T.C.

ANTALYA BILIM UNIVERSITY

INSTITUTE OF POSTGRADUATE EDUCATION

ELECTRICAL AND COMPUTER ENGINEERING

MASTER’S PROGRAM

AN INVESTIGATION ON ENERGY HARVESTING FROM WRIST FOR SMART ELECTRONIC DEVICES

Ahmed AFZAAL

JANUARY 2023

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This thesis was accepted by the jury (with unanimous vote / majority vote) on the date 11/01/2023 in MASTER PROGRAM of ELECTRICAL AND COMPUTER ENGINEERING

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DECLARATION

M.Sc. Thesis of this study named "An Investigation on Energy Harvesting from Wrist for Smart Electronic Devices", which I presented, I declare that scientific moral principles were followed in the preparation of this study, in case of benefiting from the works of others, reference is made in accordance with scientific norms, no falsification has been made in the data used, and that any part of this study is not presented as another academic study.

... /... /2023

Ahmed AFZAAL

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ABSTRACT

AN INVESTIGATION ON ENERGY HARVESTING FROM WRIST FOR SMART ELECTRONIC DEVICES

Ahmed AFZAAL

Master Thesis in Electrical and Computer Engineering

Supervisor: Assoc. Prof. Dr. Mustafa İlker BEYAZ

January 2023; 51 pages

In this thesis energy harvested using the wrist movement of human arm is discussed. Human arm is constantly being used during our normal routine work, walking running or doing chores. These actions could be helpful in producing electricity. Previously research has been performed on the human body's ability to produce energy. Magnets have been utilized to design a device that harvests the energy using the wrist movement for electronic devices. The magnets were placed inside a 3-D printed tube and coils were wrapped the tube to convert the electromagnetic field into electricity. It can be worn to collect energy all day long. To determine the maximum performance throughout the arm movements, simulations were performed on software called COMSOL. The experiments were carried out by placing this device on the shaker and open circuit voltage was calculated with and without a resistor using an oscilloscope. The open circuit voltage generated at the least frequency of the shaker was 0.24 V and 0.064 V with resistance and without resistance, respectively. Different frequencies were applied to further measure the voltages. As batteries are constantly being needed to be replaced for the wearable electronic devices so, we developed the device which will continuously recharge them. This is a significant step towards future wearable electronics not requiring battery maintenance as it can charge the batteries as the wearer is normally doing their work in their routine.

KEYWORDS: Energy Harvesting, Human Motion, Magnets, Wearable electronic devices.

COMMITTEE: Assoc. Prof. Dr. Mustafa İlker BEYAZ

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ÖZET

AKILLI ELEKTRONİK CİHAZLAR İÇİN BİLEKTEN ENERJİ TOPLAMASI ÜZERİNE BİR ARAŞTIRMA

Ahmed AFZAAL

Yüksek Lisans Elektrik ve Bilgisayar Mühendisliği

Danışman: Assoc. Prof. Dr. Mustafa İlker BEYAZ

Ocak 2023; 51 Sayfa

Bu tezde insan kolunun bilek hareketi kullanılarak elde edilen enerji ele alınmıştır. Normal rutin işlerimizde, yürürken, koşarken veya ev işleri yaparken insan kolu sürekli olarak kullanılmaktadır. Bu eylemler elektrik üretiminde yardımcı olabilir. Daha önce insan vücudunun enerji üretme yeteneği üzerine araştırmalar yapılmıştır. Bu çalışmada mıknatıslar, elektronik cihazlar için bilek hareketini kullanarak enerji toplayan bir cihaz tasarlamak için kullanıldı. Mıknatıslar, 3 boyutlu baskılı bir tüpün içine yerleştirildi ve elektromanyetik alanı elektriğe dönüştürmek için tüpe bobinler sarıldı. Bu cihaz gün boyu enerji toplamak için giyilebilir. Kol hareketleri boyunca maksimum performansı belirlemek için COMSOL adı verilen yazılım üzerinde simülasyonlar yapılmıştır. Bu cihaz çalkalayıcı üzerine yerleştirilerek deneyler yapılmış ve osiloskop kullanılarak dirençli ve dirençsiz açık gerilim voltajı hesaplanmıştır. Çalkalayıcının en düşük frekansında üretilen açık devre voltajı dirençli ve dirençsiz durum için sırasıyla 0,24 V ve 0,064 V olmuştur. Voltajları daha fazla ölçmek için farklı frekanslar uygulandı. Giyilebilir elektronik cihazlar için pillerin sürekli olarak değiştirilmesi gerekmektedir. Bu, pilleri şarj edebildiği için pil bakımı gerektirmeyen, geleceğin giyilebilir elektronik cihazlarına doğru önemli bir adımdır çünkü kullanıcı normal olarak rutin işlerini yaparken pilleri şarj edebilir.

ANAHTAR KELİMELER: Enerji Hasadı, giyilebilir elektronik cihazlar, insan hareketi, mıknatıslar.

JÜRİ: Assoc. Prof. Dr. Mustafa İlker BEYAZ

Dr. Öğr. Üy. Deniz Kaya

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ABBREVIATIONS

EH : Energy harvesting

TEG : Thermoelectric generator

RF : Radio Frequency

FEM : Finite element method

FEHN : Electromagnetic-triboelectric nanogenerator

TENG : Triboelectric Nanogenerator

IC : Integrated Circuit

PV : Photovoltaic Cell

AC : Alternating Current

PZT : Lead Zirconium Titanate

DC : Direct Current

IoT : Internet of Things

WBAN : Wireless Body Area Networks

PTFE : Polytetrafluoroethylene

PDMS : Polydimethylsiloxane

PLA : Polylactic Acid

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1. INTRODUCTION

1.1. Overview

Energy harvesting is the method used to convert energy from external sources into useful sources. Vibrational motions, solar energy, thermal energy, radio-frequency, chemical energy, and electrostatic energy are all examples of energy source. This energy can be used in small electronic wearable devices and wireless sensor networks. As the world has become very mobile in the recent few years so it has become a necessity to utilize these sources which can generate electrical energy without the help of fuel or battery and can be used anywhere. We have seen that some of the wearable devices are using batteries to power themselves but batteries have a limited use. With time and constant use of devices batteries run out of charge, making the devices to stop working and we need to replace them. Hence, we have to find the ways so that we can provide the sources to charge the batteries even when we are using them in the device.

The term battery was first used by Benjamin Franklin in 1749 while he was conducting experiments with electricity. In 1800, Italian physicist Alessandro Volta built the first electrochemical battery and called it voltaic pile. These batteries could not provide charge for longer period because of their fluctuating voltages. So, in 1834, British Chemist, John Frederic Daniell invented Daniell cell (Wikipedia, 2018) which became the first practical source of electricity. Batteries are divided into two types; primary batteries are used until the charge is finished and then discarded while secondary batteries can be recharged as their chemical reactions are reversible. Battery demand has been growing ever since and annual demand reached up to 30% between the years of 2010 and 2018 and it is considered to be maintained at 25% in the future because of cost reductions.

So, we have to come up with a way to continuously supply the power to the batteries so that we don’t need to replace them and they are constantly charged. While moving we produce mechanical energy and which can be converted into electrical energy and then can be used to operate different devices. Piezoelectric materials and magnets can be used to produce to electrical energy with the help of these mechanical movements of our body. This is an effective method to produce renewable electrical energy to power wearable devices. This research uses the magnets to convert the mechanical energy produced by arm movements into electrical energy. In recent years the it has become common to power the wrist watches with electrical energy with arm movement but all of these used batteries to store the energy. In this thesis we will provide the constant power supply to the wrist watch so that battery is charged continuously and we don’t need to replace it. Two magnets will be used to convert the mechanical energy of arm movement into electrical energy by putting them in a sheet covered with coil. This electrical energy can be produced during walking, running or doing any normal activity in our daily life. The main objective of our thesis is to provide the constant power to the wrist watch during walking running and normal activity work without storing it in a battery. This is a big development in the wearable devices which will be used in the future generation technology.

1.2. Motivation

The main motivation of the thesis is to generate constant electrical energy for wrist watches with hand gestures during walking, running, writing or any activity using magnets and to eliminate the need of changing battery. This is an easy way to generate electrical energy as humans are constantly involved in physical activity which produce mechanical energy, so our goal is to utilize these physical movements and convert them into electrical energy using magnets. The advantage of our wrist watch is that the wearer doesn’t have to replace the batteries as it will be getting the constant electrical power supply during the physical activities and can be constantly charged. This magnetic energy harvester provides the continuous and sustainable source of power for wrist watch all day long.

1.3. Organization of Thesis

This thesis explains the energy harvesting by arm movements or hand gestures during physical activities performed all day which include walking, running, writing etc. Chapter 1 briefly discusses the history of energy harvesting. Chapter 2 describes the literature review of energy harvesting from human body and how we can use the mechanical energy produced by human body movement into electrical energy to power different devices. Chapter 3 discusses the simulations performed on the COMSOL software and the results we obtained. Chapter 4 describes the experimental setup and the results obtained with the help of oscilloscope. Chapter 5 is about the conclusion of our thesis.

1.4. History of Energy Harvesting

It is a process of converting external energy in the environment into usable electrical energy is called energy harvesting (*Energy Harvesting - Wikipedia*, 2021). This includes solar, wind, thermal and motion energy. Many wearable electronic devices with low energy can be powered using this ambient energy. For example, because of the operation of combustion engines temperature gradients exist in urban regions as the environment has huge abundance of electromagnetic rays because of television and radio broadcasting.

Analog devices offer a large variety of low power ICs to store energy. These are used to store energy from different sources and then it is used to charge either super conductors or batteries. Capacitors are used when the devices need a huge energy spike but batteries are more frequently used when device needs a steady flow of energy.

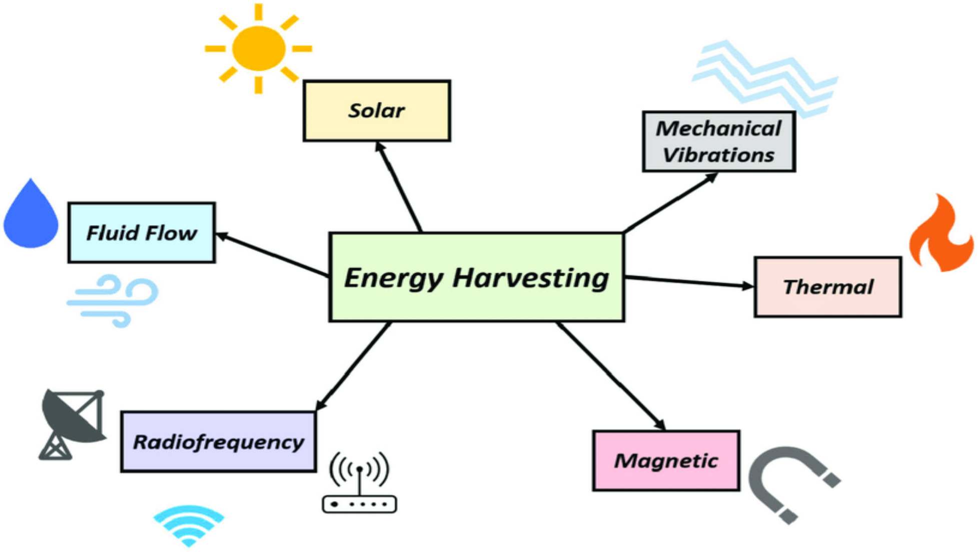

Figure 1.1. Energy Harvesting sources

Source: (Williams et al., 2021)

The advantages for energy harvesting are so many to be ignored. It is environment friendly and are either maintenance free or cost very less on maintenance. This technology opens up so many opportunities for future and so it need a proper knowledge of energy conversion, storage, materials used and systems engineering. Some examples of energy harvesting sources are wind, solar, thermal, radiofrequency and kinetic energy.

1.4.1. Wind Energy

It is the process by which wind is used to produce electric energy by converting the kinetic energy from the wind movement. It is a very famous, reliable and sustainable source of energy. It is environmentally friendly and mostly used to produce electricity.

