UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN AND DEVELOPMENT OF PIEZOELECTRIC ENERGY HARVESTING SYSTEM ON THE STREET LIGHT

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Engineering Technology ((Industrial Automation & Robotics) (Hons.)

by

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Engineering Technology (Industrial Automation & Robotics) (Hons.). The member of the supervisory is as follow:

……

(Miss Herlanda Windiarti)

ABSTRACT

In the high demanding energy of modern society, the resource of fossil fuels are getting decreases in supplies and causing the increasing of energy costs. New renewable sources of energy and alternative method need to be explore for the future in order to reduce global oil crisis. Energy generates using mechanical energy convert into electrical energy for purpose use to harvest energy through storage system and provide renewable energy to utilize for road light. Piezoelectric materials have property to provide energy and have ability to convert a mechanical vibration strain into an electrical energy potential for harvesting energy. Piezoelectric can generate energy and convert the energy of mechanical vibrations into electrical energy that can be found in environmental such as movement of vehicles and vibrations of vehicles. Main purposes of this project is to generate energy from being waste and sustain the energy remain resources in the earth. Selection of piezoelectric materials is vital to choose the most suitable piezoelectric sensor based on the specifications and suitable energy output. Thus, the piezoelectric energy harvesting system needs to be developing for renewable energy and uses to harvest the energy normally lost in environment and convert it into electrical energy supply for road lamp system. The piezoelectric energy harvesting system reduces the dependency on the non-renewable energy and develops a self-generate system. Furthermore, project focuses on the design and development of piezoelectric energy harvesting system for the road lamp system.

ABSTRAK

Dalam masyarakat yang moden sekarang kegunaan tenaga semakin bertambah, sumber bahan api yang semakin hari semakin berkurangan menyebabkan kos tenaga semakin meningkat. Sumber tenaga boleh perbaharui dan cara alternative perlu diterokai untuk masa hadapan dalam mengurangkan krisis minyak global. Tenaga yang dijana menggunakan tenaga mekanikal untuk menukarkannya kepada tenaga elektrik bertujuan untuk mengumpul tenaga melalui sistem simpanan dan membekalkan tenaga boleh perbaharui untuk kegunaan lampu jalan raya. Piezoelektrik ialah bahan yang mempunyai kebolehan untuk menjana tenaga dan menukarkan tenaga mekanikal kepada tenaga elektrik. Piezoelektrik adalah salah satu sistem yang cekap dan bertenaga hijau kerana boleh menukar tenaga getaran kepada tenaga eletrik yang boleh diperoleh melalui persekitaran iaitu kenderaan yang bergerak dan menghasilkan getaran. Objektif projek adalah menjana tanaga daripada tenaga yang tidak digunakan dan juga bagi mengekalkan bahan api semulajadi yang sedia ada. Oleh itu, pemilihan piezoelektrik adalah penting mengikut kesesuaian berdasarkan spesifikasi dan keluaran tenaga. Penghasilan sistem tenaga piezoelektrik perlu dibangunkan untuk tenaga boleh perbaharui dan digunakan untuk menghasilkan tenaga yang biasanya dibiarkan hilang dipersekitaran dan menukarkan kepada tenaga elektrikuntuk sistem lampu jalan. Sistem piezoelektrik boleh mengurangkan kebergantungan pada tenaga yang tidak diperbaharui dan membina satu sistem janakuasa sendiri. Projek ini memberi tumpuan kepada reka bentuk dan pembangunan penghasilan sistem tenaga piezoelektrik untuk sistem lampu jalan.

DEDICATIONS

To my beloved parents

To my kind lecturers

And not forgetting to all friends

For their

Love, Sacrifice, Encouragements and Motivation

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D	=	Dielectric displacement
T	=	Mechanical stress
E	=	Electric field
S	=	Mechanical strain
d	=	Piezoelectric charge constant
ε^T	=	Permittivity (T=constant)
s^E	=	Elasticity constant (E=constant)

CHAPTER 1
INTRODUCTION

1.0 Background of Project

Nowadays, most of the research in the energy field is to develop sources of energy for future. Non-renewable resource like oil resource being over tapped and eventually bound to end, it is time to find new renewable sources of energy for the future. Piezoelectric materials are being more and more studied and researches because it is very specific generation and interesting properties. In fact, piezoelectric materials have the ability to produce electrical energy from mechanical energy, for example it able to convert mechanical behaviour like vibrations into electricity. Such devices are commonly referred to as energy harvesters and can be used in applications where outside power is unavailable and batteries are not a feasible option.

