# DEVELOPMENT OF A WIDE-BAND VIBRATION-BASED PIEZOELECTRIC POWER GENERATION SYSTEM

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This Report Is Submitted In Partial Fulfillment Of The Requirements For The Bachelor Degree In Electronics Engineering (Industrial Electronics) With Honours

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**BORANG PENGESAHAN STATUS LAPORAN**
**PROJEK SARJANA MUDA II**

**Tajuk Projek** : Development of a Wide-Band Vibration-Based Piezoelectric Power Generation System

**Sesi Pengajian** : 1 6 / 1 7

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For mom, dad, and family,

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## ABSTRACT

This project is about a development of a wide-band vibration based power generation system. The project propose a new method to produce output voltage and power in a wide frequency range. It is used mechanical impact that is applied onto the piezoelectric in compared to previous method which is using a vibration of cantilever. By using this new method, the output voltage produce is depend on acceleration and load resistance $R_L$ while the other method mentioned depend on the single resonant frequency. The type of the piezoelectric that will be used in this project is piezoelectric transducer (diaphragm type). A prototype will be designed and developed to test the output of piezoelectric. Different types of conditions will be tested to observe the output of piezoelectric. The method and result of this project will be presented in this thesis.

## ABSTRAK

Projek ini adalah mengenai reka bentuk sistem penjanaan kuasa berdasarkan jalur lebar getaran. Projek ini mencadangkan satu kaedah baru untuk menghasilkan voltan keluaran dan kuasa dalam julat frekuensi yang luas. Ia menggunakan kesan mekanikal yang dikenakan ke atas piezoelektrik berbanding dengan kaedah sebelum ini yang menggunakan getaran julur. Dengan menggunakan kaedah baru ini, hasil voltan keluaran bergantung kepada pecutan dan beban rintangan $R_L$ Manakala kaedah lain yang disebutkan bergantung kepada kekerapan salunan tunggal. Jenis piezoelektrik yang akan digunakan dalam projek ini adalah transduser piezoelektrik (jenis diafragma). Prototaip akan dibina untuk menguji voltan dan kuasa keluaran piezoelektrik. Jenis keadaan akan diuji untuk melihat keluaran piezoelektrik. Kaedah dan hasil daripada projek ini akan dibentangkan di dalam tesis ini.

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| | | |
|---|---|---|
| m | Mass of object | [g] |
| g | Acceleration of gravity | [m/s2] |
| V | Voltage | [V] |
| P | Electrical power | [W] |

## LIST OF APPENDIX

# CHAPTER 1

# INTRODUCTION

Chapter 1 contains the introduction of the energy harvesting and piezoelectric device. Here, the performance of the piezoelectric is stated in the problem statement. Then, the objectives, scope of work and the methodology of this project has been explained.

## 1.1 Background study

The process of capturing the external power source energy and convert it into the usable electrical energy is known as energy harvesting [1]. There are many types of external power source such as photons energy, kinetic energy, thermal energy and biochemical energy [2]. Figure 1.1 show the process of energy harvesting.

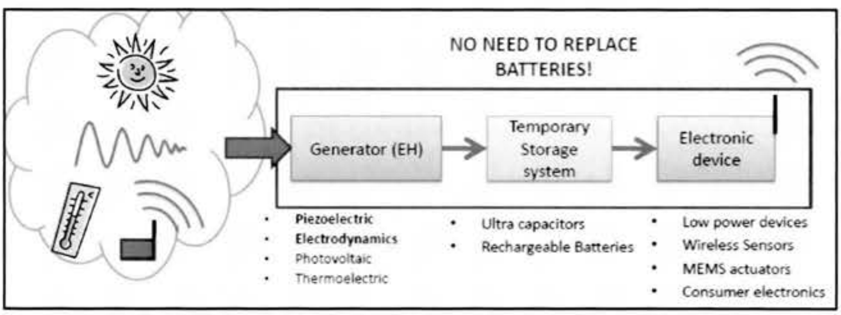


Figure 1.1: The process of energy harvesting [2]

Piezoelectric is a device that can produce electrical energy whenever there is an external force are applied onto it. This is because piezoelectric materials have a crystalline structure that allow it to convert from the mechanical strain energy into the usable electrical energy. The crystalline structure in the piezoelectric able to absorb mechanical energy from their surrounding usually ambient vibration, and transform into electrical energy that can be used to power other device [3]. Figure 1.2 show the crystalline structure in the piezoelectric material.

