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Piezoelectric Model of Water Drop Low Voltage Harvester

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Abstract

This research proposes the low voltage measurement from a piezoelectric transducer. The vibration source is acquired from water drop impact for different distances. A strip chart was used to record voltage signal from piezoelectric at a 100-Hz sampling rate. The voltage for each sample was saved in excel format and analysed in MATLAB software. The voltage generated has been compared with and analysed for three types of piezoelectric transducers from polyvinylidene fluoride type (PVDF). Based on the experiment and analysis, it was discovered that transducer equipped with ring mass-generated high amplitude voltage compared with other type of PVDF. The finding also showed PVDF equipped with a mass ring oscillated more amplitude voltage compared with PVDF without a mass ring. The voltage comparison between the three types of PVDF at different heights discovers that there are significantly different for each type. The more height increases the more force impact given, which will change the voltage generated by a PVDF transducer. Other than that, the result also showed that the transducer dimension will change the inductive and resistive value and can influence the voltage generated from the transducer.

Subject Areas

Electric Engineering

Keywords

Piezoelectric, Low Voltage, Water Drop Impact, Energy Harvester

1. Introduction

The high electricity consumption causes more amount of energy generated in order to meet the needs of users. This led to rising demand for fossil fuels as fuel in electric power stations. Furthermore, it also increases the electricity tariffs and billing electric energy services which are indeed a burden to the public. The use of renewable resources is seen as an alternative way to replace the existing energy sources.

One of the new method promises is through the conversion of ambient vibrations into electrical energy through a piezoelectric device. This energy can be stored and used to power up electrical and electronics devices (Jedol Dayou *et al.*, 2009) [1]. Energy harvesting from piezoelectric has been growing rapidly over the last decade. The focus in this research field is due to the reduced power requirement of small electronic devices, such as the micro sensor networks used for monitoring and self-charging applications (Alper Erturk and Daniel, 2011) [2].

The piezoelectric is discovered in 1880 by Pierre and Jacques Curie. They studied the generation of electrical charge by crystals such as Quartz, tourmaline, and Rochelle salt. The term piezoelectricity was first introduced by W. Hankel based on the thermodynamics principles (Jordan and Ounaies, 2001) [3].

The piezoelectric device has been designed in many forms depending on its application. The device can be found in many forms, including piezoceramic, single crystal, thin film, screen-printable thick film, and polymeric material (Beeby *et al.*, 2006) [4]. The most common types of piezoelectric material being used are polyvinylidene fluoride (PVDF) and lead zirconate titanate (PZT) (Wong *et al.*, 2014) [5]. The comparison between two material types piezoelectric ceramic Lead Zirconate Titanate (PZT) and polyvinylidene difluoride (PVDF) shows that PVDF has a lower cost than PZT and PVDF is not toxic, while PZT is toxic, and PVDF makes it available to the electrodes higher power (Vioala *et al.*, 2013) [6].

The piezo technology has been widely applied in many applications, for example, it has been used to convert stress from the vehicle. The transducer is embedded beneath the road and will convert energy while vehicles pass them (Aqsa Abbasi, 2013) [7]. In addition, it has been designed as a micro electromechanical system which supplies energy to the wireless sensor network (Nechibvute *et al.*, 2012) [8].

The power conversion using piezoelectric is very wide and expended to convert sound waves to electrical power, for example, energy also can convert from aircraft noise such as aerodynamic noise, engine and other mechanical noise (Gupta *et al.*, 2013) [9]. The comparison of vibration is from three sources which is construction pilling, hydraulic pump and train wheel discovered that vibration from train wheel give high voltage (Arnab *et al.*, 2014) [10]. Other than that, the study about piezoelectric connection effect has shown that the series connection has a higher voltage output and suggested for any designer who intends to design a voltage generator from the PZT should consider the series connection of the PZT (Bonface, Mwanzia, and Kamweru Paul Kuria, 2020) [11].