Piezoelectricity materials nature is closely linked to the significant quantity of electric dipoles within these materials. An electric dipole has a direction and a value in accordance with the electrical charges around. Piezoelectric materials creates a voltage is because when a mechanical stress is applied the crystalline structure is disturbed and it changes the direction of the polarization. As a consequence, the bigger the mechanical stress, the bigger the change in polarization and the more electricity is produced.

Piezoelectric circuit need to develop in a system in order to extract the electrical energy produced by the piezoelectric material. Thus, it is to convert a maximum amount of mechanical energy into electrical energy and that will provide a great amount of voltage. A step-up voltage circuit is ideally suited to harvest a maximum amount of voltage because it is only composed of passive electrical

components such as capacitors, resistor and does not need an outside source of energy that could disturb the extraction of energy from the vibration.

With the recent growth and development in power energy and high demand of power, generation demand and transmission system are getting increases in the community. Transmission system energy losses are increase between generation and demand due to long distance, voltage leakage, and system failure. In order to decreases losses, piezoelectric harvesting energy system can be implements to replace long distance transmission system such as traffic light, highway streetlight and so on. Piezoelectric materials suitable to captures of ambient vibration can be obtained on the road surface structure that energy conversion from mechanical to electrical energy.

This project focuses on the design and development of piezoelectric energy harvesting system to power up the road lamp system. Concerns regarding low voltage energy generated from piezoelectric materials, voltage multiplier circuit and electrical storage system are needed to overcome the problem. Once the harvesting energy system developed can use store and supply power, it can light up lamp system along the road side. Therefore, piezoelectric materials can be use to produce the electrical energy from vibration, reduce transmission energy losses and play an important role to increase renewable energy generation widely in the future.

1.1 Problem Statement

With the recent growth and development in power energy and high demand of power devices as well as the global interest in the concept of green product, the topic of green energy harvesting has received much attention since the past decade. The demands of renewable energy requirements have steadily increased with the advancements in energy harvesting systems. Therefore, piezoelectric is one of the reliable renewable energy to produce the electrical energy from vibration and also plays an important role to harvesting green energy. Furthermore, piezoelectric will not affect by the weather of Malaysia, when the car passing by, the vibration will be absorb by the piezoelectric.

The road lamp system have voltage leakage due to poor grounding that has produced a voltage surge and affected the lighting system and causes some safety issues on the road. Therefore, it is important for the road lamp to have a storage device that will power up the road lamp. In Malaysia rich raining and cloudy day country but most of street light will not light up because it have set with timer where power up from 7 pm to 7 am only. The evaluation of a piezoelectric system has ability to operate in a self-charging manner to produce energy for road lamp and implement with light sensor which can switch on and off streetlight according weather condition. With the piezoelectric energy harvesting system, the power failure on road lamp will be decreased effectively and provide green environmental solution.

1.2 Objective of Research

The objectives of this project are:

I. To design a real plant application and prototype of piezoelectric energy harvesting system which can be use to generate voltage for the road lamp.
II. To testify and evaluate the performance of piezoelectric energy harvesting system.
III. To develop a rechargeable battery system for the road lamp.

1.3 Scope of the Research

This project is devoted to design and develop a real plant application and prototype of piezoelectric harvesting system, where the main design is to harness the vibration energy. Piezoelectric energy produced from the stress and vibration of running vehicles on the road and turns the wasted energy into electricity to power the road lamp. The piezoelectric materials are selected based on size, generated output and material hardness and reliability before it is installed under the modelled road.

1.4 Report Outline

This report had included five chapters.

Chapter 1 presents the introduction of the project title of piezoelectric energy harvesting through vibration from movement vehicles. This chapter also describes the project background history, problem statement, objectives, and scope of the project.

Chapter 2 explains the literature review focus on the piezoelectric energy harvesting from vibration energy that previous researchers investigate and piezoelectric materials exploration.

Chapter 3 discusses the procedure and steps to build the project explained in detail, which include the flow chart of the system. In this part also include location, specification for road lighting and circuit design.

Chapter 4 presents experimental results of the project, which tested by piezoelectric sensor applied forces on the surface membrane. Experimental results shown in forms table for analysis and explained briefly.

Chapter 5 explains and summarize the conclusion for this whole project. There are some of the recommendations and improvement for future works discussed and it is also highlighted the commercialization potential of piezoelectric harvesting energy in the market.

