EXPERIMENTAL ANALYSIS ON VIBRATION ENERGY REGENERATION SYSTEM USING PIEZOELECTRIC SENSOR FOR WIDEBAND APPLICATION

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I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.

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DEDICATION

I dedicate my dissertation to my family which I am blessed with their continuous support on financially and emotionally throughout my studies in UTeM. Also, to my supervisor, Dr. Amat Amir bin Basari for guiding me from the scratch and along the process of completing this project.

ABSTRACT

Vibration energy produced high power in specific frequency but in a narrow bandwidth. This project consists of a method on widening frequency bandwidth by using non-uniform mass using concept centre of gravity. The movement of liquid when the beam bends has result in changes to the centre of mass which contributed in bandwidth widening. Piezoelectric sensor in cantilever structure is used as a transducer to convert vibration energy to electrical energy. The liquid mass is placed on the tip of the piezoelectric sensor. The liquid used to demonstrate in this project are differ in term of density and viscosity. Low acceleration (1 g) that applied to the sensor has given impact to the performance which has affect the movement of liquid for different viscosity. Two types of container (round and rectangular) were also used to determine the best shape to produce greater frequency bandwidth. Result shows that the frequency bandwidth is broadened by 2 times higher for honey in round container with low volume (10ml) compared to without tip-mass. This technique also increased the frequency bandwidth by 1.6 times compared with the solid tip-mass. The demonstrated technique overall has increased the frequency bandwidth without reducing the harvested power.

ABSTRAK

Tenaga getaran menghasilkan kuasa yang tinggi di frekuensi tertentu tetapi dalam jalur lebar yang kecil. Projek ini terdiri daripada kaedah meluaskan jalur lebar frekuensi dengan menggunakan cecair berdasarkan pusat konsep graviti. Pergerakan cecair apabila struktur piezoelektrik membengkok telah menghasilkan perubahan kepada pusat jisim yang menyumbang kepada pelebaran frekuensi jalur lebar. Sensor piezoelektrik dalam struktur sokongan digunakan sebagai transduser untuk menukar tenaga getaran kepada tenaga elektrik. Jisim cecair diletakkan pada hujung sensor piezoelektrik. Cecair yang digunakan untuk menunjukkan dalam projek ini berbeza dari segi ketumpatan dan kelikatan. Pecutan rendah (1 g) yang digunakan untuk sensor telah memberi impak kepada prestasi yang memberi kesan kepada pergerakan cecair untuk berlainan kelikatan. Dua jenis bekas (bulat dan segi empat tepat) juga digunakan untuk menentukan bentuk terbaik bagi menghasilkan jalur lebar frekuensi yang lebih besar. Keputusan menunjukkan bahawa jalur lebar frekuensi diperluaskan dengan 2 kali lebih tinggi untuk madu dalam bekas bulat dengan isipadu yang rendah (10ml) berbanding tanpa jisim. Teknik ini juga meningkatkan lebar jalur frekuensi sebanyak 1.6 kali berbanding dengan jisim pepejal. Teknik ini secara keseluruhan telah meningkatkan jalur lebar frekuensi tanpa mengurangkan kuasa yang dihasillkan.

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	:	Alternating Current
BW	:	Bandwidth
DC	:	Direct Current
H_2O	:	Dihydrogen Monoxide
PCB	:	Printed Circuit Board

CHAPTER 1

INTRODUCTION

1.1 Overview

Energy harvesting has been widely implemented in various application over past decades to reduce the dependency on non-renewable energy. Various types of energy harvesting including vibration, solar, wind have taken place to generate electrical energy. These renewable energies do not harm the environment and mostly low cost rather than non-renewable energy. Vibration energy regeneration is one of the methods used in low power electronic applications [1-4]. Many researches have been conducted in design, efficiency and material development in order to achieve several parameters in the usage of vibrational energy harvesting. Various sources of vibration energy can be utilizing to convert to electrical energy and use in our daily life. The conversion of mechanical energy(vibration) to electrical energy can be approaches in electromagnetic, electrostatic and piezoelectric. Piezoelectric acts as a transducer device which generate electrical energy when stress is applied on it. Because of this characteristic, these devices have been used to harvest sources of energy such as ambient vibration and convert it into energy generator to power small devices. Such devices are commercially available, however those in the market tend to function at much narrower frequency and at a lower efficiency for certain applications. The major challenge in vibration energy harvester is it produces narrow bandwidth which is not feasible for real life applications [5,6]. Vibrational energy regeneration of piezoelectric demands high Q-factor and low bandwidth to achieve high power. In order to have high power, it requires narrow bandwidth which is not suitable to be implement in many real-life applications. Therefore, this project is to focus on the use of piezoelectric effect for energy harvesting to enhance the bandwidth for wideband application. The solution for broadening the bandwidth of piezoelectric energy harvester with significant cantilever-based design is proposed in this project. The liquid filled mass placed on the tip of piezoelectric sensor based on the principle of sliding mass will be using to achieve the objectives of this project.