Most previous studies on piezoelectric energy harvesting have concentrated on a machine and human activity which is involved heavy vibration. Recently, there are an effort to generate energy from water drop and raindrop. The voltage produce by single PVDF and two parallel PVDF when exposed to the raindrop showed that single PVDF produced high voltage value compared with double PVDF (Viola *et al.*, 2013) [6]. Besides that, a study on a piezoelectric harvester of rainfall energy model demonstrated that by increasing height there is an increase in the maximum value of the voltage produced by the drop (Viola *et al.*, 2014) [12]. The other factor also can influence the voltage value produce by piezoelectric is water drop size and volume (Emma and Antoinette, 2015 [13]; Aashay Tinaikar, 2013 [14]).

The literature previously reported that a single drop of water hitting the piezoelectric plates generates voltages less than the tens of volts (Viola *et al.*, 2014) [12]. Therefore, a force from water drop can be used as a vibration source for the piezoelectric to convert mechanical energy to electrical energy.

The investigation of vibration effect from water drop previously only involved one size of piezoelectric and has been tested without weighting element. In this study, there are two factors will be investigated which is vibration signal pattern between PVDF design with and without mass. The second factor is to investigate how the size of piezoelectric transducer can change the voltage value. The purpose of the study is to see if the size of the PVDF can affect the voltage value generated by the sensor. The experimental finding of this study is considered important and can be used to design small supplies of energy and self-charging device.

2. Piezoelectric Energy Harvesting and Equivalent Model

Piezoelectric materials can be used as mechanisms to transfer mechanical energy, usually ambient vibration, into electrical energy that can be stored and used to power other devices. Basically, source of vibration can come from mechanical force. However, it also can generate from natural forces such as wind, rain and atmospheric noise. Generally, the alternating voltage produced by piezoelectric material will be fed to a bridge rectifier and stored in a rechargeable cell or capacitor as shown in **Figure 1**.

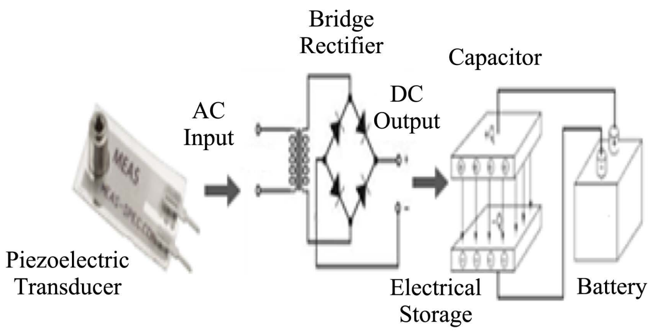

Figure 1. Piezoelectric energy harvester system.

The method of modelling piezoelectric vibration reaction consists of two main parts which is both the mechanical and electrical portion. The mechanical part is representing vibration force and electrical part is represent the voltages produced by piezoelectric. The method of modeling piezoelectric elements such as system equations for PVDF type has been discussed comprehensively by many researchers. The easy concept to understand piezoelectric effect is by modelling the device as a transformer (Viola *et al.*, 2014 [12]; Roundy and Wright, 2004 [15]) as shown in **Figure 2**.

In the mechanical portion, L_m represents the equivalent mass and the inertia of the vibrating mass, R_m represents the mechanical damping, C_m represents the mechanical stiffness, stress generator σ_{in} is due to external mechanical vibration that represents the stress developed as a result of the vibrations source. n represents the equivalent turns ratio of the transformer. C_b is the capacitance of the piezoelectric bender. V is the voltage generated by piezoelectric transducer. The variable source on the mechanical side of the circuit is stress, σ (analogous to voltage in electrical circuit), and the variable flow is strain rate $\dot{S}$ (analogous to current in electrical circuit) [14].

The equation from mechanical portion can be determined using Kirchhoff's voltage law (KVL) and Kirchhoff's current law (KCL). By applying KVL which stated that the total voltage in close loop circuit is zero, the voltage equation is then expressed in Equation (1). The equivalent currents at node 1 in **Figure 2** yield the expression in Equation (2).