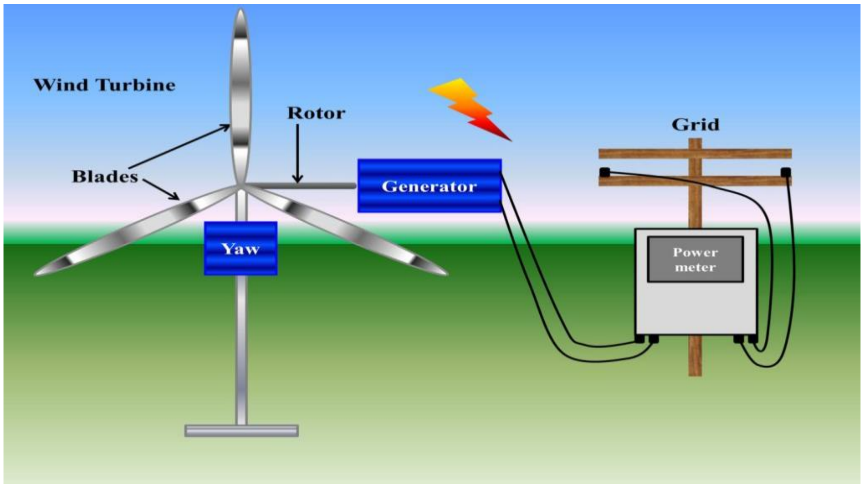

Figure 1.2. Wind Energy Harvesting System

Source: (Williams et al., 2021)

When wind moves across the blades the air pressure is reduced on one side of the blade. The air pressure difference on both sides of blade causes lift and drag. The lift is stronger which causes the blades to move resulting in spinning the rotor. Rotor is connected to the generator which converts this mechanical energy into electricity.

In 2021, wind was responsible for supplying 6% electricity to the world (Contributors, 2021). It is one of the fast-growing sources of energy. It is very sustainable and clean source of energy. It is very cost effective so research efforts are being made to get the greater use from wind energy.

1.4.2. Solar Energy

Sun is the source of light and heat and which is processed into solar energy using different techniques and then converted to electrical energy. Photovoltaic cells (PV) are used to transform light energy into electrical energy directly from the sun (Wikipedia, 2019). Photovoltaics exhibit the phenomenon of photovoltaic effect in which light is absorbed and electrons are excited to high energy state which produces electric energy.

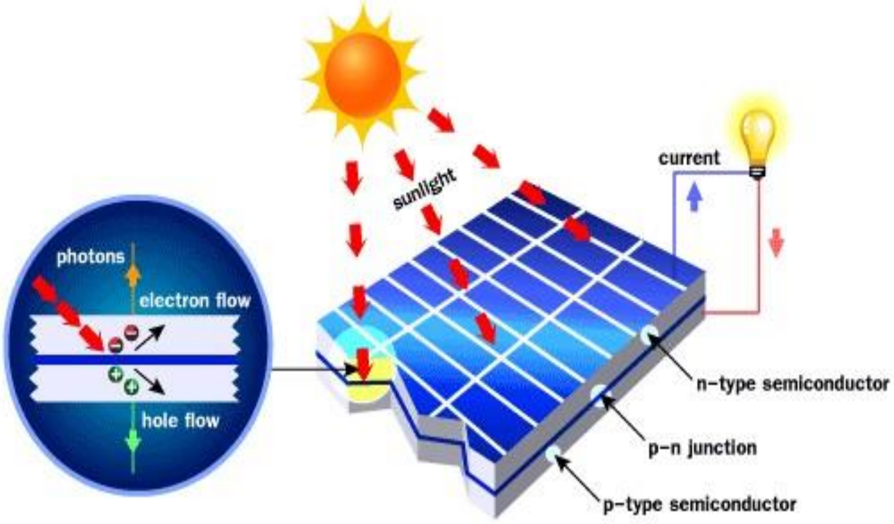

Figure 1.3. Solar Energy Harvesting System

Source: (*Resources- SolarPath Sun Solutions*, n.d.)

It is the most essential source of renewable energy as Sun is available for large part of the year all over the world. This makes it the highly attractive source for electricity. It is environmentally friendly as well as the cleanest source of energy. Solar energy can be used to power satellites, provide electricity for domestic use as less electricity is lost during long-distance transportation. It can also be very helpful in agriculture as it is very cheap source. This technology should be promoted all over the world because of its availability and less cost.

1.4.3. Kinetic Energy Harvesting

It is the process of converting the vibration or movement energy produced by humans, vehicles, wind and machines into electrical energy. This energy can be used to power small power electronic. When piezoelectric material is subjected to environmental vibrations, AC voltage is generated proportional to the stress applied. Different vibrations will generate different AC voltage patterns. Piezoelectric transducers use electrically polarized materials such as PZT for high electromechanical coupling. It occurs when electric charge is developed within the material by applying mechanical stress as shown in the Figure 1.4.

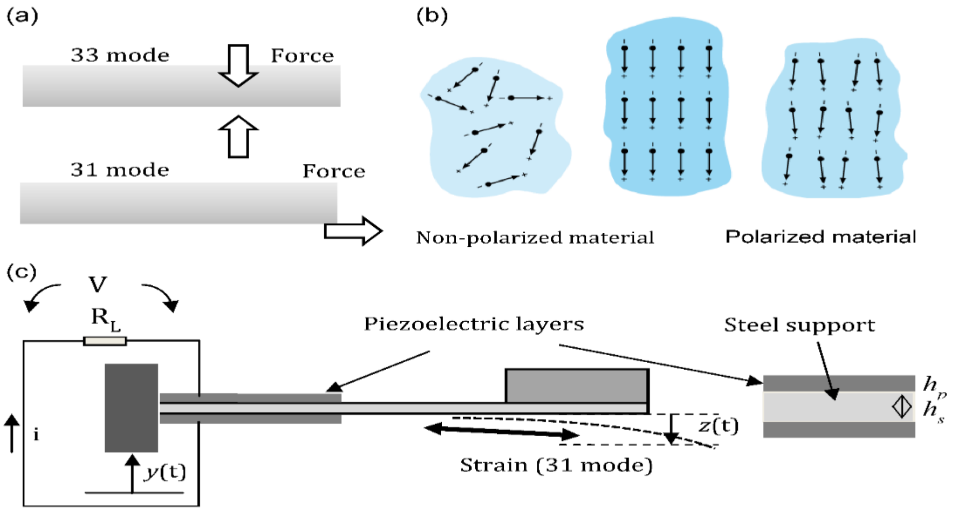

Figure 1.4. Piezoelectric Energy Harvester

Source: (Yeo et al., 2018)

Another example of generating electrical power using kinetic energy is with movement of foot (Kornbluh et al., 2011). The purpose of it is to harvest constant electrical power while walking without physically burdening the walker. This uses the compression of heel during walking.

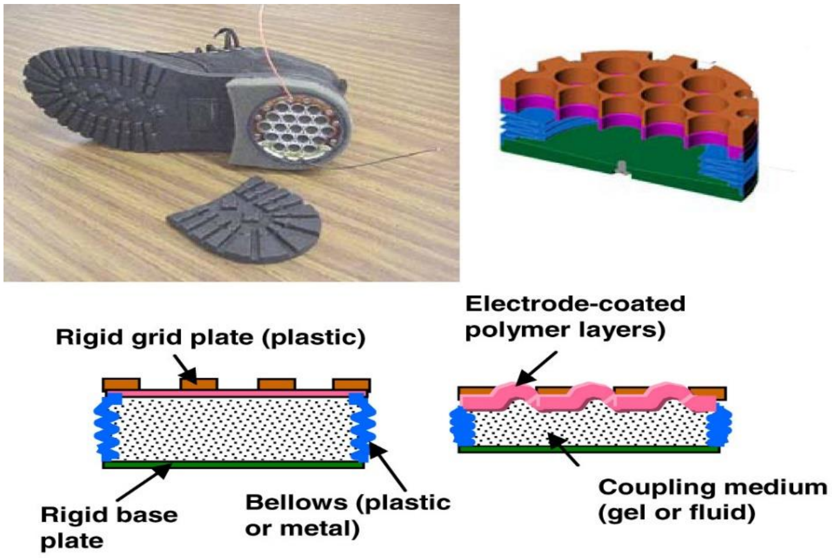

Figure 1.5. Shoe Energy Harvester

Source: (Kornbluh et al., 2011)

It produces electricity through 20 stacked films. The generator transfers the compression of heel to stretch the elastomer films using fluid coupling to generate electricity as shown in Figure 1.5.

Similarly, we can harvest power using kinetic motion of ocean waves. They are great reliable source to produce energy than solar or wind energy generators because of clean renewable energy and less visual and auditory impact.

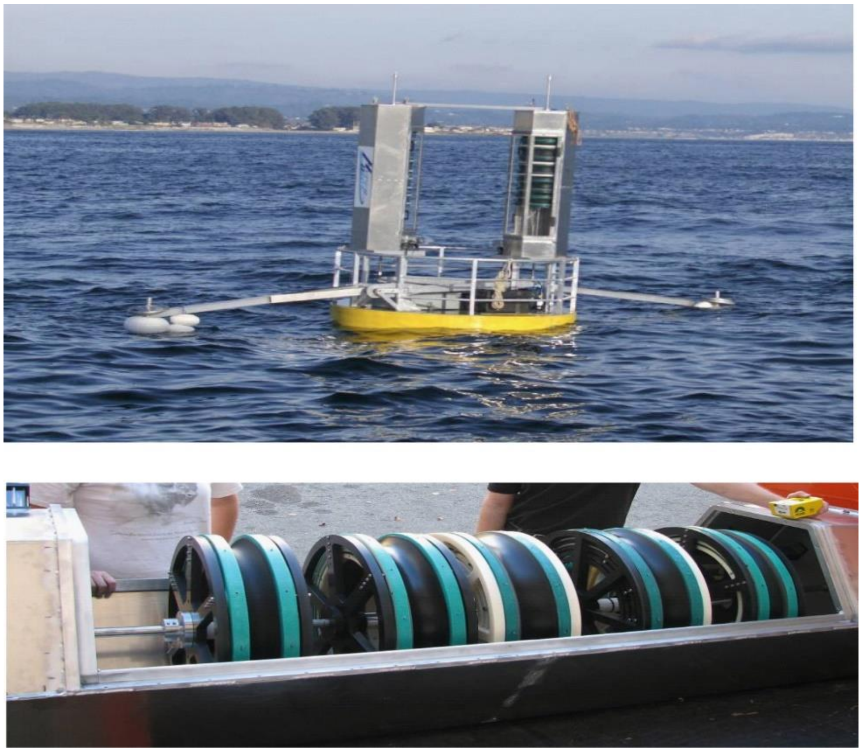

Figure 1.6. Ocean Energy Harvester

Source: (Kornbluh et al., 2011)

When waves pass the outriggers more relative to the buoy and stretch the rolls using a lever arm. The black material with green rings is the electrode-coated dielectric elastomer. It uses principle of hydrodynamic energy to mechanically stretch and contract dielectric elastomers.

1.4.4. Thermal Energy Harvesting

We are utilizing the Earth resources at faster rate so we have to find alternative sources to produce sustainable energy. So, we can use thermal energy as an alternative source. It is the energy harvested which is available in environment or which is emitted by heat engines, machines or any sources in the environment. The energy generated through this has very low value so that is the reason it has limitation only to low-energy electronics such as wearable electronics, wireless sensor networks etc. Two methods are used to harvest energy pyroelectric and thermoelectric. Thermoelectric is mostly used because it converts heat into electrical energy as it uses temperature gradient. Temperature differences are everywhere in nature as well as man-made and these differences can be utilized to harvest thermal energy.

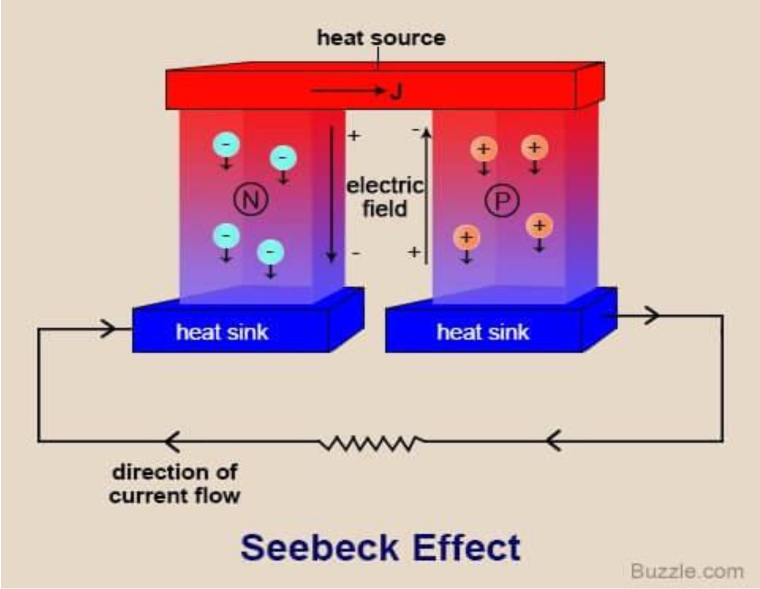

Figure 1.7. Thermal Energy Harvester using Seebeck Effect

Source: (*Seebeck Effect Theory - Inst Tools*, 2022)

Thomas Seebeck was the one who discovered that electric current is produced when exposing dissimilar metals to different temperatures. The Seebeck effect (*Seebeck Effect Theory - Inst Tools*, n.d.) is used at metals which are paired with copper, iron or aluminum. Seebeck generators are commonly known as Thermoelectric generators (TEGs). The voltage produced by TEGs is directly proportional to the temperature difference between the metals. Thermoelectric energy has a very bright future in big as well as small industries. It has captured attention in military use as well as wireless sensors and other microdevices.

