

ENHANCING PIEZOELECTRIC EFFECT PERFORMANCE IN PIEZOELECTRIC BEAM DESIGN

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DECLARATION

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LIST OF ABBREVIATIONS

FYP	Final Year Project
USM	Universiti Sains Malaysia
IOT	Internet Of Thing
FOM	Figure Of Merit
PZT	Lead Zirconate Titanate
BaTiO ₃	Barium Titanate
PEH	Piezoelectric Energy Harvester
FEA	Finite Element Analysis
DCB	Double Cantilever Beam
SCB	Single Cantilever Beam
PMN32	Lead Magnesium Niobate-Lead Titanate
MEMS	Micro-Electro-Mechanical Systems
FGPM	Functionality Graded Piezoelectric Material
FEM	Finite Element Method
2-DOF	Two Degree of Freedom
RMS	Root Mean Square
LiNbO ₃	Lithium Niobate
LiTaO ₃	Lithium Tantalate
Li ₂ B ₄ O ₇	Lithium Tetraborate
CAD	Computer-aided design

MENINGKATKAN PRESTASI KESAN PIEZOELEKTRIK DALAM REKA BENTUK RASUK PIEZOELECTRIK

ABSTRAK

Penggunaan bahan-bahan piezoelektrik dalam struktur berbentuk rasuk telah menarik perhatian yang besar kerana keupayaannya untuk menukar getaran mekanikal kepada tenaga elektrik. Kesan piezoelektrik ini telah membuka jalan bagi pembangunan pengumpul tenaga menggunakan struktur berbentuk rasuk, yang menggabungkan satu atau dua lapisan piezoelektrik dipasang pada substrat. Projek ini bertujuan untuk mengkaji pengaruh bahan lapisan piezoelektrik yang berbeza terhadap output voltan struktur berbentuk rasuk tersebut. Fokus utama adalah pada pemodelan dan analisis simulasi reka bentuk berbentuk rasuk, dengan mempertimbangkan pelbagai bahan piezoelektrik. Dalam kertas ini, kami meneroka dua jenis simulasi BEH berbentuk rasuk: model unimorph dan bimorph. Simulasi dilakukan dalam perisian Ansys Workbench, di mana analisis modal, tindak balas harmonik, dan penghasilan voltan disusun dan dijalankan untuk kedua-dua jenis, dan hasilnya disahkan dari kertas terdahulu. Didapati bahawa bimorph memberikan hasil yang lebih baik dalam penghasilan voltan, oleh itu simulasi diteruskan dalam bimorph dengan model yang dipertingkatkan untuk menentukan penghasilan voltan tertinggi pada lapisan bahan piezoelektrik iaitu PZT-5H, PZT-5A, PZT-8, PZT-4, PZT-26, Lithium Niobate, Lithium Tantalate, dan Lithium Tetraborate. Memandangkan deformasi model dengan bahan piezoelektrik yang berbeza mempunyai frekuensi yang berlainan, satu frekuensi tertentu dalam julat untuk semua bahan telah dipilih untuk membandingkan hasilnya. Lithium Niobate memiliki voltan tertinggi yang diperoleh pada 196Hz dengan 5681 millivolt diikuti oleh PZT-5A dan Lithium Tantalate dengan 3906 millivolt dan 150 millivolt masing-masing. Hasil analisis simulasi dihasilkan dan diinterpretasikan secara grafik, yang menunjukkan deformasi model, voltan, dan respons frekuensi untuk semua rasuk dengan beban, daya dan dimensi yang sama.

