UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN AND ANALYSIS OF PIEZOELECTRIC STACK MODULE BY USING NUMERICAL FINITE ELEMENT MODELS

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A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours

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DECLARATION

I declare that this Choose an item. entitled " Design And Analysis Of Piezoelectric Stack Module By Using Numerical Finite Element Models" is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : 

Name : Roohakimi Bin Roosdi

Date : 27/01/2022

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours.

Signature : 

Supervisor Name : Ts. Khairul Azri Bin Azlan

Date : 27/01/2022

DEDICATION

To my beloved mother, Puan Norhayati Binti Mohd and

my beloved father, Encik Roosdi Bin Abd Rasid

ABSTRACT

Piezoelectric is device that can be either actuator or generator. When electricity is supplied, the molecules of the piezo expand or contract, making it ideal for use as an actuator. When external pressures, such as tensional and compressive forces are applied, the random molecule charge is organized and the potential difference arises, causing the charge to transfer. Voltage is created as a result of this circumstance. Stacking the piezoelectric plate is able to manipulate the energy output by considering several parameters. The theory found that piezoelectric material volume will influence the output power. The volume can be controlled by regulating the surface area or the thickness of the piezoelectric materials. The objective of this project is to design and analyse the piezoelectric stack module with various design methods in order to achieve optimum performance. To achieve this objective, 20 pieces of piezo plate have been used to study the stacking method with a cumulative force of 290kg. The challenge is to stack the commercial piezo that has top surface wiring and to make sure the force is fully through each piezo plate. Stack style is one of the major parameters that affects the force distribution toward the peizo plate. Quality Functional Deployment, the QFD method has been used in design the product. This method consists of House of Quality, HoQ that demonstrates how customer criteria are linked to the techniques and strategies of achieving those goals. Benchmarking has also been used as a reverse engineering tool to derive client requirements from other products for comparison. To proceed with the analysis, a combination of products was selected. The analysis consists of the reaction of the stack arrangement method to the resulting voltage and the structure that holds the stack. Different stacks produce different voltages. As a result, the series stack is the most optimal stack design since it produces the highest voltage output, is the simplest to construct, and is designed to be connected to a series circuit to supply maximum total voltage.

ABSTRAK

Piezoelektrik adalah peranti yang boleh menjadi penggerak atau penjana. Apabila elektrik dibekalkan, molekul piezo mengembang atau mengecut, menjadikannya ideal untuk digunakan sebagai penggerak. Apabila tekanan luaran, seperti daya tegangan dan mampatan dikenakan, cas molekul rawak diatur dan perbezaan potensial terjadi dan menyebabkan cas itu berpindah. Voltan tercipta akibat keadaan ini. Menyusun plat piezoelektrik mampu memanipulasi tenaga yang terhasil dengan mempertimbangkan beberapa parameter. Teorinya mendapati bahawa isipadu bahan piezoelektrik akan mempengaruhi daya output. Isipadu dapat dikawal dengan mengatur luas permukaan atau ketebalan bahan piezoelektrik. Objektif projek ini adalah merancang dan menganalisis modul piezoelektrik dengan pelbagai kaedah reka bentuk untuk mendapatkan prestasi yang optimum. Untuk mencapai objektif ini, 20 keping plat piezo telah digunakan untuk mengkaji kaedah susun dengan daya terkumpul 290kg. Cabarannya adalah untuk menyusun piezo komersial yang mempunyai pendawaian yang berada di permukaan atas piezo dan untuk memastikan daya sepenuhnya melalui setiap plat piezo. Gaya tindanan adalah salah satu parameter utama yang mempengaruhi pengagihan daya ke setiap plat peizo. Quality Functional Deployment, kaedah QFD telah digunakan dalam merancang produk. Kaedah ini terdiri daripada House of Quality, HoQ yang menunjukkan bagaimana kriteria pelanggan dihubungkan dengan teknik dan strategi untuk mencapai tujuan tersebut. Penanda aras juga telah digunakan sebagai alat teknik terbalik untuk memperoleh keperluan pelanggan dari produk lain untuk perbandingan. Gabungan produk telah dipilih untuk meneruskan analisis. Analisis terdiri daripada gerak balas cara susunan kepada voltan yang terhasil dan struktur yang memegang tindanan. Timbunan yang berbeza menghasilkam voltan yang berbeza. Hasilnya, tindanan siri adalah reka bentuk tindanan yang paling optimum kerana ia menghasilkan output voltan tertinggi, paling mudah untuk dibina, dan direka bentuk untuk disambungkan kepada litar bersiri untuk membekalkan jumlah voltan maksimum.