1.4.5. Radiofrequency Energy Harvesting

It is a technique to convert electrical energy from electromagnetic field using the antennas (Serdijn et al., 2014). This cutting-edge technology provides wireless electricity that may be used for battery-free gadgets, making it a potential alternative energy source for applications in the future. There are so many sources for transmission of RF signals such as mobile phones, radio and television stations and wireless networks.

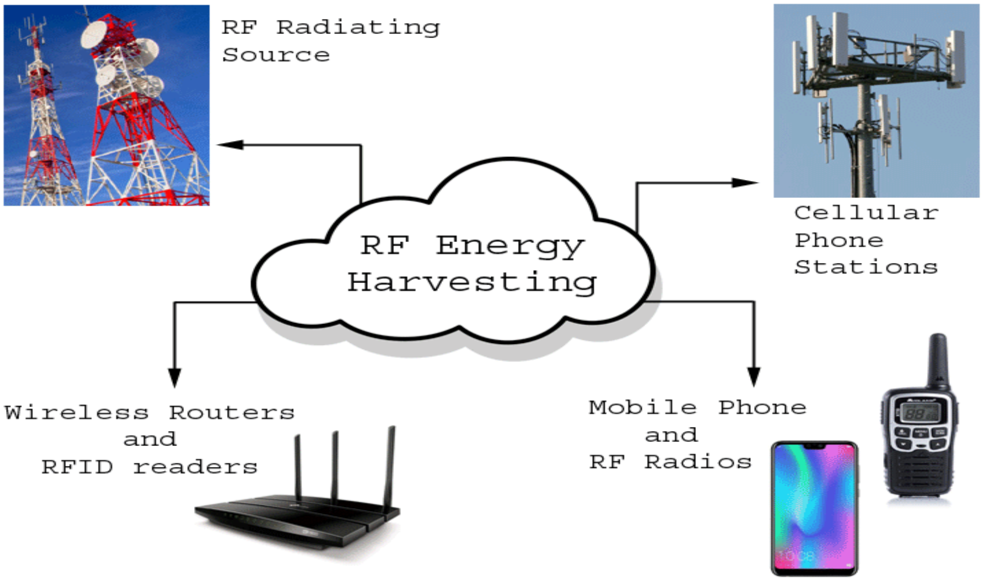

Figure 1.8. RF Energy Harvesting

Source: (Rathod, 2019)

The process to convert radio frequency starts at receiving antenna which causes a potential difference across its length and produce a movement in charge carriers. They move to the connected impedance matching circuit through wires. The power transfer is maximum and voltage generated is AC which has to be converted to DC. RF energy harvesting has found popularity in Internet of Things (IoT) in automating the electronic devices. These can be developed for industrial as well as domestic purposes.

1.5. Contribution

Kinetic energy has been utilized to run the small wearable electronic devices. We used the magnets to convert this kinetic energy to electrical source and use it to recharge the batteries of wearable electronic devices. The harvester device was designed, simulated and tested. The results show that it is possible to achieve substantial voltages and microwatt-level power. These results show the feasibility and functionality of the piezoelectric energy harvester reported in this thesis

2. LITRATURE REVIEW

2.1. Different Methods of Energy Harvesting Using Human Motion

Kinetic motion is utilized in a lot of ways recently to produce electrical potential. With the progression of research and technology new applications using human body motion have been developed. The movement of different human body parts used to develop these applications are from wrist, elbow, knee, foot etc. Different methods of harvesting electrical energy from human motion are as follows.

2.1.1. Energy Harvesting Schemes for Wearable Devices

Batteries are not ideal for the requirements of Wireless Body Area Networks (WBANs), eHealth systems, and wearable gadgets. They optimize the size of the sensor nodes and require human intervention for replacement every few years. At this time, energy harvesting is being investigated as the main source of electricity for wearable technology. Several programs have been successful in employing energy harvesting to power the electronic components of wearable gadgets. However, there are significant challenges that must be overcome before wearable technology may rely solely on energy collecting. This study examines the evolution of several energy collecting techniques used to power wearable technology. Piezoelectric, glucose biofuel cells, triboelectric generators, thermoelectric generators, solar cells, and radio frequency harvesters are among the harvesters that are addressed. The benefits, drawbacks, and difficulties of the harvesters in question are all described.

2.1.2. Energy Harvesting from Bracelet

The arm movement is utilized by (Zhang et al., 2019) to generate electrical power. The device consists of a bracelet worn around the arm. The bracelet consists of two magnetic coils for EMG, two copper shells attached on a shell structure of TENG component, a magnetic mover with electret PTFE and a power magnet circuit containing RuO2 supercapacitor as shown in the figure 2.1.

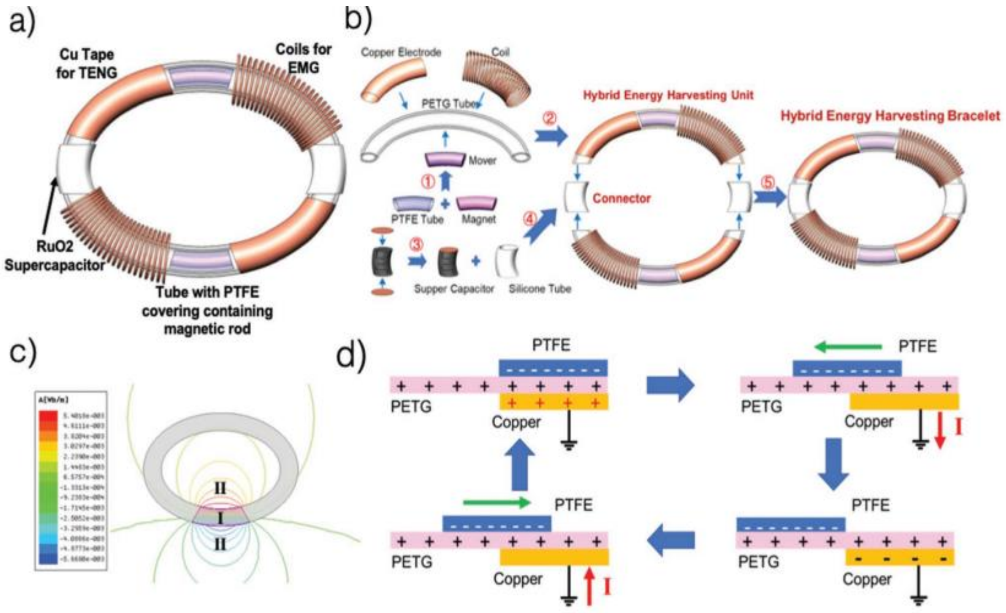

Figure 2.1. Process and Mechanism of Bracelet Energy Harvester

Source: (Zhang et al., 2019)

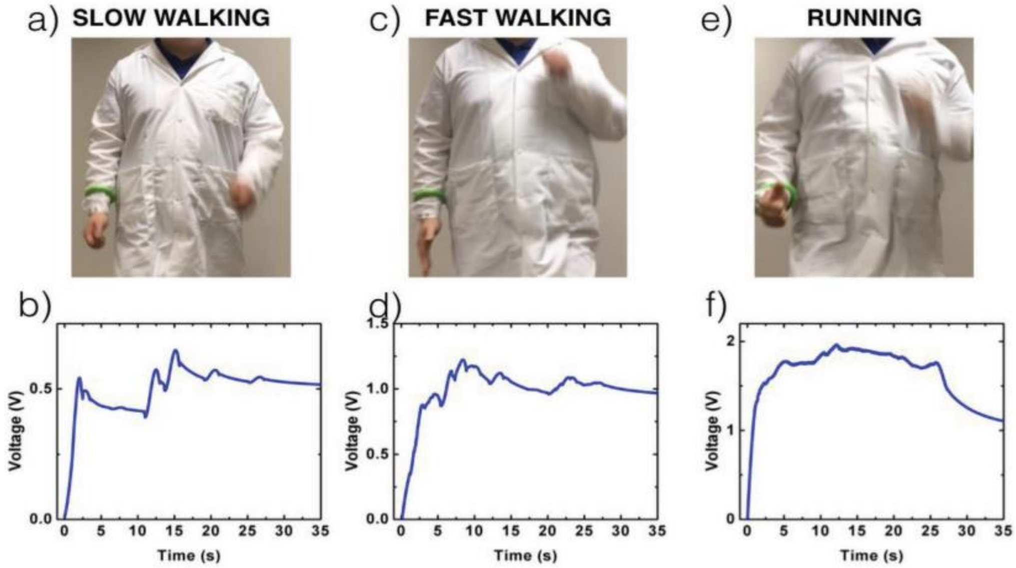

Figure 2.2 Energy Harvested During Different Activities

Source: (Zhang et al., 2019)

The measurements were done with 25s of actuation with 10s of rest. As shown in the figure 2.2. during walking the excitation frequency was low so supercapacitor was only charged to 0.5V in 2.5s whereas in case of fast walking it was charged to 1V in 5s because excitation frequency was high. It was charged to 2.5V in 5s in running situation.

2.1.3. Energy Harvesting Using Repulsive Magnetic Spring

The performance of wrist-worn energy harvester is improved by (Cai & Liao, 2021) in this paper. He explained that introduction of repulsive magnetic spring increases the power generation because it lowers the potential energy of the harvester. The system consists of proof mass, magnets, rotor, fixed magnets and coil. The rotor is fixed with proof mass which vibrates due to the swinging of arm while walking or running.

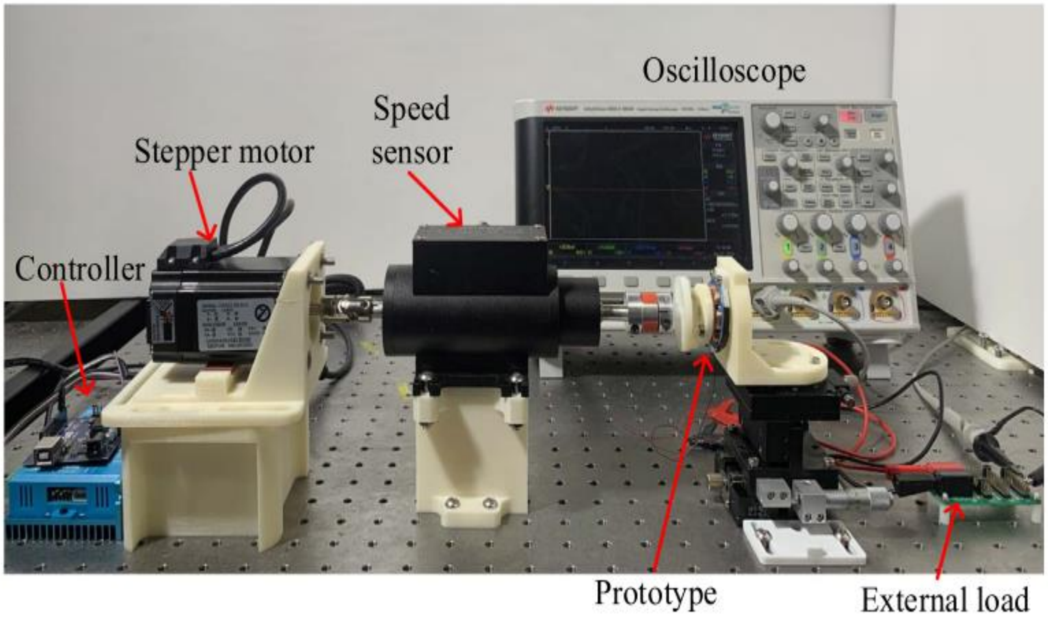

Figure 2.3. Experimental setup for energy harvester

Source: (Cai & Liao, 2021)

An electromagnetic force is induced in the coils because of the axially magnetized permanent magnets that are connected to the rotor. This is considered like pendulum driven by the movement of swinging arm. This converts the kinetic energy to electrical energy. The permanent magnets are introduced to remove the friction in the system and the improve the system. The experiment is tested between 0-7-1.3 Hz frequency and air gap of 2.2-3.6 mm. With the help of magnetic spring the output power gained is 151uW at a frequency of 1.3 Hz and 2.6 mm air gap. It improves the maximum power up to 425% at 0.7 Hz frequency and air gap of 2.2 mm.