ENHANCING PIEZOELECTRIC EFFECT PERFORMANCE IN PIEZOELECTRIC BEAM DESIGN

ABSTRACT

The utilisation of piezoelectric materials in beam structures has garnered significant attention due to their ability to convert mechanical vibrations into electrical energy. This piezoelectric effect has paved the way for the development of energy harvesters using cantilevered beam structures, incorporating one or two piezoelectric layers mounted on a substrate. This project seeks to investigate the influence of different piezoelectric layer materials on the voltage output of such beam structures. The primary focus is on the modelling and simulation analysis of cantilevered beam designs, considering a various of piezoelectric materials. In this paper, we dive into two types of simulation PEH cantilever beam: unimorph and bimorph model. The simulations were done in Ansys workbench software, in which modal analysis, harmonic response and voltage generation were set up and run for both types, and the results were validated from previous paper. It is shown that bimorph have a better result in voltage generation, so the simulation proceeds in bimorph with improvised model to determine the highest voltage generation on eight piezoelectric materials which are PZT-5H, PZT-5A, PZT-8, PZT-4, PZT-26, Lithium Niobate, Lithium Tantalate and Lithium Tetraborate. Since the deformation of the models with different piezoelectric materials have different in frequency obtained, a certain frequency within range for all materials were selected to compare the result. Lithium Niobate have the highest voltage obtained at 196Hz with 5681 millivolts followed by PZT-5A and Lithium Tantalate with 3906 millivolts and 150 millivolts respectively. The outcome of the simulation analysis was generated and interpreted graphically, which shows the model deformation, voltage and the frequency response for all the beams with same weight of load, force and dimensions.

CHAPTER 1

INTRODUCTION

Over the years, energy harvesting technologies have been used in various self-powered systems [1], [2]. These technologies have several methods of application depending on their usage. Renewable energy is one of the types of energy harvesting technologies [3] where energy is generated from naturally replenished sources. Energy harvesting involves gathering energy from the surroundings or alternative sources and converting it into electrical energy. Currently, there are three harvesting mechanisms are established which are electromagnetic induction, electrostatic conversion, and piezoelectricity [4], [5], [6], [7]. The utilisation of electromagnetic induction technology is widespread in various energy collectors; however, its effectiveness depends on the relative motion of the magnet and the coil or alterations in the magnetic field. This complexity poses challenges in applying it to wireless sensing systems [8]. Electrostatic conversions are preferred at extremely low accelerations because they have reduced losses [6]. With the advantages of high output voltage, no pollution, and high capacitances, piezoelectric can produce electricity under external force [9]. Motivated by those advantages, piezoelectric materials have been widely used for the development of piezoelectric energy harvester (PEH) since they are generally robust and can withstand high mechanical stresses, temperature and vibrations, making them suitable for applications in harsh environments [10], [11].

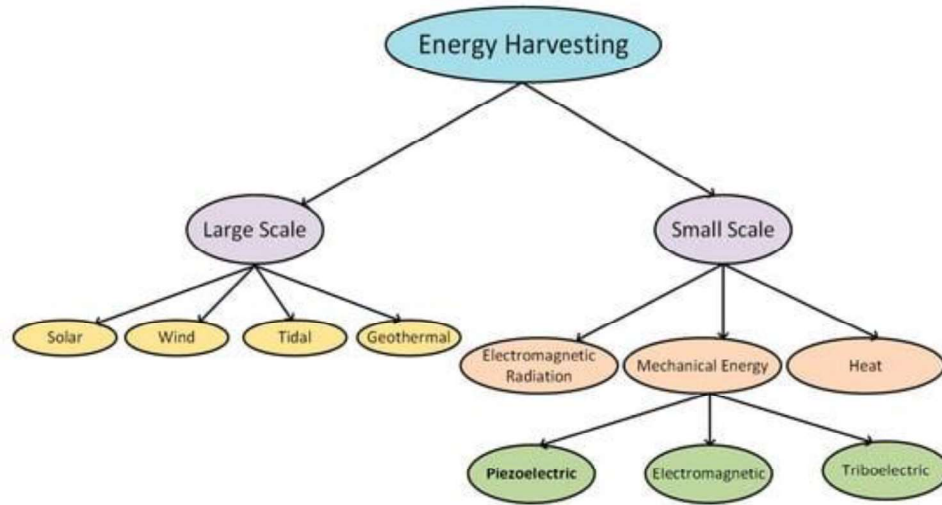


Figure 1.1: Classification of energy harvesting sources [12]