1.2 Problem statement

Piezoelectric is capable in producing electrical energy when mechanical stress is applied on it. This energy regeneration method has been a great interest since it is environmental-friendly and low cost. However, it produces narrow bandwidth which allows them to generate high amounts of power but only at specific frequency [7]. The main problem of having a narrow bandwidth is it may not suitable to be implement in certain applications.

Various methods have been conducted in previous research using piezoelectric sensor to broaden the frequency bandwidth such as mechanical stopper, cantilever array with different geometries and magnetic or electrostatic attraction forces. These techniques increased the bandwidth but significantly decreased the power harvested by either reducing the Q-factor or by increasing the volume thus decreasing the power density [8,9].

1.3 Objectives

Several objectives need to be archived throughout this project are:

a) To design a suitable configuration of piezoelectric power harvester for wide frequency bandwidth.

b) To analyse the impact of density and viscosity of the fluid on the frequency bandwidth.

c) To evaluate the performance of the method used for the designed cantilever piezoelectric.

1.4 Scope of project

This project focus on how to generate wide frequency bandwidth by applying piezoelectric effects with the support of fluid fill mass on the tip of the sensor. The power generator uses are in term of vibrations that applied certain forces to the piezoelectric where it converts to electrical energy as an output. The output expected to be in wide frequency range which can be used for wideband application. The fluid fill mass will be tested with several types of fluid like distilled water, dishwashing and honey. Types of fluid is chosen based on their density and viscosity. Different shapes of the container which are rectangular, and round are also used to determine whether it will give impact to the bandwidth or not.

1.5 Thesis outline

There are five chapters included in this thesis. Chapter 1 is about the introduction of this project which involved problem statement, objectives and scope of project and thesis outline as the overview of this project report. Next, chapter 2 is briefly explained about the history of piezoelectric, types of piezoelectric materials, piezoelectric equations and constants, piezoelectric as energy harvester also previous studies about the methods used to broaden the bandwidth. Chapter 3 consists of the flow diagram of the method used, experimental setup, detail description on rectifier circuit and storing. Chapter 4 focused on the result and discussion of the project. The last part of the thesis which is chapter 5 summarized the whole project under conclusion and recommendation for future works.

CHAPTER 2

BACKGROUND STUDY

2.1 History of Piezoelectric

In 1880, piezoelectric effect was discovered by French physicist, Jacques and Pierre Curie. The word 'piezo' itself is comes from the Greek word meaning pressure. Piezoelectric phenomenon is when the pressure is applied to a quartz crystal, electric charge will be formed in the crystal. Brothers Curie worked on together with their knowledge of pyroelectricity to predict crystal behavior and demonstrated with various of crystals such as tourmaline, quartz, topaz, cane sugar and Rochelle salt. They came out with the result that determined Quartz and Rochelle salt has shown the most piezoelectricity. Later, in 1881 the inverse piezoelectric effect was discovered from the fundamental thermodynamic principle by Gabriel Lippman. It was confirmed that the material will be deformed if the electrical field is applied to the crystal [10-14].

Sonar was the first device that implemented piezoelectric which developed during World War I. Ultrasonic marine detector was developed by Paul Langevin and his co-workers in 1917. The transducer of the detector was made up by thin quartz crystals glued amid two steel plates, also with hydrophone which to sense returned echo. The transducer emitted high frequency pulse and measure the amount of time by hearing the echo of the sound waves from the object, then calculated the distance to the object. The application of piezoelectric in sonar was a success, few decades later new applications and materials of piezoelectric has become an interest of many researchers.

Ferroelectrics was a new class synthetic material that discovered during World War II by the independent research groups in the United States, Russia and Japan. The research continues to develop on barium titanate and lead zirconate titanate materials for certain applications. The growth of piezoelectric in United States was bad compared to Japan's industry. They kept the development of the piezoelectric within the companies and the scientists looked for higher performance material which lead to lower rates of new applications of piezoelectric. In contrast, Japan created new markets by overcome technical and manufacturing difficulties through sharing their information. Their efforts on aggressive development of piezoelectric becomes a competitor to United States. This includes the design of piezoceramic filter, piezo buzzer and piezoelectric igniter.

2.2 Types of piezoelectric material

Piezoelectric material is one that have the property of converting mechanical energy into electrical energy and vice versa. To exhibit piezoelectricity, two main necessary conditions are:

i) Crystal should have ionic or partially ionic bonds

ii) The structure should not have no center of symmetry

Piezoelectric materials consist of two types which are natural and synthetic. The table shows the list of piezoelectric materials.

Table 2.1 Piezoelectric materials

Natural	Synthetic
Quartz	Lead zirconate titanate (PZT)
Tendon	Zinc Oxide (ZnO)
Sucrose	Barium titanate ($BaTiO_3$)
Rochelle salt	Piezoelectric ceramics Barium titanate
Topaz	Calcium barium titanate
Tourmaline	Gallium orthophosphate ($GaPO_4$)
Lead titanate	Lead titanate ($PbTiO_3$)
Enamel	Lithium tantalite ($LiTaO_3$)
Dentin	Langasite ($La_3Ga_5SiO_{14}$)
DNA	Sodium tungstate (Na_2WO_3)

Barium titanate was the first piezoelectric ceramic discovered while lead zirconate titanate is the most common piezoelectric ceramic use today.