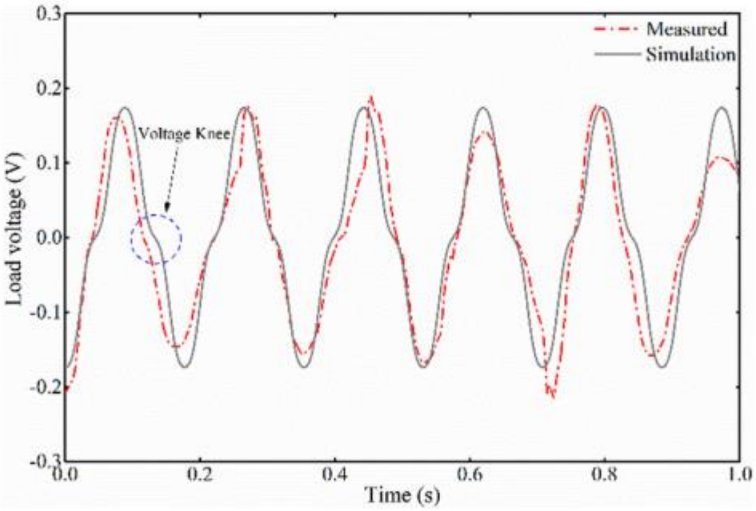

Figure 2.4. Generated load voltage

Source: (Cai & Liao, 2021)

2.1.4. Energy Harvesting with Heat of Human Body

A model to study the performance of wearable TEGs on a wrist in this paper (Wang et al., 2017). There are different type of N-types and P-types thermoelectric legs on TEGs which has copper strips and encapsulating PDMS around it as shown in the figure 13.

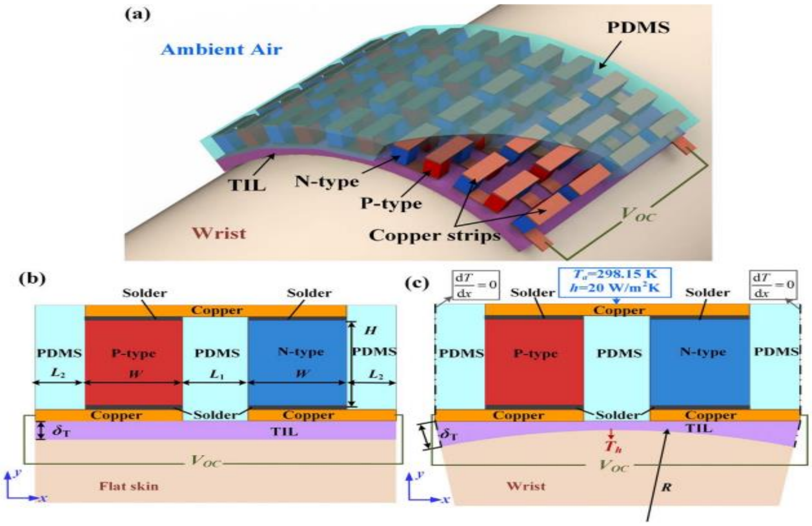

Figure 2.5. Structural design of wearable TEG on wrist

Source: (Wang et al., 2017)

For wearing it on the curved wrist a thin layer of TIL substrate made of silicone is used. The thermoelectric legs are connected electrically in series to the copper strips while thermally they are connected in parallel. Thin layer of TIL substrate is considered as hot side as it is in contact with the skin while upper side of the TENG is considered to be cold side. When the wearer is standing still voltage generated at the wrist TEG is 3mV whereas it increases to 112mV when the wearer is walking and swinging the arm. So, the body movement and temperature affect the performance of TEG.

2.1.5. Energy Harvesting Using Hybridized Nanogenerator

A wrist worn hybridized electromagnetic-triboelectric nanogenerator (FEHN) is used in this paper by (Maharjan et al., 2018) to utilize the energy from the wrist motions of humans. The device structure is shown in the figure 2.6. consists of 3D printed hollow tube fabricated with the polylactic acid (PLA) and a thin film of PTFE after nanowires were uniformly distributed with etching process. Magnetic ball was placed in it. Copper coils connected in series were wrapped around the tube at 90 degrees.

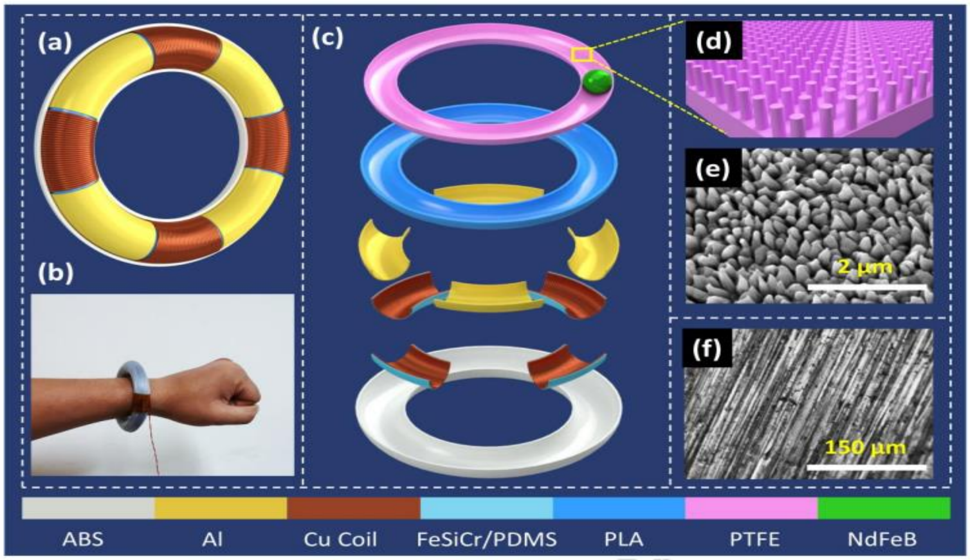

Figure 2.6. Hybridized electric nanogenerator energy Harvester

Source: (Maharjan et al., 2018)

Similarly aluminum film was wrapped around it. To act as a flux concentrator FeSiCr/PDMS was wrapped at the coil. It was then enclosed in the 3D circular hollow tube to make it enclosed hybrid nanogenerator. Magnetic ball act as positive triboelectric material while 3D material PLA act as negative triboelectric material. It uses the electrostatic induction and electromagnetic induction as the ball moves freely inside. The experiment performed shows different values of voltage of 470 uF capacitor during different positions of the device placed on the hand.

2.1.6. Bimorph PZT for Wrist Worn Piezoelectric Energy Harvester

To get a higher power density for piezoelectric energy harvesters, a large volume of piezoelectric material with a high figure of merit is necessary. In order to create a bimorph structure, strongly (001) orientated sputtering lead zirconate titanate (PZT) sheets (f 0.99) surpassing 4 m in thickness were grown on both sides of a Ni foil (Yeo et al., 2018). These films are used in innovative wrist-worn energy harvesters (16 cm2) that use an eccentric rotor with embedded magnets to magnetically pull piezoelectric beams in order to achieve frequency up-conversion.

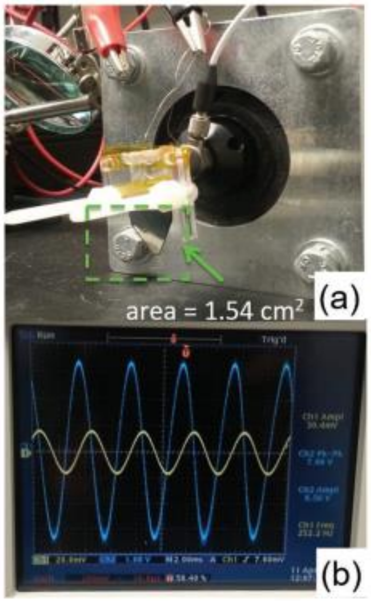

Figure 2.7. Experimental Setup

Source: (Yeo et al., 2018)

The resulting devices successfully transform low-frequency vibration sources—such as those caused by jogging, walking, and wrist rotation—into higher-frequency PZT beam vibrations (100–200 Hz). At 0.15 G of acceleration, six beams provide an output of 1.2 mW when measured at resonance. 40–50 W are generated during light activity when a wrist-worn non resonant gadget is magnetically pulled.

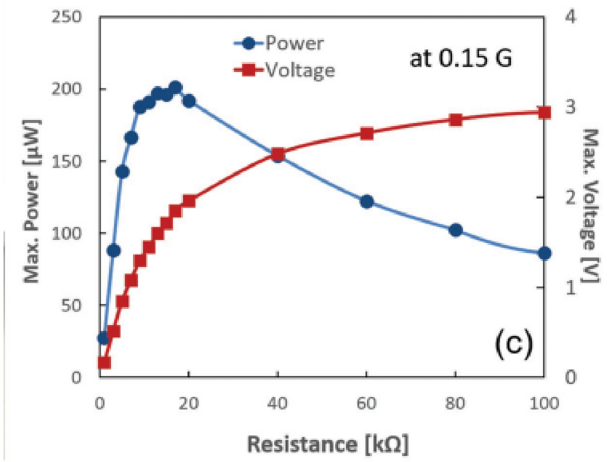

Figure 2.8. Bimorph beam's maximum power and external load resistance

Source: (Yeo et al., 2018)

2.1.7. Energy Harvesting Through Knee Joint

Knee movements can also be utilized to harvest energy as it was done by (Beyaz, 2019). It consists of two patches which covered the knee as shown in the figure. They were MEMES-based piezoelectric transducers. The patch transducer has the internal capacitance of 80 nF, whereas the resistance was of 470kΩ. COMSOL was used to run the simulations to get the maximum performance under normal walking. Open circuit voltage and rms value measured to be 14 V and 6.2 µW, respectively under normal walking conditions. During running these values seem to be increased by 14.4 V and 12 µW. This shows that the device has the potential to be used as constant battery charger for wearable devices.

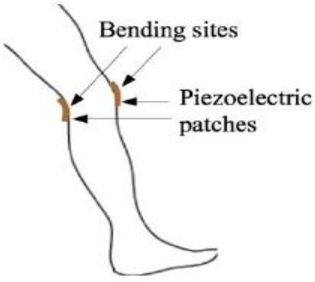

Figure 2.9. Piezoelectric Energy Harvester Through Knee Joint

Source: (Beyaz, 2019)

(Donelan et al., 2008) presented a device for the knee joint based on the muscles' negative effort. This 1.6-kg gadget was made out of an orthopedic knee brace that was designed to transfer solely knee extension action to a DC brushless motor that functioned as the generator. Knee motion powered a gear train through a unidirectional clutch. A load resistor was used to disperse the electrical energy that was produced. This technique produced 2.5 W per knee at a 1.5 m/s walking speed.

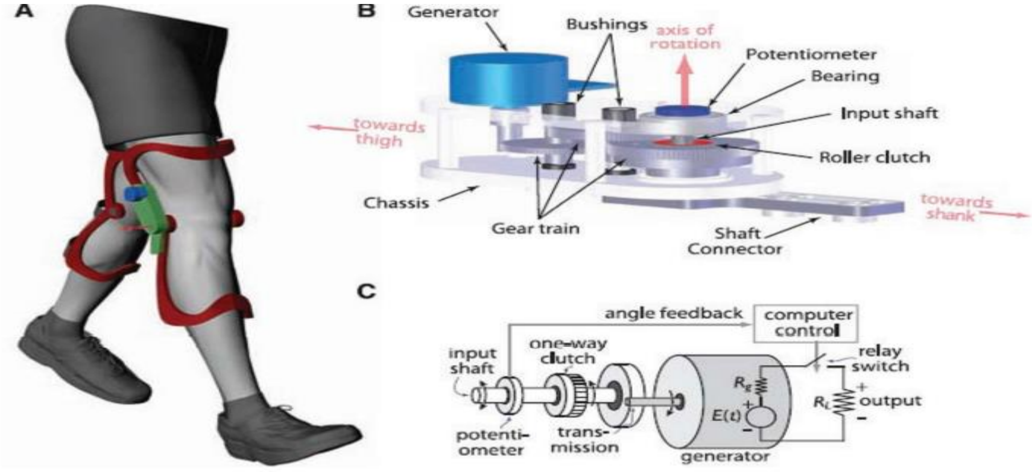

Figure 2.10. Knee Energy Harvester

Source: (Donelan et al., 2008)

2.1.8. Energy Harvesting Through Elbow Joint

Humans are always moving and walking so the arms are in constant motion as well. These arm swings can be put into more beneficial way and can be utilized to harvest electrical energy. (Yang & Yun, 2011) presented a way to harvest energy using the arm movement in his work. A shell structure was used which has an elastic piezoelectric polymer wrapped around the elbow.