The field of energy harvesting has witnessed a remarkable evolution, driven by the pursuit of sustainable and self-sufficient technologies. Among the various approaches, the integration of piezoelectric materials into cantilevered beam structures has emerged as a promising avenue for converting ambient mechanical vibrations into electrical energy [13]. The PEH refers to the ability of the piezoelectric materials to harvest an electric field in response to applied mechanical stress. The piezoelectric effect, a phenomenon where mechanical stress induces an electric charge, underpins the potential of these structures to serve as efficient energy harvesters [14]. It is discovered by French physicists Jacques and Pierre Curie in 1880, Conversely, the reverse piezoelectric effect occurs when an applied electric field causes the material to deform or change shape [15], [16]. The PEH structure has three components: mechanical structure, piezoelectric material, and electrical interference. Typically, the beam is used as a mechanical structure to produce mechanical energy. In contrast, the piezoelectric material layer is bounded on the structure's surface; it converts mechanical energy into electrical energy. In the end, the electrical interference accumulates the charge and transforms it into usable electrical energy. This research project delves into the intricate interplay between piezoelectric materials and the performance of cantilevered beam designs, seeking to enhance the piezoelectric effect performances.

Moreover, in recent years, the demand for sustainable and autonomous electronic systems has fuelled a growing interest in piezoelectric energy harvesting. The piezoelectric cantilever beam is introduced with the benefits of flexibility, ease of

production and modelling, simple encapsulation, suitable for low-frequency conditions and low self-vibration frequency [17]. In addition, the concept of the Internet of Things (IoT) has led to placing smart equipment in remote areas, for example, in health care devices inside the human body, where it is difficult and sometimes impossible to charge batteries. Therefore, energy harvesting has become necessary to sustain such self-powered systems [18]. Furthermore, cantilevered beam structures, featuring one or two piezoelectric layers mounted on a substrate called unimorph and bimorph, represent a versatile and scalable platform for capturing ambient mechanical energy [19], [20]. An inertial mass is frequently added to the tip of beam harvesters to reduce or optimise the system's resonance frequency and increase mechanical responsiveness and output power in low-amplitude excitations [4], [5], [21].

A crucial factor influencing the performance of cantilevered beam structures as energy harvesters is the choice of piezoelectric material [22], [23]. The diverse range of materials available poses a significant challenge in determining the optimal selection for maximising energy harvesting efficiency. This project is motivated by the need to systematically analyse the impact of different piezoelectric layer materials on the power output of cantilevered beams. Through advanced modelling and simulation analyses, we aim to unravel the nuanced relationships between material properties and energy harvesting performance.

1.1 Brief overview

Piezoelectric energy harvesting has gained considerable attention as a sustainable means of converting ambient mechanical vibrations into electrical energy. Cantilevered beam structures, with one or two piezoelectric layers mounted on a substrate, represent a promising configuration for such energy harvesting systems. The piezoelectric effect, where mechanical strain induces an electrical charge, allows for the development of self-powered devices and sensors, eliminating the need for external power sources.

While the potential of piezoelectric-based energy harvesting is evident, the selection of appropriate piezoelectric materials remains a critical challenge. The literature highlights a wide range of materials with varying electromechanical properties, making it vital to understand the influence of these properties on the overall performance of cantilevered beam structures. Current research suggests that the choice of piezoelectric material significantly affects the system's energy harvesting efficiency and dynamic response [12]. The integration of piezoelectric materials into cantilevered beam structures has become a focal point in the realm of energy harvesting technologies. The cantilevered beam configuration, unimorph and bimorph provide an ideal environment for harvesting energy from ambient mechanical vibrations.

One of the primary engineering challenges in piezoelectric energy harvesting is selecting the optimal piezoelectric material. The diverse range of materials available introduces material stiffness, damping characteristics, and electrical conductivity. These properties directly impact the cantilevered beam's dynamic response and energy harvesting efficiency. A comprehensive understanding of material engineering is essential to navigate this complexity and make informed decisions regarding material selection.