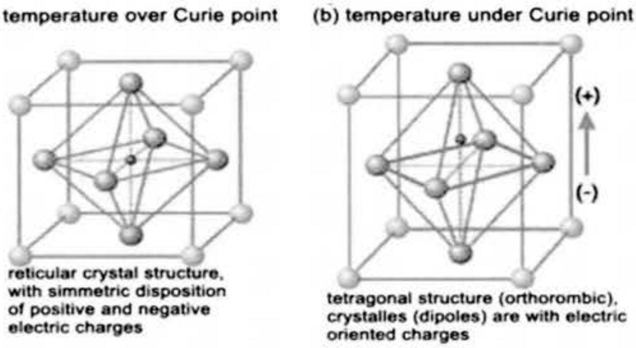


Figure 1.2: Crystalline structure of piezoelectric ceramic [4]

There are many types of piezoelectric that is applied in generators which is ceramic, composite, polymers and monocrystals. The most frequently used piezoelectric in generator design is ceramic materials. It is a mixed crystal of titanate and lead zirconate [5].

Composites is a materials that consists of different shapes, layers of adhesive, polymer film and approximately was formed. On bolt-on parts of this material, there is a layer of composite electrodes installed correctly. There are two types of composite piezoelectric which is PFC (piezoelectric filter composite) and MFC (macro-fibre composite). PFC contain the circular piezoceramic fibres that placed in the layer of adhesive and on bolt-on parts of the polymide film and electrodes. Meanwhile, MFC are made of rectangular piezoceramic bar, separated by adhesive layers and polymide film and an electrode on the bolt-on part. It is manufactured by Smart Material Corporation. Figure 1.3a show PFC type and 1.3b show MFC type [5].

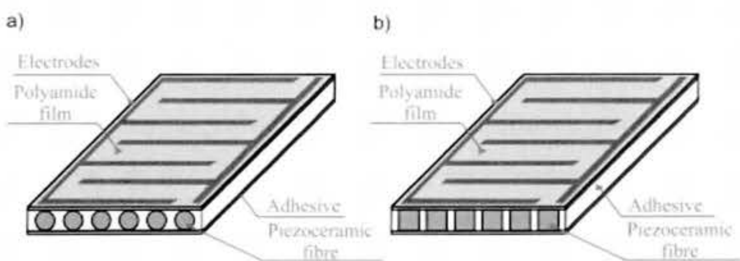


Figure 1.3: Types of composite piezoelectric [5]

Chemical substance consist of multiple constituent parts is called polymers. Between polymers, the most important is polyvinylidence fluoride (PVDF). It is a semicrystal and consist of a maximum of 50 – 60 % of the crystal phase. The application of this type of piezoelectric is to powering a damage sensor and energy harvesting acoustic resonator with beams [5].

For monocrystal type, it is most promising piezoelectric materials in generator field of research because they are very effective when it comes to energy conversion [5].

## 1.2 Objectives

There are three objective in this project which is:

i) To study about the piezoelectric and how it functions.
ii) To generate high power output of piezoelectric harvesters.
iii) To develop a wide-band vibration-based piezoelectric power generation system.

## 1.3 Problem Statement

Most of piezoelectric-based energy harvesters are design and operated at the frequency of ten to hundreds Hertz. However, the traditional piezoelectric harvesters can only generate a single resonance peak and they are limited by a narrow band and low power output. To make a better performance, a multi-impact energy harvester is design to enhance the performance of the energy harvesting on a wideband frequency.

## 1.4 Scope of work

The scope of work in this project is:

i) Make a preliminary study about how the piezoelectric function.
   - Gather all the information about how to harvest the vibration source energy into electrical energy.
   - Know the concept on how to convert the vibration source into the electrical energy by using the piezoelectric materials.

ii) This project is focus on ambient vibration energy only. The type of piezoelectric use is piezoelectric diaphragm.

iii) For device development, the prototype will be produce by using suitable material.

iv) For testing and measurement, the model of piezoelectric will be tested by using the shaker device to obtain the output voltage and power against the frequency.