Figure 2.11. Shell Structure

Source: (Yang & Yun, 2011)

This shell structure can convert stress into electrical energy even during the smallest motion of arm. To make the shell structure a curved polymer was used. The output produced by this shell structure was much higher than the other structures. The output produced during the motion of arm at elbow joint is presented in the figure below.

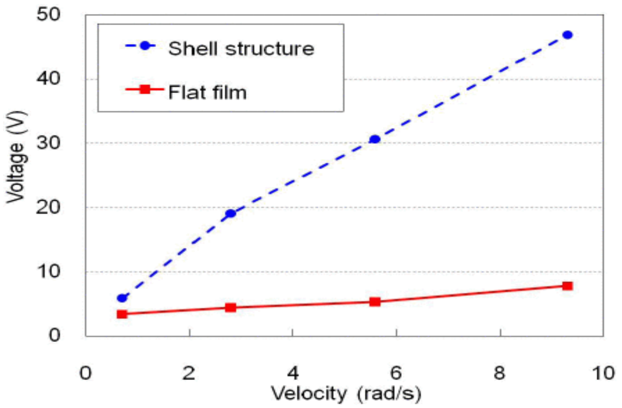

Figure 2.12. Shell Structure Voltage Generation

Source: (Yang & Yun, 2011)

2.1.9. Energy Harvesting Using Shoes

Humans are constantly in motion during their daily life. The average human walks normally 3000 to 4000 steps in a day or 1.5 to 2 miles. This can be easily utilized in advantage to generate electrical energy. In this study, (Zhao & You, 2014) investigate a piezoelectric energy harvester for the kinetic motion of shoes based on human physical movement. The energy harvester is built on a sandwich frame that is specifically designed to be thin and easily fits inside a shoe.

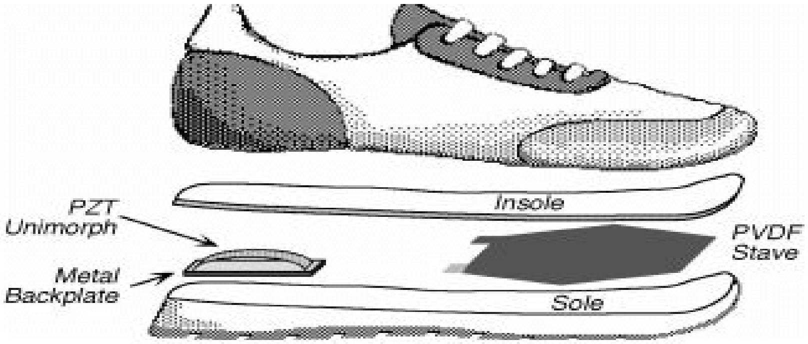

Figure 2.13. Piezoelectric Shoe Energy Harvester

Source: (Zhao & You, 2014)

While walking the output power generated by this was 1 mW. A wireless transmitter simulator is used to evaluate the DC power, with a 5 ms active time that is needed to move through 2-3 steps. During this test, 50 mW of mean power is produced.

Numerous machines have been created to harness the power of heel-strike motion. During the stance phase, when the foot is on the ground, some devices harness the energy from the relative motion between the foot and the ground. Others make use of the energy generated by the shoe sole's bending. Both times, the technology tries to capture energy that would have otherwise been wasted to the environment. An illustration of such a device by (Riemer & Shapiro, 2011) is a hydraulic reservoir with an integrated electrical magnetic generator that creates a flow during the gait cycle using the variation in pressure distribution on the shoe sole. Depending on the user's weight and gait, this prototype generates an average power of 250–700 mW while walking.

Piezoelectric materials were used in the construction of a shoe that (Hayashida, 2000) created to capture energy from heel striking and toe off motions. A gait cycle uses an average power of 8.3 mW. The same team also developed a shoe with a magnetic rotating device that generates an average power of 58.1 mW during the entire gait and a maximum power of 1.61 W during the heel strike.

(Kornbluh et al., 2011) and his associates at SRI International produced electrostatic generators based on electroactive polymers, employing a different strategy (EAPs). These substances have the ability to produce electricity in response to mechanical stress. Energy densities of 0.2 J/g are possible with their technique for use in practical applications. Furthermore, these materials are capable of "coping" with quite high strains (between 50% and 100%). A membrane that is inflated by the heel strike served as the foundation for their generator design. They used this gadget to achieve 0.8 J/step (800 mW). The energy was obtained by compressing the boot's heel by 3 mm while the device was installed.

2.1.10. Energy Harvesting Through Finger Movement

The results of the study on the mobility of the fingers for energy harvesting are presented in this work by (Omar & Sifuentes, 2020). In this study, the amount of voltage generated when the piezo films are positioned on both the anterior and posterior side of the fingers is measured. Finding the ideal location for the piezo films on the fingers is intended to maximize voltage generation. The findings of this study serve as a springboard for further research into the ideal circumstances for enhancing energy harvesting from finger movements, which enables powering a less wearable battery system that monitors cardiac activity in the wrist.

An experimental investigation is provided to identify the ideal energy harvesting conditions. PVDF piezo films were employed as piezoelectric generators, and they were positioned on the glove to correspond with numerous joints on both sides of the right-hand fingers. Two scenarios were tried for five minutes each, and the RMS voltage of each piezo film was determined. The usage of the computer keyboard produced higher rms voltage than the use of the computer mouse. Given that during the studies, there were more keystrokes than clicks, this is the expected result.

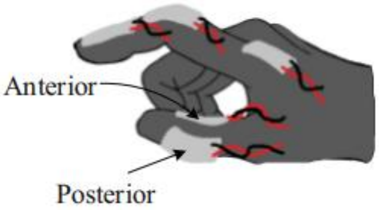

Figure 2.14. Generator for Computer Mouse

Source: (Omar & Sifuentes, 2020).

In Case 1, the piezo film on the rear side of the index finger produced 0.834 volts, whereas the piezo film on the front side produced 0.847 volts. The findings demonstrate that the placement of the piezo films—on the post or the anterior side—had no impact on the voltage generation.

Figure 2.15. Computer Keyboard piezoelectric generators

Source: (Omar & Sifuentes, 2020).

The anterior-side and posterior-side piezo films of the thumb in Scenario 2 each produced 2.329 and 1.180 V, respectively. To put it another way, 1.149 V was produced by shifting the side of the piezo film on the same finger. With the piezo film positioned on the proximal interphalangeal joint of the tiny finger, the maximum voltage was produced (3.044 V).

2.1.11. Energy Harvesting Through Ankle

An electromagnetic energy harvester was created by (Cai et al., 2019) to take use of the human ankle's ability to dorsiflex, which causes the ankle joint to exert negative force. Interestingly, the ankle continues to undertake negative effort while it dorsiflexes at the stance stride. This enables the use of a one-way clutch to filter the ankle's plantarflexion and to avoid positive work when a swinging step's ankle dorsiflexes, as well as to deploy a mechanical touch transfer array. In order to counteract the low angular velocity typical of dorsiflexion, the input ankle dorsiflexion is accelerated using a planetary gear train. The harvester is put in shoes for comfort of the wearer as illustrated in figure 2.16.

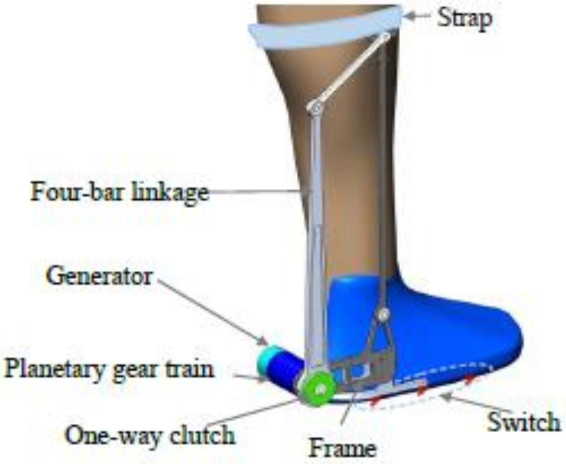

Figure 2.16. Energy Harvester for Ankle

Source: (Cai et al., 2019)

The power and metabolic expenditure of users while walking will be assessed by a prototype. Additionally, the energy extraction process is modeled and researched. According to the findings, the harvester produces an average power of 0.35 W at 4.9 km/h. This work is worth mentioning even though it does not have any piezoelectric components because it is a fantastic example of creative energy harvesting from the body.

2.1.12. Energy Harvesting from Human Motion; Swing and Shock Excitation

Wearable systems are becoming more and more integrated thanks to contemporary small and low-power sensors and systems. The power supply is one of this technology's major bottlenecks. Energy harvesting techniques provide a way to power sensor devices without the requirement of batteries or upkeep. The creation and characterization of two inductive energy harvesters that take use of various aspects of the human gait are presented in this paper. A multi-coil topology harvester that makes use of the foot's swinging action is demonstrated (Materials et al., 2015).

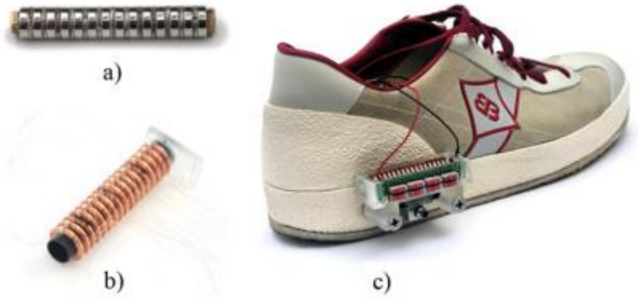

Figure 2.17. Swing motion Harvester

Source: (Materials et al., 2015)

The second device is a harvester that generates shockwaves when a heel is struck, causing it to ring into resonance (Materials et al., 2015). To make integration into the shoe bottom easier, both devices were modeled and created with the important constraint of device height in mind.

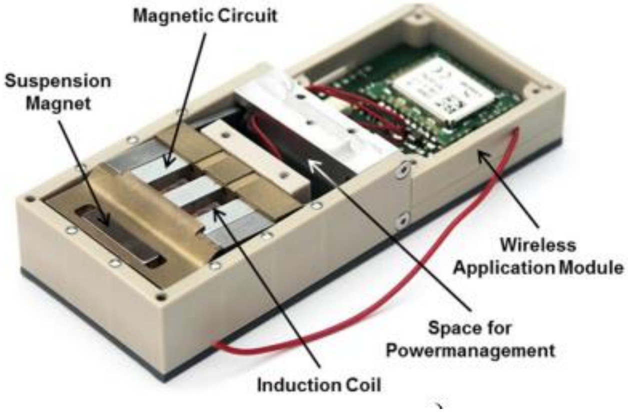

Figure 2.18. Shock-excited energy harvester

Source: (Materials et al., 2015)

The gadgets were evaluated with two test subjects on a treadmill and at various motion speeds. With the swing harvester, an average power output of up to 0.84 mW is possible. Using a device with a total volume of 21 cm3 (including the housing), a power density of 40 W cm3 is obtained. Average power generation from the shock harvester can reach 4.13 mW. For the 48 cm3 overall volume of the device, the power density is 86 W cm3. Difficulties and potential improvements are discussed briefly.

2.1.13. Energy Harvesting Through Head Movement

In this study, (Wang et al., 2015) describe the design of the piezo-magnetic harvester that transforms the non-harmonic motion of the human head into energy. The device's double-clamped piezoelectric structure and rolling magnet make it efficient at capturing the low-frequency, small-amplitude motion of the human head. Additionally, as depicted in the figure, the technology can covertly be used with spectacles.

Figure 2.19. Energy Harvester using Glasses

Source: (Wang et al., 2015)

The results indicate that this energy harvester is capable of producing a maximum instantaneous power of 0.5 W. For the obvious reason that the human head cannot move like the arms and legs, it may be quite useful to power head-mounted gadgets. During talks, head nodding happens, and such motions can produce electricity.