The success of this project relies on sophisticated modelling and simulation analyses. Cantilevered beam structures exhibit nonlinear behaviours influenced by both mechanical and electrical factors. Accurate representation of these complexities requires advanced engineering approaches, considering factors such as piezoelectric coupling, dynamic response, and the interaction between the materials and the external environment. Developing robust models is essential for gaining meaningful insights into the relationship between piezoelectric layer materials and beam power output

Enhancing the piezoelectric effect in cantilevered beam designs is relevant in a world increasingly focused on sustainable technologies. This project's outcomes have the potential to revolutionise the field of energy harvesting, offering practical solutions for self-powered sensors, low-power electronics, and other applications. By addressing the identified engineering issues, we aim to contribute to the academic understanding of piezoelectric energy harvesting and the development of real-world, sustainable engineering solutions.

1.1.1 Piezoelectric Cantilever Beam Design

The piezoelectric cantilever beam arrangement is defined by an active piezoelectric layer affixed onto a passive substrate beam. The most frequent configurations for cantilevered laminated beams are typically either unimorph or bimorph. In a unimorph cantilever beam comprises a single layer of piezoelectric material bonded with the substrate; in contrast, a bimorph cantilever beam configuration consists two layers of piezoelectric material poled along the substrate in the middle as depicted in Figure 1.2. When subjected to base excitation, the cantilever beam generates mechanical energy, and the subsequent piezoelectric layer converts this mechanical energy into electrical energy. Consequently, the piezoelectric effect produces an electrical voltage across the load resistance.

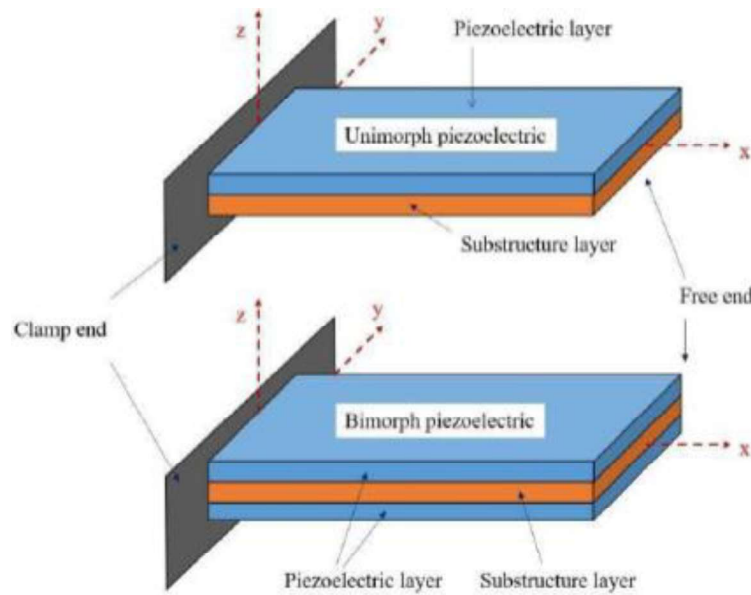


Figure 1.2: unimorph and bimorph piezoelectric cantilevered beam configuration [20]

1.2 Problem Statement

The demand for renewable energy has significantly increased with the advancements in energy harvesting systems. Batteries have become less favourable [24] due to their limited full discharge cycles, which degrade their capacity and performance over time, and the significant safety risks posed by thermal runaway [25] from improper charging. Additionally, they suffer from reduced energy efficiency with repeated use and have a considerable environmental impact due to the hazardous chemicals involved in their production, disposal, and recycling. To address these issues, a piezoelectric energy harvesting cantilever beam has been introduced to generate electrical energy from mechanical vibrations. This approach promotes green energy by harnessing mechanical vibrations [26], which are environmentally friendly. Additionally, the cantilever beam can store energy by absorbing ambient vibrations. For analysing the electromechanical interaction and power output of these piezoelectric energy harvesters, the finite element method using ANSYS software is employed.