$$\sigma_{in} - L_m\dot{S} - R_b\dot{S} - \dot{S}C_m - V_m = 0 \tag{1}$$

$$i = C_b V \tag{2}$$

The relationship between electromechanical couplings then can write as transformer constitutive equation and can be express as

$$V_m = n_v V_e \tag{3}$$

The PVDF transducer has been studied and value of inductance and resistance has been proposed in the electromechanical model [11]. The inductive and resistance value can be represent as

$$L_m = k_1 k_2 m \tag{4}$$

$$R_m = k_1 k_2 b_m \tag{5}$$

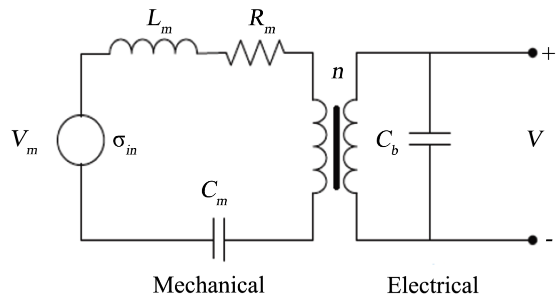

Figure 2. Circuit representations of mechanical and electrical portions.

where m is the mass of the water drop, b_m is a traditional mechanical damping, k_1 and k_2 are geometrical coefficient, given by:

$$k_1 = b\left(2L_b - L_e\right)/2I\left(b\right) \tag{6}$$

$$k_2 = 2L_b^3/3b\left(2L_b - L_e\right) \tag{7}$$

The voltage value generated by piezoelectric is dependent on dimension of transducer. The moment of inertia relative to a homogeneous mass is represented by $I(b)$ and the other quantities dimension as presented in **Figure 3**. The change of geometrical coefficient will change the inductance and resistance and further can affect the amount of voltage across transducer.

3. Methodology

In this study, three categories of piezoelectric transducer have been used, which is from polyvinylidene difluoride type (PVDF-LDTM-028K) as shown in **Figure 3**. LDTM-028K is a flexible component comprising a 28 μm thick piezoelectric PVDF polymer film with screen-printed, laminated to a 0.125 mm polyester substrate, and fitted with two crimped contacts. As the piezo film is displaced from the mechanical neutral axis, bending creates very high strain within the piezopolymer and therefore high voltages are generated.

The detailed PVDF category and dimension size involved in this study has been shown in **Table 1**. The selected piezoelectric was made to try to provide a comprehensive overview of the possibility to extract energy from water drop.

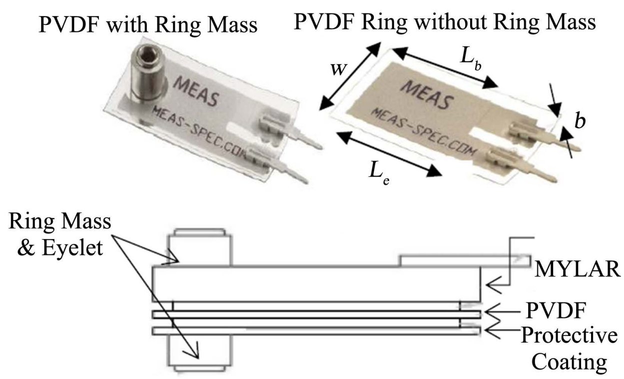

Figure 3. LDTM-028K Polyvinylidene Difluoride (PVDF).

Table 1. Type of Polyvinylidene difluoride (PVDF).

Material	Type	Dimension
Polyvinylidene difluoride (PVDF) (LDT0-028K)	Type A: PVDF with Ring Mass	25 mm × 13 mm
Polyvinylidene difluoride (PVDF) (LDT0-028K)	Type B: PVDF without Ring Mass	25 mm × 13 mm
Polyvinylidene difluoride (PVDF) (Minisense 100)	Type C: PVDF with Ring Mass	17 mm × 6 mm

The PVDF sensor was connected to digital oscilloscope to confirm the impulse response produced by the sensor. The sample of impulse voltage then was recorded on a computer using high speed input device (Measurement Computing-USB1208HS). The amplitude of voltage was read in strip chart graph using TracerDAQ software provided by Measurement Computing. The impulse response for each sample was saved in excel format and analysed in MATLAB software. The experiment setup in this study is shown in **Figure 4** and **Figure 5**.

The voltage produced by each type of piezoelectric device was investigated when water fall on the surface transducer. The voltage effect has been observed by changing the height of water drop. In this study, the size of water drop is constant for each fall-out. The average diameter of water drop is 0.4 cm, which is has been controlled manually using water drop valve controller.