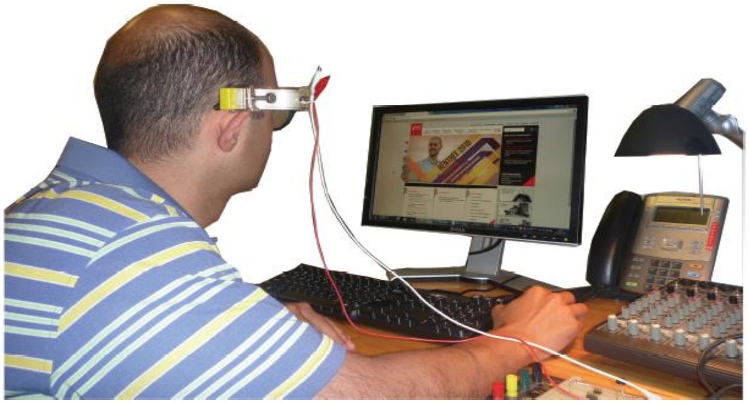

Figure 2.20. Glasses Experimental Setup

Source: (Wang et al., 2015)

2.1.14. Energy Harvesting Through Backpack

(Sodano, 2009) and coworkers used a different strategy to gather energy using a backpack. In order to create 50 mW, a piezoelectric material was put by them inside the shoulder strap of a 44-kg backpack. Another type of gadget is based on oscillations of a floating magnet as a result of this motion and exploits the motion of the center of mass to harvest energy. According to the walking circumstances, (Riemer & Shapiro, 2011) created a linear electrical generator that weighs 1 kg and generates 90–780 mW using body motion. To maximize the power output from the walking motion, they adjusted the electrical circuits and linear generator architecture.

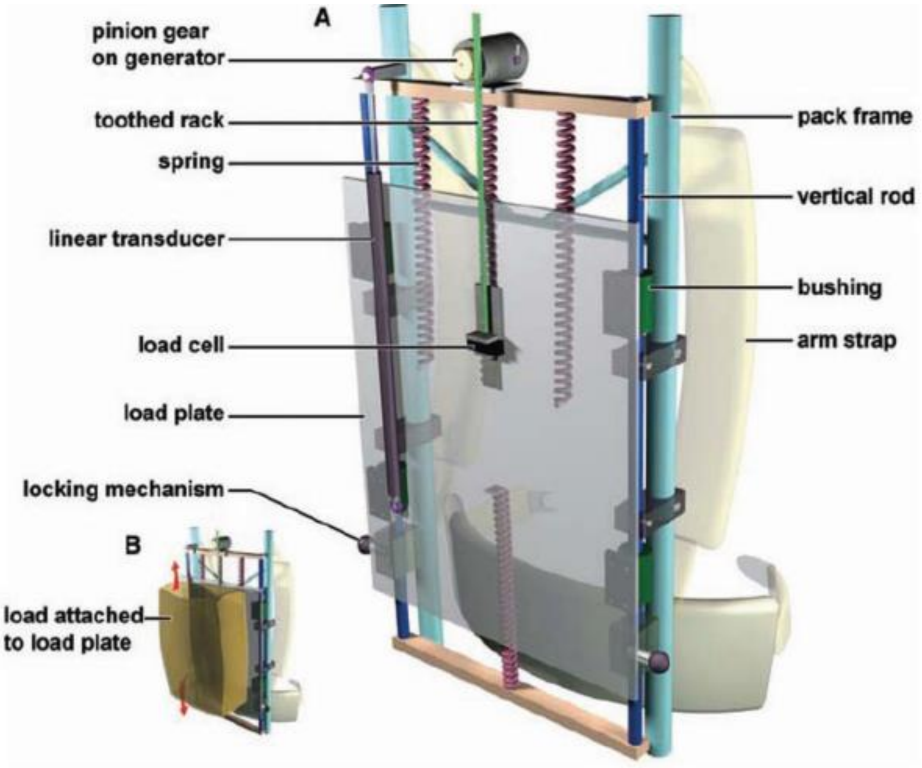

Figure 2.21. Suspended-load backpack with an energy-producing load

Source: (Sodano, 2009)

2.1.15. Energy Harvesters Functionality Improved Using Magnets

Numerous methods have been put out in recent years to enhance the functioning of energy harvesters under broadband vibrations, however these methods only enhance the effectiveness of energy harvesting under specific circumstances. In order to better understand how magnets can be used to enhance the functionality of energy harvesters under various vibration scenarios, a thorough experimental research is carried out in this work (Tang et al., 2012). First, the performance of vibration energy harvesting is enhanced by taking use of the nonlinearities that magnets introduce. Under sinusoidal and random vibrations with different excitation intensities, both monostable and bistable topologies are explored.

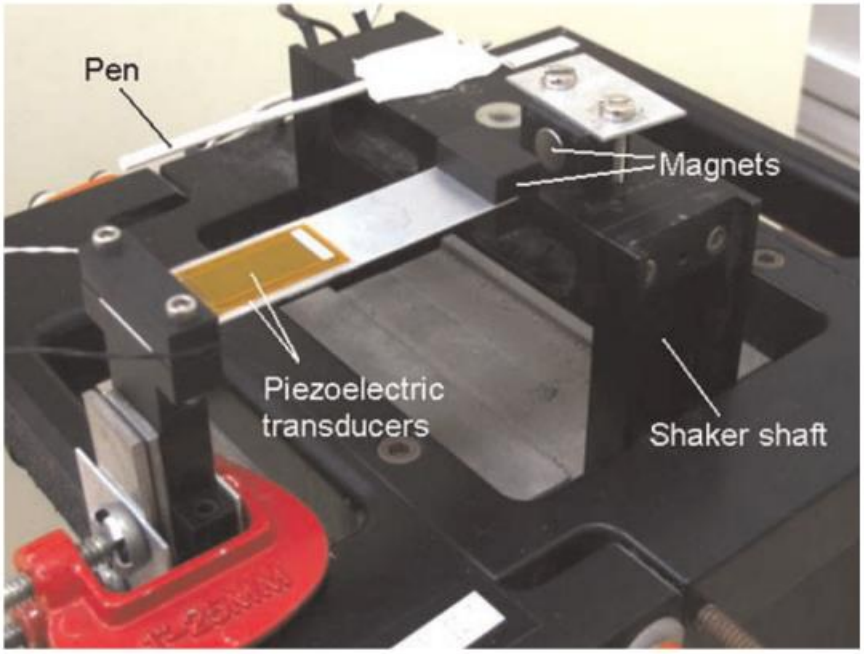

Figure 2.22. Experimental implementation of frequency-up conversion

Source: (Tang et al., 2012)

The monostable-to-bistable transition zone is found to be close by the ideal nonlinear arrangement (in terms of distance between magnets). Results indicate that near this transition zone, both monostable and bistable nonlinear designs can perform much better than the linear harvester.

Second, a frequency up-conversion method utilizing magnets is suggested for ultra-low-frequency vibration scenarios such wave heave motions. When the magnets are put sufficiently near together, the repulsive configuration of magnets is found to be superior in the frequency up-conversion approach, which is effective and unaffected by varied wave circumstances. When nonlinearity or frequency-up conversion techniques are used to enhance the functionality of vibration energy harvesters, these findings could be helpful design guides.

2.1.16. Wrist-Worn Energy Harvester Architecture

In this study by (Rantz et al., 2018), the simulation-based examination of six dynamical structures' potential for vibratory energy harvesting on the wrist is presented. In this work, rotational and linear motion-based architectures are investigated in order to address the issue of maximizing energy harvesting potential at the wrist. The development and experimental validation of mathematical models.

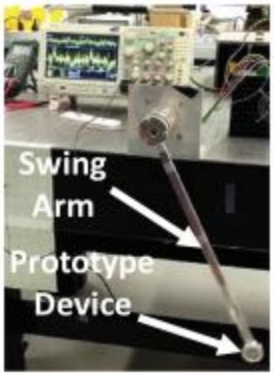

Figure 2.23. Experimental setup for swing arm operation

Source: (Rantz et al., 2018)

The proposed architectures are subjected to an optimization procedure to increase average power output and enable comparison. The power output of the structures might be increased by including a linear spring element; for rotational structures, a 211% increase in power production was predicted under realistic walking excitation. When real walking data is used as input to the simulations, the research finds that a sprung rotating harvester architecture beats a sprung linear architecture by 66

3. THEORETICAL STUDIES AND SIMULATIONS RESULTS

3.1. Electromagnetism

In physics, electromagnetism is an interaction that takes place between charged particles. After the strong force, it is the second-strongest of the four fundamental interactions, and it dominates interactions between both atoms and molecules. Electricity and magnetism, two separates but closely related phenomena, can be combined to form electromagnetism. The theorem of electromagnetism has been improved in the current era to incorporate the implications of modern physics, such as quantum mechanics and relativity. Theoretical implications of electromagnetism, in particular the calculation of the speed of light based on characteristics of the propagation "medium," are real. Faraday’s Law has been used to find the emf magnitude (V) for the magnets moving in a tube with coils.

$$\mathrm{V} = (\mathrm{N} \times \mathrm{d\phi}) / \mathrm{dt} \tag{3.1}$$

N = number of turns of coil

ϕ = magnetic flux density

As,

$$\mathrm{d}\phi = A \times \mathrm{dB} \tag{3.2}$$

A = Area of the coil

B = Magnetic flux density

So, putting it in the above equation,

$$\mathrm{V} = \mathrm{N} \times \mathrm{A} \times \mathrm{dB}/\mathrm{dt} \tag{3.3}$$

3.2. Simulations

3.2.1 COMSOL Software

The platform used to perform the simulations in this thesis was COMSOL. This software is used to solve problems and run simulations for various physics and engineering problems. This enables to simulate electromagnetics, structural mechanics, fluid flow etc. All features can be accessed and overview of the model as it provides the Model Builder.

Finite element method (FEM) is used by COMSOL which is subdividing the large parts of the system into smaller and simpler parts. COMSOL Multiphysics is used in order to solve this three-dimensional and non-linear problems as well as to easily optimize the design.

3.2.2. Model Builder

The Model Builder window, which is effectively a model tree with all the capability and functions for generating and solving models and displaying the results, controls the modeling process. These are added by including a branch, such as the geometry branch, to your modeling process. Branches may have additional nodes that connect to their parent node (or subbranches). A node contains unique attributes, including properties and a Settings window. Branches and subbranches may also include settings and characteristics.

The components and their geometry can be selected from the model builder. It is an easy way to access the materials, their parameters and geometry. Results and tables can also be accessed easily. Everything is displayed on the model builder and it act as the shortcut to go to that specific section.

3.2.3. Magnetic Effect, No Current

In setting up the system for the simulation we will select the magnetic effect with no current interference. It is used to compute magnetostatic fields from permanent magnets as well as other sources of magnets without current. It has the stationary formulation but is supported in 2D and 3D systems. It is used to solve the Gauss' Law for the magnetic field using the scalar magnetic potential as the dependent variables. Following are the equations are solved by the COMSOL while running the simulations.

$$\nabla \times B = 0 \tag{3.4}$$

$$B = \mu_0 \mu_r H + B_r \tag{3.5}$$

$$H = -\nabla V_m \tag{3.6}$$

3.2.4. Stationary Study

The study selected for our simulations is stationary as the variables does not change over the course of time. As we are using the magnets so in electromagnetics it is used to study the static electric or magnetic fields as well as direct current.

3.2.5. Materials

Materials used in the design is a magnet which has the relative permeability of 1. A block is selected from the geometry section and is considered as magnet. The dimensions for magnet block used are 0.5 cm in width, 1 cm in depth and 1 cm in height. Air is also used in it which also has the relative permeability as 1. It is filled in the big block containing the magnet block.