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LIST OF SYMBOLS AND ABBREVIATIONS

Sjk	-	Piezoelectric strain
dijk	-	Third rank tensor of the piezoelectric coefficient
Ei	-	Applied electric
d31	-	Longitudinal piezoelectric coefficient
d33	-	Longitudinal piezoelectric coefficient
d15	-	Shear piezoelectric coefficient
d24	-	Force direction piezoelectric coefficient
ε	-	Dielectric permittivity
E	-	Electric displacement
g33	-	Piezoelectric voltage coefficient constant
ε0	-	Permittivity of free space
εr/ e33	-	Dielectric constant
σ	-	Stress

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CHAPTER 1

INTRODUCTION

1.1 Background

Majority of countries in the worlds are depending on power grid that generate by fossil fuel sum of coal, oil and gas. Years by years, giant country such as Japan and China developing energy harvesting system that can fully exploit the renewable energy. The main renewable energy such as Geothermal, Biomass, Solar, Wind, and Water have been utilized as solutions to overcome the earth's limited sources(*Renewable Resources | National Geographic Society*, 2021).

Piezoelectricity is one of the branches to renewable energy. The solid substances that are usually made of crystal provide energy when stress occurs. The energy can be obtained from pressure and heat. The small amount of voltage created makes this method less emphasis. Piezoelectric is also can be expand and shrink by manipulated an electrical voltage. Piezoelectric can be commercialized in almost all fields and sectors either as generator or actuator (Carter and Kensley, 2020).

In the age of technology and industry revolution 4.0, request toward electrical appliances and devices are increase, instead of using traditional power source, energy harvesting is one of the best methods to fulfill the demands of the times. Piezoelectricity provide the simplest way to harvesting the energy. Compact and user-friendly make piezoelectric can apply at nearly all condition and transition.

1.2 Problem Statement

Fossil fuel is the main power source that drive the world. Limited source of fossil fuel being the main problem to overcome. In term of automotive, petrol and diesel are used to generate the power for the vehicles. Although, hybrid car and fully electric car have been introduced, internal combustion engine vehicles still the vehicles of choice. The huge cost to provide facilities for continuity of the electric car such maintenance center and charging station are main challenge to cultivate it. Therefore, dependence on fossil fuel is very high as it is the main energy source for automotive (Martins *et al.*, 2019).

By the time, fossil fuel will be run out. Piezoelectric energy harvest is one of the solutions to decrease dependence on the limited source. However, Piezoelectric is only can produce a small amount of voltage but it still worth harvesting due to its simple and easy energy source. In the automotive view, small voltage can back up the electronic device power supply such as radio, camera, and meter display. Piezoelectric can be used in many different ways and variables, as the difference stack arrangement will produce different output. However, in this study the segment for Piezo electric plate available are only commercial type Piezo. This type of Piezo structure has membrane and electrode at the top surface. This type of design limits the stacking method of the Piezo itself. Unlike the industrial Piezo such as P-882 PICMA Stack the wiring was design to note disrupt piezo electric stack design as the wiring was positioned the outer end of the plate.

1.3 Research Objective

The main aim for this research is to design the piezoelectric stack that can deliver optimum performance. Detail objective are as follows:

a) To analysis relationship between stress and voltage output for piezoelectric stack.

b) To design the best stack for optimum energy harvesting.

c) To fabricate the stack.

1.4 Scope of Research

The scope of this research are as follows:

- Output Voltage created by Piezoelectric stack.
- 20 pieces of comercial 27mm diameter circular piezoelectric plate.
- Input force consider is within automotive background which is 290kg as quarter car model sprung mass.
- Input frequency are within automotive range which are between 15Hz-50Hz.
- One direction force.
- Compression force.
- *One-point source* force.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In today's modern lifestyle, the rapid growth of advanced technologies in electronic industries has had an impact on the increase of energy demand. Harvesting energy from the environment, such as mechanical vibrations, heat, fluid flows, electromagnetic radiation in the form of light and radio waves (RF), and in-vivo energies, can provide clean power for a variety of electronic devices, including wireless sensor networks, mobile electronics, and wearable and implantable biomedical devices (Sezer and Koç, 2021). This project is trying to solve the energy crisis by finding the most significant piezoelectric stack to produce the optimum performance. Several variables affect the performance of the piezoelectric and one of them is stack arrangement. The output voltage can be manipulated by controlling the stack shape as manipulating the force exerted through each piezoelectric plate.