4. Results and Discussion

The voltage across three different PVDF has been recorded using a strip chart graph provided by Measurement Computing. The diameter and speed of each water drop were controlled using a water valve controller. In this experiment, the vibration pattern was observed for certain distances (90 cm, 100 cm, 10 cm and 120 cm) which is to investigate the magnitude change for each water drop impact. The vibration pattern or three types of PVDF at 90 cm height are shown in **Figures 6-8**.

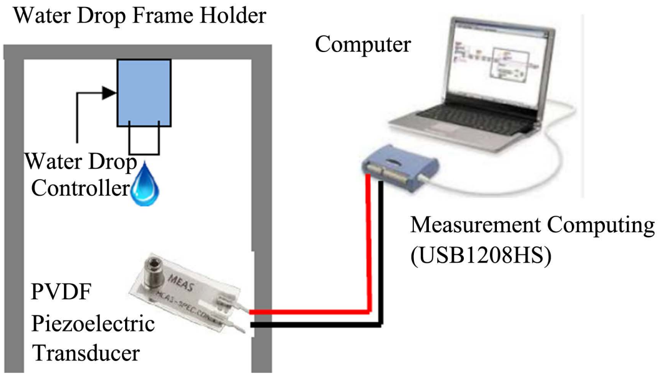

Figure 4. Piezoelectric energy harvesters experiment setup.

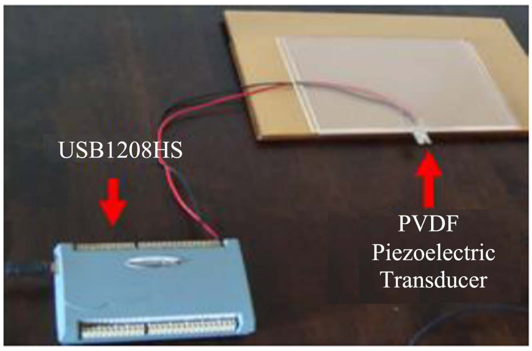

Figure 5. Piezoelectric transducer position.

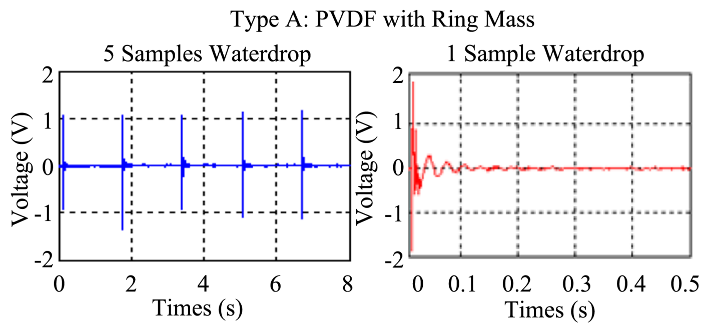

Figure 6. Vibration pattern of PVDF with ring mass.

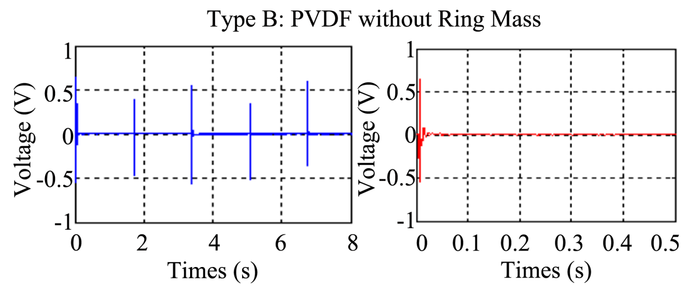

Figure 7. Vibration pattern of PVDF without ring mass.

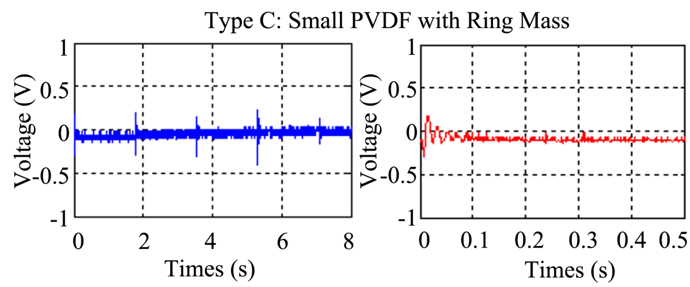

Figure 8. Vibration pattern of small PVDF with ring mass.