CHAPTER 2
LITERATURE REVIEW

2.0 Introduction

This chapter discusses the applicable piezoelectric information, fundamental and research relates to piezoelectric. Initial the project piezoelectric harvesting system, selection of piezoelectric materials are very important and voltage output condition need to be considered. Research and review for theory of piezoelectric and applicable device of piezoelectric are explained in detail in this chapter. Design and development for an idea and good practice piezoelectric system, piezoelectric properties, specification, and output source need to be applied properly and efficiently. Review of high efficient and cost consideration for piezoelectric materials in the project taken into consideration. Design and develop of software and hardware circuit must be practical in order to achieve the goal. Piezoelectric elements need to investigate based on the specification and ambient vibration condition, it is because different structural vibration are generated different output of energy. In the same way, there is an interest how to increase output voltage of piezoelectric to work as sources for road lamp during the night from harvested energy.

2.1 Energy Harvesting from Vibration

Piezoelectric harvester generates energy uses ambient vibration, many opportunities can be found for converting vibrations into electrical power in the environment. Vehicle traffic produces intense mechanical disturbances and even the simple act of heel striking the ground while walking produces energy in the range of several Watts. There are commercial products for both of these applications and piezoelectric harvesting is being built into some new pedestrian walkways in modern buildings.

Piezoelectric materials generation can be different with sizes and shapes, according acting pressure and stress with precision springs. (Ji Wang et al. 2005) Figure 2.1 show material configurations that piezoelectric transducers (PZT) under pressure and generate energy with frequency and rigidity.

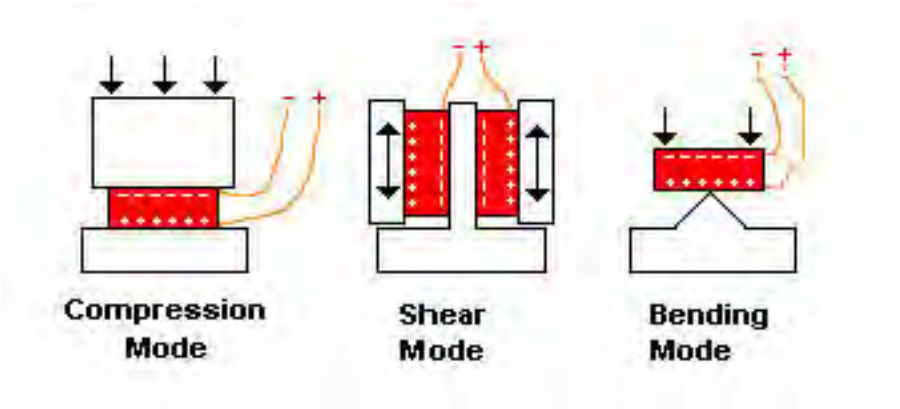

Figure 2.1: Material Configurations (source : <http://www.beraninstruments.com/Applications/Glossary/Accelerometer>29/05/15)

Piezoelectric structure compression design can be divided into compression, flexural and shear. Accelerometers can be compression are applies on the white colour surface and different configuration provide different voltage output. Feature of material configuration such as compression are highly rigidity using for higher frequency pressure and force. Moreover, flexural design feature usually apply in narrow frequency range and low over shock ability. For shear configuration are simplicity designs with low off axis sensitivity, low thermal inputs sensitivity and low base strain sensitivity.

The hybrid device suggests that harvesting both solar and vibration energies can enable more efficient harvesting in certain environments compared to a device that harvests just one kind of energy. This energy harvester can be very useful where there is no electric grid connected. For example, this device will be useful in moving vehicles such as moving boats, trains, automobiles, etc. Piezoelectric efficiency depends on the vibration force from a moving object that is higher speed will provide

higher output generation. Once the mechanical vibration for the road structure device and fabrication condition, an optimized the output power will be increased significantly. (Mickael Lallart and Daniel J. Inman, 2010)

2.2 Properties of Piezoelectric Materials

Piezoelectric materials forms are begin from a single crystallite to a polycrystalline ceramic to build up the structure of ceramic. Normally crystal form with negative and positive ions atom in occupy specific position and symmetry in the cell. Piezoelectricity in the crystals ceramic are divided into 32 classes or groups, such as monoclinic, triclinic, cubic, hexagonal, orthorhombic, rhombohedral and tetragonal.