2.2 Piezoelectric Materials

For piezoelectric materials, the mechanical and electrical fields are constantly connected. The variations in the electric field or mechanical stress of piezoelectric materials are supposed to be linear, with no effect of temperature on the material characteristics (He *et al.*, 2021). Furthermore, inertia effects are ignored since the piezoelectric energy harvester is considered to operate in a quasistatic and low-frequency mode**.** Piezoelectric properties can be influenced by ceramics, polymers, and composites as different materials. As stated by (Banerjee, Bairagi and Wazed Ali, 2021), Ceramic can be categories as lead-based or lead-free. However, lead-free piezoelectric materials have less piezoelectric properties than

lead-based materials. Although, lead-based materials have a higher performance they will threaten the environment. In consequence, the use of lead-free materials is more encouraged. KNN, Barium titanate, bismuth multi-layer-based systems have been proposed to become a possible substitution of lead-based ceramics. Despite the fact, ceramic has better piezoelectric performance nevertheless less applicable for flexibility requirement. Piezoceramic is very weak in tension but able to receive high compression. Based on (Carter and Kensley, 2020), 20-35 x 10^6 Newtons/meters^2 are the maximum recommended tensile strength. Considering that, the flexible application can be achieved by using piezoelectric polymers, for instance, polyvinylidene difluoride (PVDF). Through the consideration of both flexibility and piezoelectric performance, composited properties have been approached. Piezoelectric performance has been manipulated by using ceramic lead-free based filler into the composites. The commonly used lead-free ceramic filler is sodium potassium niobate (KNN). In a further study, KNN chemical doping has been used to change its phase transition temperature called as hybrid filler (Banerjee, Bairagi and Wazed Ali, 2021).

Piezoelectric is dielectric substance. A dielectric substance is electrically insulating (non-metallic), and it has or may be modified to have an electric dipole structure, which means that positive and negative electrically charged units are separated on a molecular or atomic level. Depending on the material and how the external field is applied, dielectric materials usually display at least one of the polarization types outlined in the preceding section. Dielectrics are divided into two categories. Polar dielectrics, for example, are dielectrics with permanent electric dipole moments. In the absence of an external field, the position of polar molecules is random. A torque is created when an external electric field is applied, causing the molecules to align with E. However, according to random thermal motion, the alignment isn't perfect. The second category of dielectrics is the nonpolar

dielectrics, which are dielectrics that do not contain permanent electric dipole moments. Electric dipole moments may be produced by putting the substances in an externally supplied electric field. Dielectric substances are electrically insulating, but subject to polarization in the existence of an electric field. This polarization phenomenon explains the capacity of the dielectrics to improve the charge storing potential of capacitors, the effectiveness of which is expressed in the form of a dielectric constant(Dahiya and Valle, 2014).

2.3 Piezoelectric Variables

There are several parameters affect the piezoelectric performance. The piezoelectric charge or strain coefficient (d) is a contributor to piezoelectric effectiveness as it correlates between mechanical stress that is applied and electrical charge generates. "i" and "j" are the subscript that indicates the charge motion or polarization direction and mechanical stress direction, correspondingly (Eltouby *et al.*, 2021). Material polarity and electric field relative direction determine the piezoelectric material condition whether been elongate or compress. Thus, the piezoelectric effect produces a strain that has a linear relationship with the applied electric field and can be expressed in tensor notation terms, **equation 1**. S_{jk} means piezoelectric strain, d_{ijk} is a third rank tensor of the piezoelectric coefficient and E_i for applied electric. The piezoelectric coefficient commonly used are transverse piezoelectric coefficient (d_{31}), longitudinal piezoelectric coefficient (d_{33}), shear piezoelectric coefficient (d_{15}) and possible poling orientations and force direction piezoelectric coefficient (d_{24}). Dielectric permittivity (ε) is material storing energy capability that is related to applied electric field (E) and electric displacement (D). The equation should be referred to as **equation 2.** For energy harvesting, three variables contribute to piezoelectric open-circuit voltage. Open circuit voltage indicates the voltage created at the certain stress, the movement of charge between electrode indicate the voltage level as no transfer charge causing voltage has been