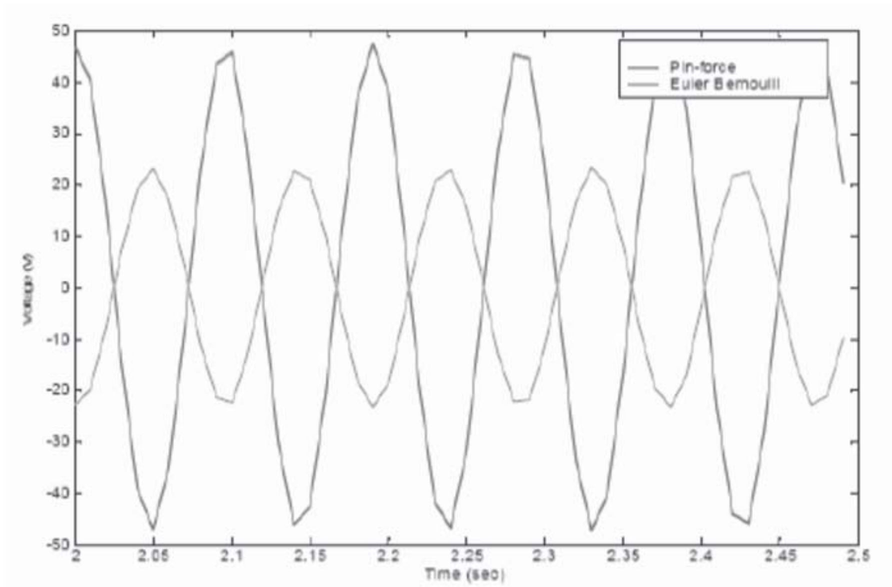


Figure 1. The voltage calculated from theoretical models.

These models tested experimentally with experimental setup shown in Figure 2. Figure 3 shows the comparison between the actual experimental data with the Euler-Bernoulli model. This shows that the Euler-Bernoulli method is more appropriate to be used to predict the output from the piezo material (Chow Man Sang *et al.,* 2007a). The error in the amplitude of the voltage output can be reduced by adding small damping into the piezo film (Chow Man Sang *et al.,* 2007b).

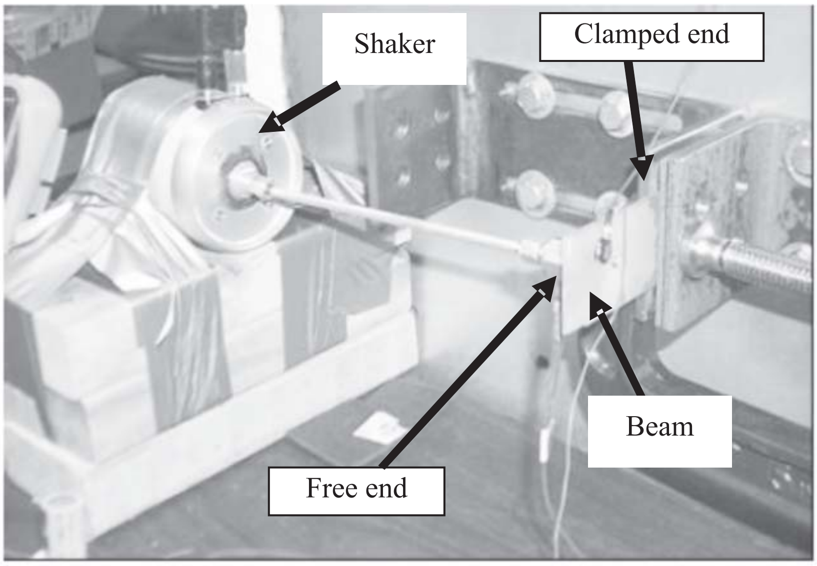


Figure 2. Experimental setup to examine the voltage output from the piezo-film. The piezo-film is attached at the back of the beam.