## 1.5 Methodology

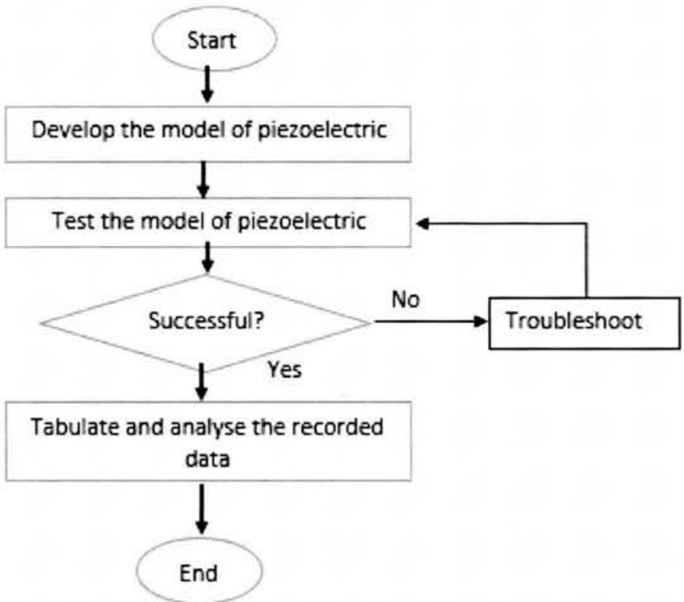


Figure 1.4: The flowchart of the project methodology

A model is built to place the piezoelectric on top of the vibration base. Next, the model is clamped onto the shaker device and connected with the load resistor and oscilloscope. Through this method, the output voltage and power can be obtained accordingly. In order to obtain the output voltage, the same frequency is used along with two different base acceleration (g-level) value. The detailed about the model of the piezoelectric will be discussed in chapter 3.

## 1.6 Thesis Outline

This thesis consists of five chapters and the content of each chapter is summarized below.

Chapter 1: Introduction

Chapter 1 will cover the introduction to energy harvesting of piezoelectric application and types of piezoelectric devices. Here, the objectives of the project, problem statement, scope of work has been explained.

Chapter 2: Literature review

Complete literature review on energy harvesting by using piezoelectric device, and previous research work are reviewed. It is include the basic introduction of piezoelectric material, piezoelectric energy harvesting and properties, and review of piezoelectric power generation system.

Chapter3: Methodology

Chapter 3 briefly explain the design methodology and technique of the project. Step by step to develop a vibration-based power generation system will be discussed in this chapter.

Chapter 4: Result and discussion

The data obtained from the experiment in the lab will be present in a graph form and will be discussed in chapter 4.

Chapter 6: Conclusion and recommendation

The conclusion, project achievement and some future recommendations are proposed in this chapter.

; REVIEW

w about energy harvesting and

## 2.1 Introduction

In recent years, energy harvesting has growth rapidly in industry. In article of Reaping The Benefits of Energy Harvesting by Greg Quirk, it is estimate that the energy harvesting will be exceed of billion in 2020 due to the market was $79.5 million in 2009 cause the average of rate growth 73%.

In piezoelectric, the technology of energy harvesting was considered unreliable and had low power output long time ago. However, it is drastically improve when the device demonstrated in 2008, the harvesting power is mw from μw.

This project will be used concept of energy harvesting that will convert an ambient vibration into the usable electrical energy. The piezoelectric material will be used in this project to obtain the voltage output. The type of piezoelectric used in this project is diaphragm type. This project will be operate where the vibration will be generate from the shaker source then the piezoelectric will be used as a device to capture the energy waste. After that, the heat will be converted into electrical energy.

## 2.2 A review on piezoelectric basic structure

A piezoelectric substance is a material that produces an electrical charge when a mechanical stress is applied. This is because the crystalline structure inside the piezoelectric material is squeezed or stretched. This phenomenon is called piezoelectric effect. Conversely, when an electric field is applied, a mechanical deformation will produced because the crystalline structure inside it become shrink or expand. This effect is formed in crystals that have no centre of symmetry [6].

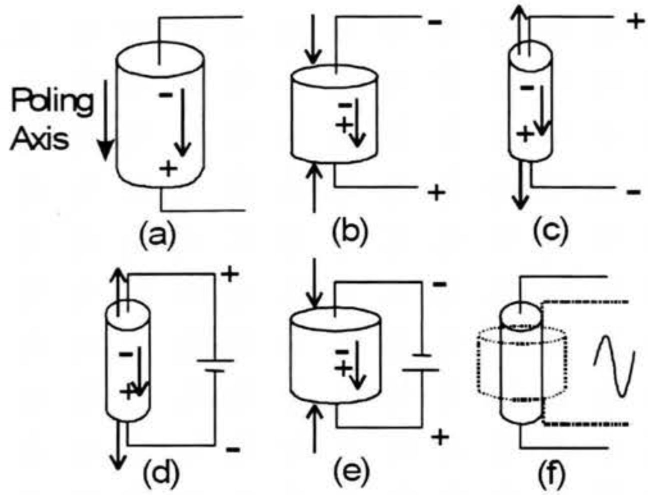


Figure 2.1: Example of piezoelectric effect [5]