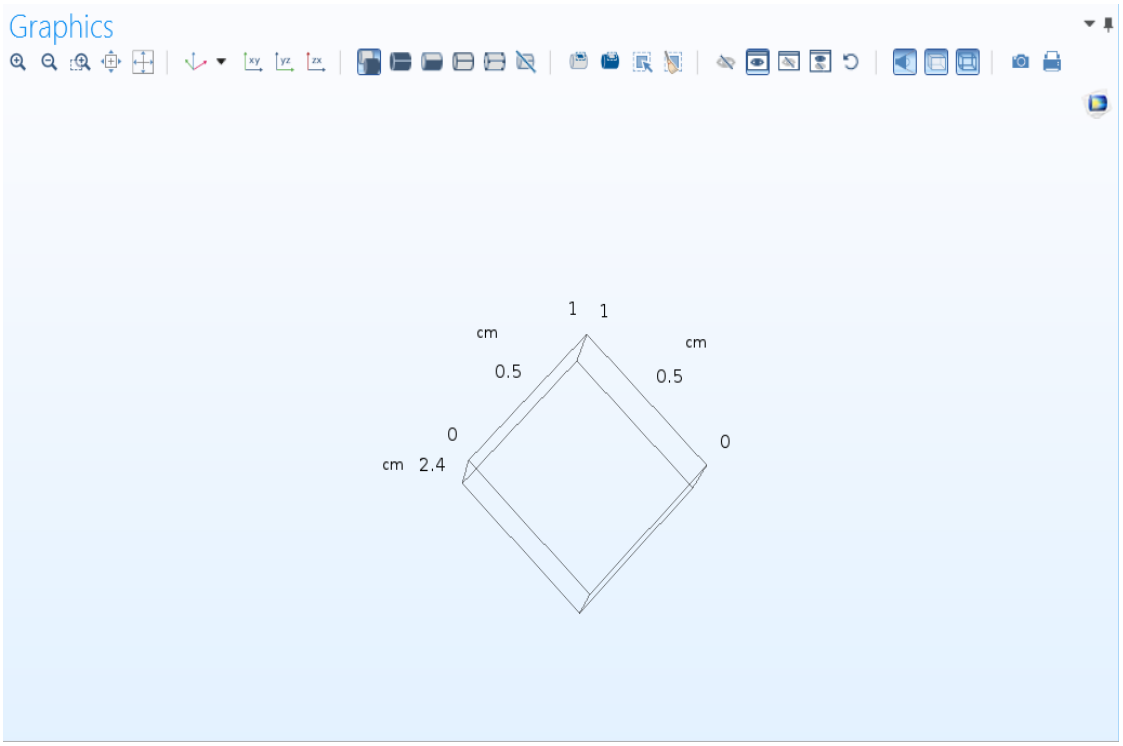

Figure 3.1. Magnetic block

3.2.6. Wristband Energy Harvester

The model designed for the simulation has the parameters set according to the wrist size of a normal person. Outer block containing magnet has 10 cm width, 7 cm height and depth around 7 cm. It is made as a tube. This is filled with the air so the magnetization is uniformly distributed inside the tube. These parameters were set during the simulation of the system. This is shown in the Figure 3.4.

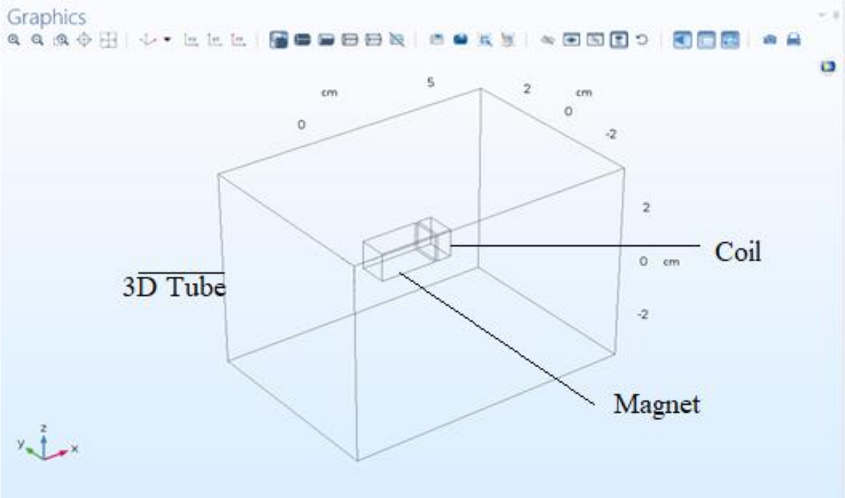

Figure 3.2. Simulation Setup of Wristband Energy Harvester

3.2.7. Meshing

Meshing is frequently utilized in computer-based simulation for computational fluid dynamics (CFD) and finite element analysis (FEA). It may have a substantial impact on the simulation's accuracy and the resources needed to run it. Meshing helps in dividing the complex structures into elements which can be then use to discretized the domain. COMSOL has two types of mesh. It can be user controlled or physics-controlled sequences of mesh. We used the physics-controlled meshing sequence which can determine the attributes such as size and operation sequence automatically to adapt according to the problem.

The next crucial step is to build the mesh after creating the geometry and giving your model the physics. How a model is solved depends critically on the mesh used for its geometry as it gives these factors.

- How the geometry is divided
- With what shape or element type the geometry is divided
- The size, density, and number of elements in the geometry
- The element quality

Element size can also be varied for the mesh to study the more accurate and minor details. The more accurate the mesh is the more accurate the results are. The system is showed with normal meshing in the figure 3.5.

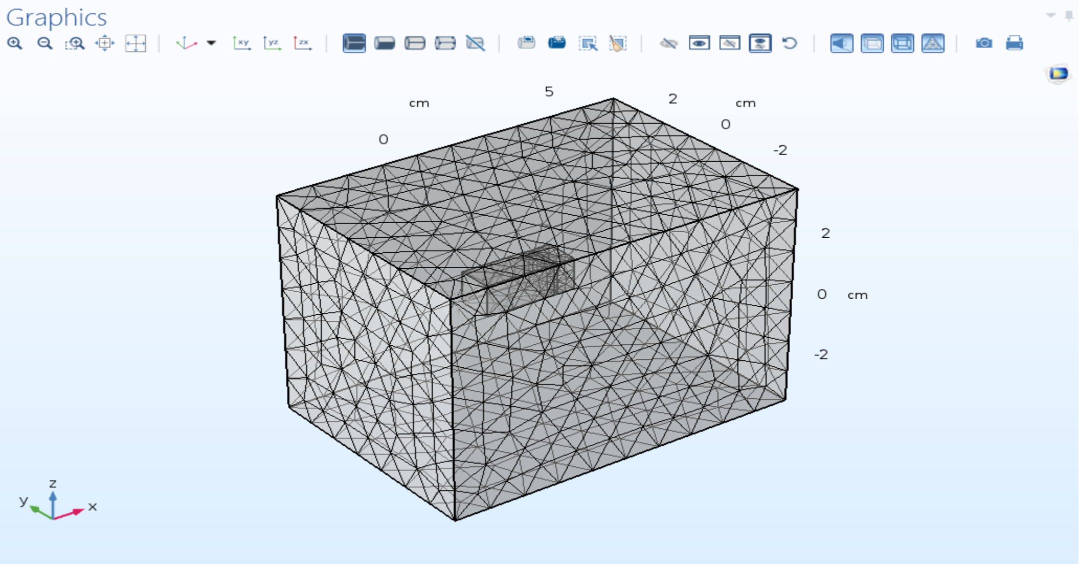

Figure 3.3. Meshing sequence of the harvester

3.2.8. Simulations

During the simulations were performed the magnetic flux density at the tube is calculated. This is shown in the figure 3.6.

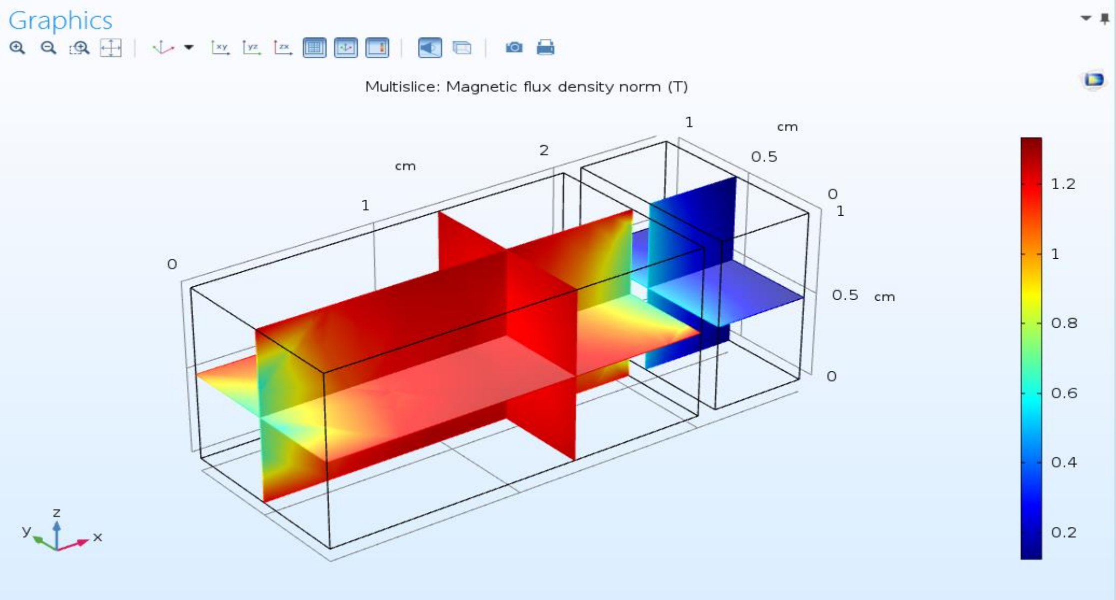

Figure 3.4. Magnetic flux density

The magnetic flux density on the coil surface is calculated to be around 0.24 T while it increases up to almost 0.48 T on magnetic surface.

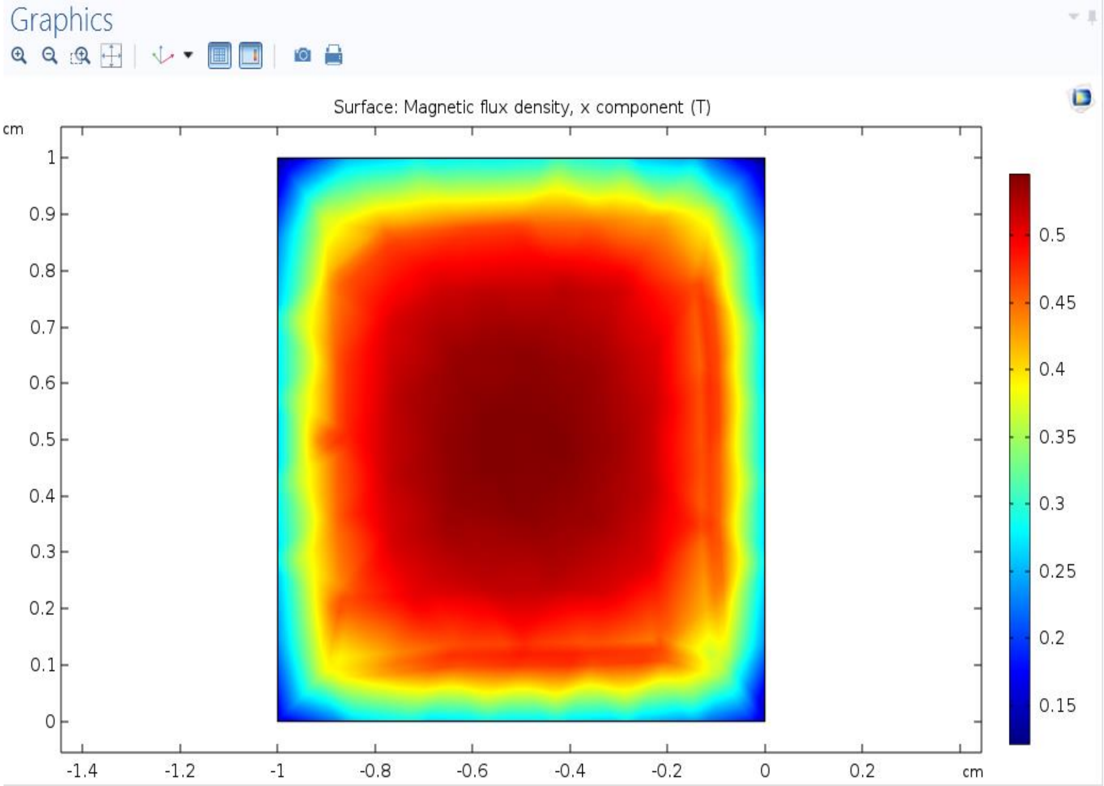

Figure 3.5. Surface magnetic flux density

So, when the magnets move through the coils the magnetic flux density varies between ±0.24T in roughly a triangular waveform. Vertical flux density is higher in the middle of the surface of the magnet while it is lower towards the edges because the magnetic field lines are parallel in the center and are stronger at that point. Magnetic field lines are curved at the edges so the magnetic flux density is lower at edges.

Assuming the magnets are moving at a reasonable speed of 1m/s, the voltage can be found by using equation 3.3 as 3.36mV per turn. Therefore, the total voltage that will be induced on the coils would be 3.36 × N. It should be noted that the area of the coils calculated considering the radius of it to be 5mm.