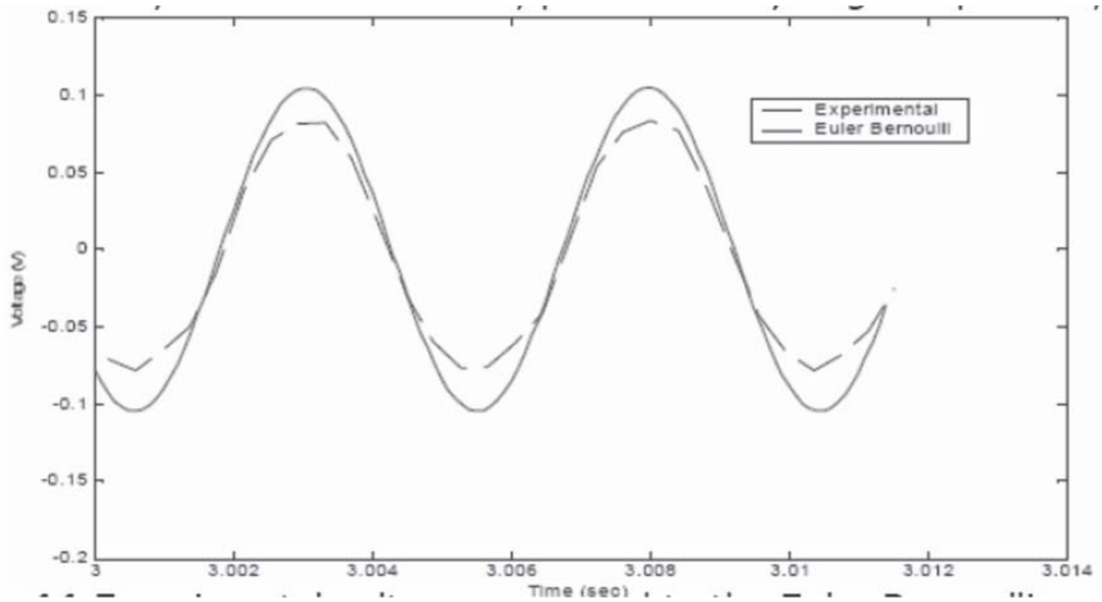


Figure 3. Comparison between experimental voltage outputs and Euler-Bernoulli model from the piezo-film.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Parametric Optimization

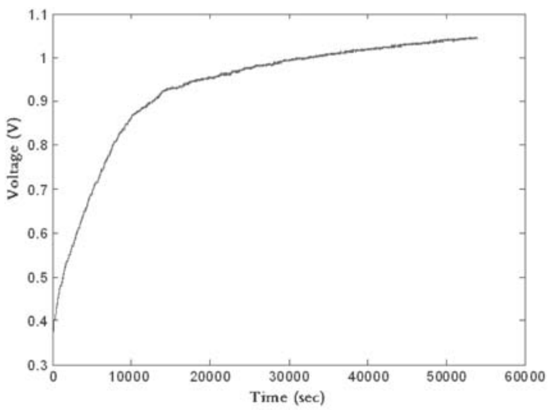
The voltage outputs from the piezo-film can be varied depending to on the piezo-beam configuration as well as the force location on the beam. Therefore, the piezo-beam-force configuration has to be optimized in order to gain the maximum output from the power generator. A series of investigation were carried out to determine optimum parameter of the experimental setup given in Figure 2.

The PZT location was found to be the best when it was attached next to clamped end of the beam (refer to Figure 2). The PZT length was optimized at a ratio of 0.54 to the beam's length whereas the thickness is optimized at the ratio of 0.53. The forcing function's optimal position was the farthest point from a clamped end as this would cause the largest moment on the beam, and the voltage outputs is proportional to the applied moment. By using these optimized variables, the power produced using the Euler Bernoulli method is increased over 150 times for the harmonically driven case and 12 times for the random noise driven case.

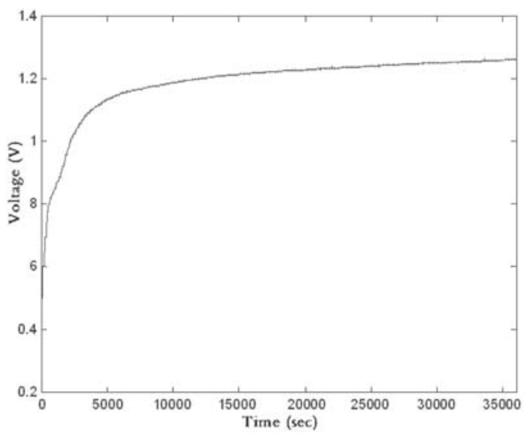
Harvesting Electrical Energy From the Piezo-film.

The investigation shows that the power output from a single piezo-film was very low in the range of 0.2μW. Therefore, direct application of the piezo-film as a power source is not practical. It is unavoidable to use a storage device to collect the weak power output for future usage. Fortunately, the voltage outputs from a single piezo-film can produce a root-mean-squared voltage of 1.18 V which is high enough to store the generated electricity into a small nickel metal hydride battery. Figure 4 shows the charging time of a 1.2V-2500 mAh nickel metal hydride battery at random force and at resonance frequency, respectively. This is equivalent to 14 hours of charging time using random force and 10 hours at resonance frequency.

After the rechargeable battery had been fully charged up, it was discharged through a load of 10 kΩ for 1 hour. During this discharging period, the current measured remained steadily at 760 mA and the potential difference across the resistor was 1.2 V. This is equivalent to an estimated power of about 0.9 W.



a) Random force



a) Random force

Figure 4. Charging a 1.2V-2500 mAh nickel metal hydride battery at random force and at resonance frequency, respectively.

Parallel and Series Connection of Piezoelectric Film

Since the power output from a single piezo-film was extremely low, combination of few piezo-films was investigated. Two possible connections were tested - parallel and series connections. The parallel connection did not show significant increase in the voltage output. With series connection, additional piezo-film results in increased of voltage output but not in linear proportion. This may be due to the non-linear modification of internal impedance of the system.

Further investigation is required to explain this non-linearity occurrence. If this is understood, an artificial modification could be added into the system to achieve the ultimate goal of producing 12V voltage output with high current density.

CONCLUSION

In this paper, a theoretical model on the generation mechanisms of electricity by piezoelectric material attached to a flexible structure has been developed and tested experimentally. The Euler-Bernoulli method was proven to be the most appropriate model in reference to the experimental data and its practicality. The piezo-host configuration was then optimized with huge increment in the voltage output. With the configuration optimised, the voltage and current density from the piezoelectric were made high enough to be stored in a 1.2V-2500 mAh nickel metal hydride battery for later applications.

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