Figure 2.1 show the example of piezoelectric effect. In figure 4(a), it show that the piezoelectric material without stress or charge. A voltage of the same polarity as the polling voltage will appear between the electrodes as shown in figure 4(b) when the material is compressed. Meanwhile in figure 4(c), it show that the opposite polarity of voltage will appear if it is stretch. In the other hand, if a voltage is applied the material will deform. For figure 4(d), it show that the voltage with the opposite polarity as the poling voltage will cause the material to expand, and the material will compress as it shown in figure 4(e) if the voltage have the same polarity. When an AC signal is applied onto it, the material will vibrate at the same frequency as the signal shown in figure 4(f) [6].

Direct piezoelectric effect and converse effect is the domains where the piezoelectric effect is exist. Direct piezoelectric effect is the material's ability to transform mechanical strain into electrical charge. It is responsible for the material's ability to function as a sensor. The converse effect means the ability to convert an applied electrical potential into mechanical strain energy. It is accountable for its ability to function as an actuator. If it has the ability to transform electrical energy into mechanical strain energy and vice versa, which mean to transform mechanical strain energy into electrical charge, it means that a material is deemed piezoelectric [3].

Piezoelectric have two behaviour that is mechanical and electrical. The mechanical and electrical of a piezoelectric material can be modelled by using two linearized constitutive equations. These equations contain two mechanical and two electrical variables. The direct effect may be modelled by the following matrix equations [3]:

Direct Piezoelectric effect: $\{D\} = [e]^T \{S\} + [\alpha^s] \{E\}$ .......... (1)

Converse Piezoelectric effect: $\{T\} = [c^E] \{S\} - [e] \{E\}$ .......... (2)

Where:

D = electric displacement vector

e = dielectric permittivity matrix

$\alpha^s$ = dielectric matrix at constant mechanical strain

T = stress factor

$c^E$ = matrix of elastic coefficient at constant electric field strength

E = electric field vector

## 2.3 A review on piezoelectric energy harvesting structure and properties

Henry Sodano et al. state that one of the most effective methods of implementing a power harvesting system is to use mechanical vibration to apply strain energy to the piezoelectric material or displace an electromagnetic coil [3].

Arman Hajati and Sang – Gook Kim conduct an experiment to get ultra-wide bandwidth by using microelectromechanical system (MEMS) structures. They state that the wide bandwidth resonance of the system can be explained by negative feedback resulting from buffing stiffening. Stretching stiffness induces an amplitude – dependent stiffness, $k_{eq} = ( k_B = k_\sigma ) + \frac{3}{4} k_s Z^2$, which force the equivalent resonance frequency to track the excitation frequency [7].

Where:

$k_{eq}$ = Equivalent linear stiffness

$k_B$ = Bending stiffness

$k_\sigma$ = Stiffness due to the residual stress

$k_s$ = Stretching- based stiffness

$Z^2$ = Amplitude of the deflection

The equivalent stiffness should be mainly controlled by the non-linear stiffness term, such that $k_B + k_\sigma \ll k_s Z^2$ to achieve a stronger non-linearity for a wider resonance bandwidth [7].

For the third case, Moheimani and Fleming state that a wide application area for piezoelectric materials is vibration control. It have two approach for its solutions. The first is active damping and the second is passive damping or it is also known as shunt damping. Active damping mean that where part of the piezo elements attached to structure is performing sensing activity and others are actuators. It requires a closed loop controller and power supply. Meanwhile the passive damping is where the piezoelectric is a transducer that transform part of the mechanical vibration energy into electrical energy that can be conveniently dissipated in the circuit [8].

Scott Meninger et al. in their research, they proposed to convert ambient mechanical energy by using MEMS variable capacitor. By moving the plates apart after placing charge on the capacitor plates, the mechanical energy can be converted into electrical energy which can then be stored and utilized by a load [9].

Furthermore, in research paper by Ye Zhang, he presented a multi-impact energy harvester to obtain a better performance of energy harvesting at low frequencies. The proposed harvester can efficiently up-convert the vibrations frequency by several impacts during one vibration cycle. By keeping the piezoelectric beam with less time interruptions, the output power can be significally increased. The multi-impact also make each impact controllable and improves the durability of the system [10].