Piezoelectric are separated into positive and negative electrical charges that contain many molecules, it know as a dipole moment and vector extending from the negative charge to the positive charge. Piezoelectric crystals properties are use to apply force to the molecular dipole moments causing a lot of variation in the surface charger density to generate voltage. Once the electric field is applied across the piezoelectric medium, materials dimensions will change significant when a slight change of dipoles shape to generate output. An ultrasound pulse enables for conversion effect on the piezoelectric elements. Primarily considered as normal fields and forces, shear forces can also produce strong piezoelectric effects. Quartz crystals normally will induce other materials, such as titanium, lead, zirconium that contain in the special formulated ceramics. Piezo ceramic properties used to form various size and shape in order to activate PZT that mix with different metals. This effect occurs naturally in quartz crystals, but can be induced in other materials, such as specially formulated ceramics consisting mainly of lead, zirconium, and titanium (PZT). Piezo ceramics can be formed to most any shape or size in order to activate the PZT properties of the mix of metals and forcing the ions to realign along this polling axis. Voltage generate through a sufficient strength of voltage field is applied in the desired direction. Piezoelectric materials generate electrical energy in response

to the vibration at different frequencies. (Daniels A et al, 2013) & (Anvinder Singh, 2014)

2.3 Piezoelectric Effect

Piezoelectric effect is piezo ceramics are materials that demonstrate and have an electrical potential once pressure across the surface of a crystals. According piezoelectric theory, piezoelectric effect that provide potential electrical when crystal ceramic under pressure and distortion once the electrical field is applied. Mechanical deformation forces on the surface ceramic causing displacement of ions in crystal structure unit potential electrical are appearances. Crystal structure unit mainly consist of Zirconium, Lead and Titanium (PZT), those element can be formed most of the shape and size for different piezo properties. Quartz crystals will appearance an electrical potential when sufficient forces and strength is applied with different direction and mechanical deformation causing displacement of ions to realign in the crystal. Crystal ceramic provide a sufficient voltage field once ions being force and under pressure in the desired direction along the polling axis. (Kumar Govind et al, 2012)

Ferroelectric materials are included in the group of piezoelectric ceramics and generate electric field once the crystal is applied force on the polar. Ferroelectric crystal can be divided into spatial regions having different directions of polarization, called ferroelectric domains. Domain in a solid body is a physically bounded spatial region in which a vector quantity characterizing the state at a point in the solid body has the same direction everywhere. Figure 2.2 shows ferroelectric domain has characteristic quantity that consists in the same alignment and the same absolute value of the spontaneous polarization. Piezo ceramic material of polycrystalline have different particle size, polycrystalline included a few domains, bounded by domain walls.

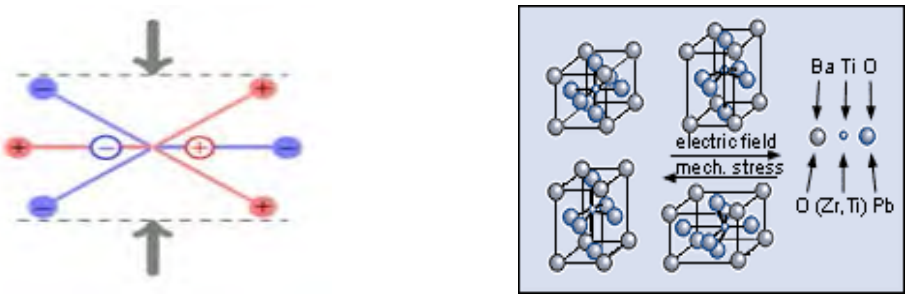

Figure 2.2 : Cubic and ferroelectric structure of PZT mechanical stress taken effect (Tomasz G. Zielinski, 2010)

Cubic structures will deform once the material to some external stress. Cubic centres have negative and positive charge each molecule coincide, different charge reaction that used to generate energy. The external effects of the charges are reciprocally cancelled as a result of electrical energy neutral molecule appears. Ferroelectric crystal is divided into spatial regions having different directions of polarization, called ferroelectric domains. Domain in a solid body is a physically bounded spatial region in which a vector quantity characterizing the state at a point in the solid body has the same direction everywhere. A ferroelectric domain can be spontaneous polarization the characteristic quantity consists in the same alignment and the same absolute value. Depending on the particle size of the polycrystalline ceramic material, the individual crystallites contain only a few domains, bounded by domain walls.

Figure 2.3 shows piezoelectric component are divided few part, such as capping layer, adhesive, piezoelectric component, adhesive and bending layer. A distribution of a linked charge appears in the materials surfaces and the material is polarized. Once the piezoelectric detect vibration the polarization generates an electric field and can be used to transform the mechanical energy of the materials deformation into electrical energy. Energy harvesting through the changing of mechanical energy like a vibrating structure into an electrical energy. Energy converted used for other purposes to drive an electrical circuit for storage in a battery or a large capacitor.