A critical challenge is the lack of a systematic understanding of how different piezoelectric layer materials impact the performance of cantilever beam structures. While existing research provides insights into the general principles of piezoelectric energy harvesting, it falls short of comprehensively analysing the effects of varied piezoelectric materials on power output. This gap in knowledge hinders the optimisation of piezoelectric beam energy harvester designs, as the influence of material property variations on the efficiency of the piezoelectric effect remains insufficiently explored.

The significance of this problem is underscored by the potential applications in sustainable technologies, including self-powered sensors, low-power electronics, and energy-efficient devices. Bridging this gap is essential for unlocking the full potential of cantilevered beam structures as efficient energy harvesters.

1.3 Objectives

1. To develop finite element models unimorph and bimorph for simulating the dynamic response of cantilevered beam structures with different piezoelectric layer materials.
2. To simulate the designed beam using Ansys workbench to analyses the modal, harmonic response and voltage generation.
3. To quantify and compare the power output of cantilevered beam structures with varied piezoelectric layer materials through simulation validation.
4. To find material that can increase volume, so that simulation analysis can indicate the stress deformation and voltage interaction.

1.4 Scope of project

This project is comprehensive investigation involving simulation that encompasses finite element modelling. Integrating these components is essential for understanding the impact of piezoelectric layer materials on the performance of cantilevered beam structures in three models which is unimorph, bimorph and improvised bimorph.

Finite element models will be developed to simulate the dynamic response of cantilevered beam structures with different piezoelectric layer materials. Ansys Workbench is used to accurately capture the complexities of the piezoelectric effect in the designed structures using Modal, Harmonic Response and Voltage Generation Analysis. Modal Analysis determines the deformations and scale of the deformation from minimum to maximum. Harmonic Response Analysis determines the response of the mechanical structure of the models at a specific frequency that varies sinusoidally with time, such as frequency response and phase response. Addition to that voltage generation also can be simulate in harmonic response analysis.

The project acknowledges the constraint of time for researches and simulation regarding the concept and materials for piezoelectric. Additionally, limited information and guidance using Ansys software, including access to specific piezoelectric materials and features, may impact the scale of the simulation work

CHAPTER 2

LITERATURE REVIEW

The integration of piezoelectric materials into cantilevered beam structures for energy harvesting has gathered significant attention in recent literature. The piezoelectric effect, where mechanical vibrations induce an electric charge, forms the foundation for harnessing ambient mechanical energy. This literature review explores relevant studies, theoretical frameworks, and engineering fundamentals that contribute to the understanding of piezoelectric energy harvesting with a cantilevered beam design.

2.1 Piezoelectric Energy Harvesting:

This literature review aims to explore the output of piezoelectric transducers, focusing on two different material types and various energy harvesting structures. Piezoelectric transducers are commonly used in energy harvesting due to their ability to generate electricity when subjected to mechanical stress. This review conducts a comparative analysis to assess the power output of different materials and structures. Piezoelectric materials generate electricity through the deformation of their inner lattice, which induces a separation of positive and negative centres, resulting in a small dipole [27].

This review presents a comprehensive overview and analysis of advancements in three distinct energy harvesting methods. It systematically outlines the performance of various harvesters across diverse excitation types, delving into nonlinear energy harvesters characterized by different structural attributes. The review combines the advantages of nonlinearity in energy harvesting and offers a synthesis of practical applications. Additionally, it explains current strategies and mechanisms aimed at enhancing the efficiency of energy harvesters. Overall, this review summarises the developmental progress in existing energy harvesting technologies, addresses the technical challenges encountered in piezoelectric energy harvesting technologies, and provides insights into prospective research and development trajectories for piezoelectric vibration energy harvesting technologies [28].

This review provides a comprehensive overview of the current state of piezoelectric energy harvesting. It outlines the principles of piezoelectric energy conversion and explains the operational modes of piezoelectric generators. The review discusses the advancements, limitations, and potential enhancements in both materials and