Based on the result, it was discovered that transducer equipped with ring mass generates high excitation compared with other type PVDF. The result also showed PVDF equipped with mass ring oscillated more amplitude voltage compared with PVDF without mass ring. In other words, when piezoelectric received force from water drop, it impacts the PVDF with mass produce more cycle compared with transducer without mass.

Figure 9 demonstrated the samples of peak-to-peak voltage produced when water drops from 90 cm height. The scatter diagram showed the value obtained from PVDF with mass for both sizes is more consistent compared with PVDF without mass. The voltage range produced by 25 mm × 13 mm PVDF with mass ring is 1.2 to 2.2 Volts and for size 17 mm × 6 mm is 0.10 to 0.15 Volts. Meanwhile the value obtained from PVDF without mass is more scattered with voltage range is between 0.5 to 2.5 Volts.

The voltage comparison between three types of PVDF at different height (**Figure 10**) discovers that there are significant differences for each type. The

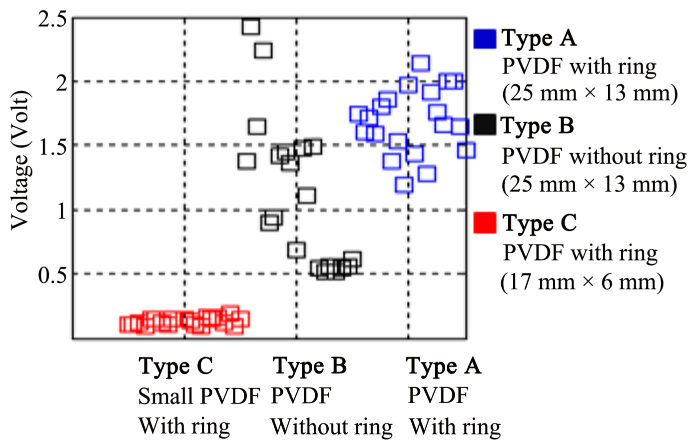

Figure 9. Average voltage samples at 90 cm height.

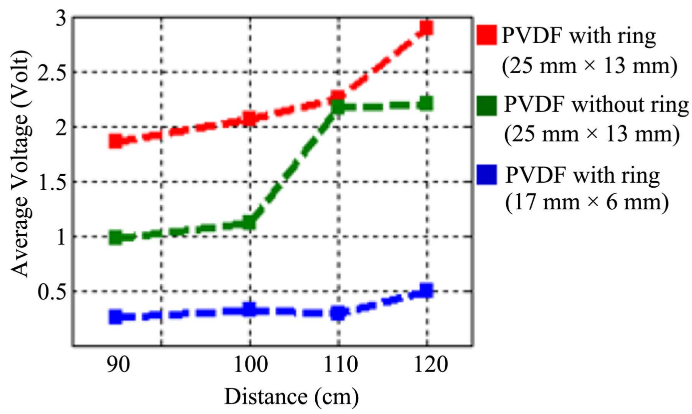

Figure 10. Average voltage generated from different PVDF.

average peak to peak value increases when the height of water drop changes. The more height increases the more force impact given, which will change the voltage generated by a PVDF transducer.

5. Conclusion

The voltage generated from piezoelectric transducer was measured for three types of PVDF. The voltage change has been analysed when the transducer received force impact from a water drop. The comparison voltage generated from PVDF shows that there are significant differences for three types of PVDF transducer. The voltage generated from PVDF with the mass ring is higher compared with PVDF without mass ring. In addition, the finding also discovered that sizes PVDF also can influence the voltage value. In other words, the geometry dimension is one of the important factors that can influence voltage generated from transducer. The changing of geometry dimension will change the value of inductive (Lm) and resistance (Rm) in Equations (4) and (5), which finally can affect the value of voltage across the PVDF transducer. In this experiment, the voltage generated was investigated only at a certain height and only involved three types of PVDF. Therefore, further research is proposed to be conducted for different heights of water drop and different sizes of transducer which is to find the inductive and resistance effect in the electromechanical model.

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Conflicts of Interest

The authors declare no conflicts of interest.

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