4. EXPERIMENTAL STUDIES

4.1. Experimental Setup

Experiment setup built to perform the experiment is explained in this chapter. Materials used to perform the setup were magnets, coil and a 3 D tube of the size 8.2 cm in length and 1.8 cm in width with permanent magnets on each end of the lid.

4.1.1. Magnets

The magnets used for the experiments are neodymium magnets. Neodymium magnets, sometimes referred to as NdFeB, NIB, or Neo magnets, are the most popular kind of rare-earth magnets. The strongest type of permanent magnet currently sold generally are neodymium magnets. They are known for their magnetic properties and strength. They have replaced other magnets. They found their applications in modern technology where stronger magnets are required. They are being used in computer hard disks, electronic devices, magnetic couplings and bearings etc. The magnet used in experiment is nickel coated cube as shown in the figure. They are brushed with the machine oil to reduce their friction against the walls of the tube during their movement. The dimensions are 1x1x1 cm.

Figure 4.1. Neodymium magnets 1x1x1 cm

4.1.2. Coil

In electrical engineering, magnetic coils are used in components including electric motors, generators, inductive loads, electromagnets, transformers, and sensory coils where electric currents and magnetic fields interact. Either a magnetic field is produced by passing an electric current through the coil's wire, or an external, time-varying magnetic field passing through the coil's interior produces an EMF (voltage) in the circuit. The coil is wrapped on the 3 D tube from both ends. It is wrapped clock-wise from one end while anti clock wise from the other end so that they add each other’s magnetic field and don’t end up cancelling the magnetic field as in the case if they are wrapped in the same direction. The number of turns for both clock wise direction and anti-clock wise direction is the same that is 200 making the total number of turns to be 400. They are insulated so they wrapped over each other and there is no danger of short circuit. The coil wrapped on the 3 D tube is shown in the Figure 4.2. The resistance of coils was calculated to be 18 ohms using multimeter.

Figure 4.2. Coil wrapped around the 3D tube

4.1.3. Tube Device

The tube used in this experiment was developed by 3D printing using CAD. The material used to print the tube is PLA. It is the most popular and widely used in 3D printing these days because of its inexpensiveness, strength, good dimension accuracy and better shelf life. The tube is 8.2 cm in length and 1.82 cm in width. The lids of the tube have permanent magnets inside them. Their function is to repel the magnets moving inside the tube making their movements easy.

Figure 4.3. 3D tube

4.1.4. Circuit

The magnets were placed inside the 3D tube which is wrapped with the coil. The magnets were placed in such way that both of them are being repelled by the permanent magnets inside the lids of tube. The magnets are pushing the magnets so that they can move easily inside the tube and they face less friction. Each end of the coil is connected to the oscilloscope and then it is placed on the shaker to run the experiments. Different frequencies were set at the shaker and voltage (V) was calculated for each one of them. The frequency set for the shaker were 240, 305, 370, 435 and 500 Hz. With the use of a Tektronix Digital USB oscilloscope, the voltage pattern as a result of these frequencies was observed.

Figure 4.4. Experimental setup of open circuit voltage calculation

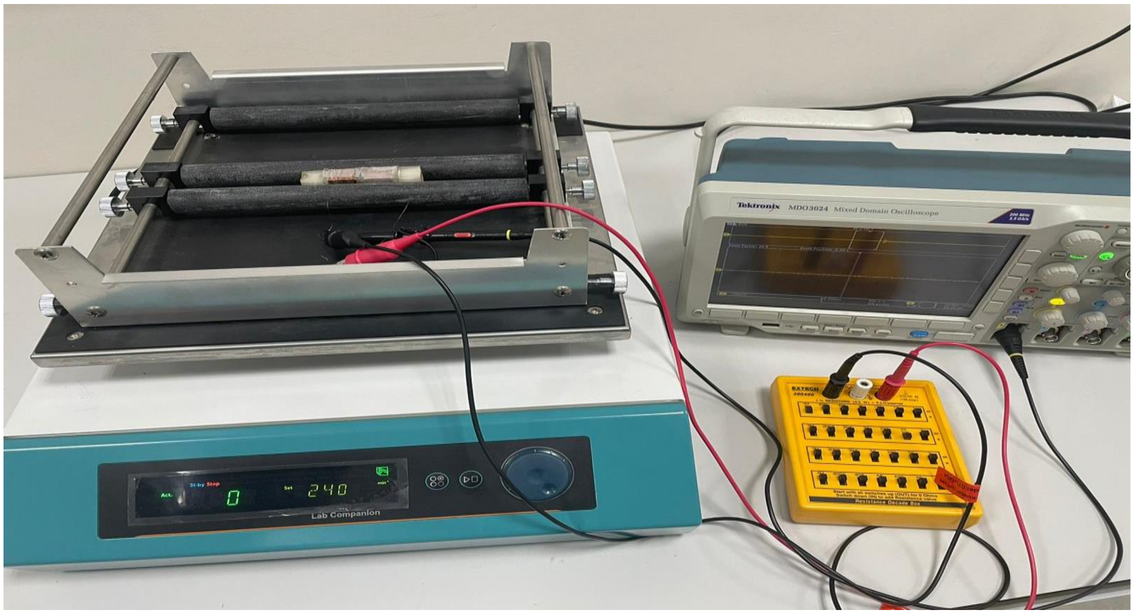

Figure 4.5. Experimental setup of open circuit voltage with resistance

4.2. Open Circuit Voltage

Open circuit voltage tests were run for each of these frequencies on the shaker. The resistance of the coils in the circuit was measure with the help of digital multimeter and found out to be 18 ohms. The measured voltage increases as the frequency of the shaker is increased with and without resistance respectively.

4.2.1. At 240 Hz Frequency

When shaker was set at the frequency of 240 Hz and the device was placed on it, the magnets inside started to move and voltage was created because of the coils around the tube because of the changing magnetic field. The voltage calculated at this frequency is to be around 0.248 V as shown in the figure 4.6.

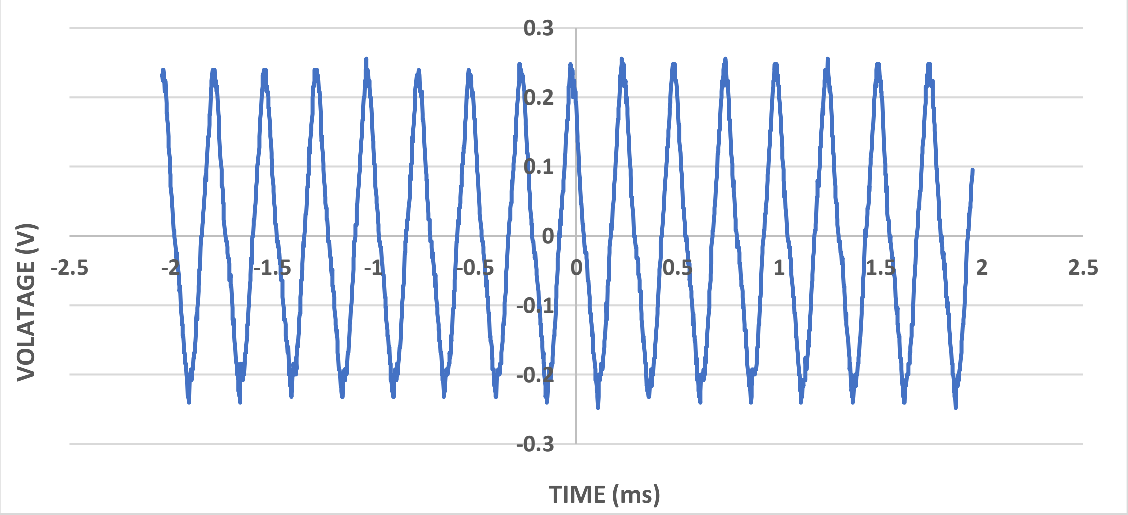

Figure 4.6. Open circuit voltage at 240 Hz

When an 18 Ω resistor matching the coil resistance was introduced into the circuit, the circuit voltage decreased. Resistance was connected to the ends of the coil. The results were then observed by using oscilloscope and are shown in the figure 4.7. The voltage was measured to be 0.064 V at this frequency.

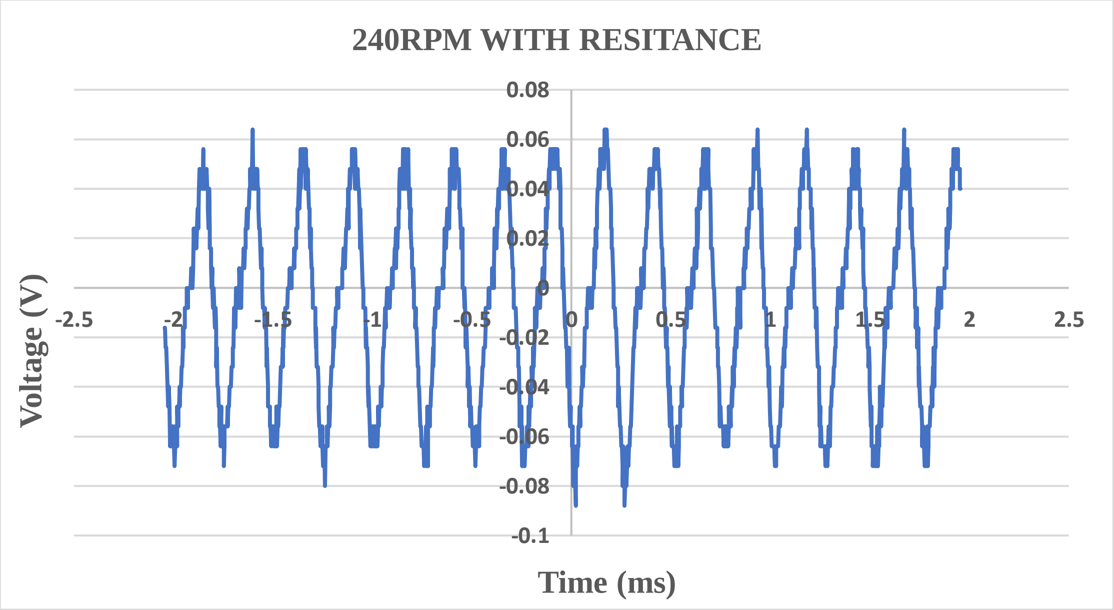

Figure 4.7. Voltage at 240 Hz with resistance

4.2.2. At a Frequency 305 Hz

When shaker was set to higher frequency of 305 Hz and voltage was measured. As the speed is increased the magnets started to move faster inside the tube and we expect voltage increase. There was an increase in the value of voltage as the frequency increased. The new value of the voltage found to be 0.352 V as is shown in the figure 4.8.

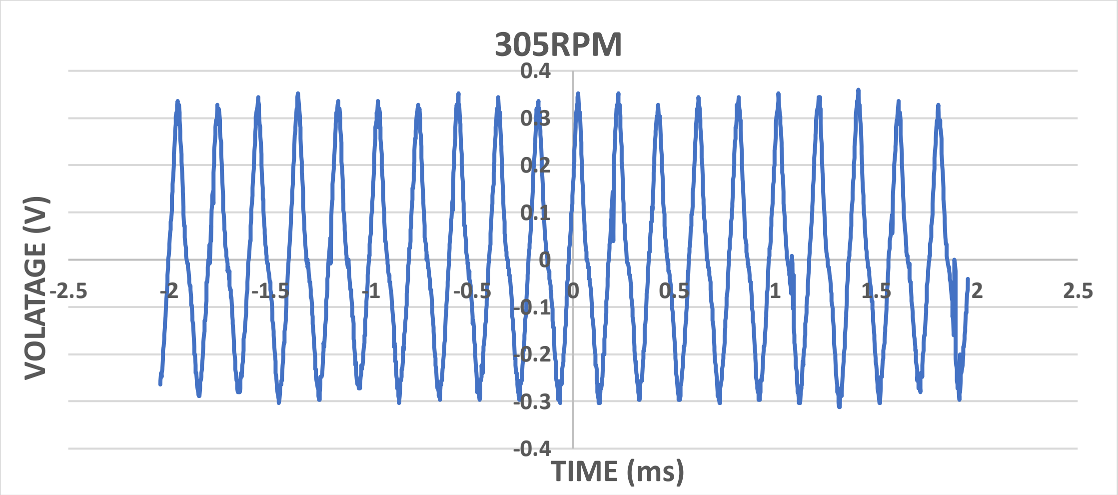

Figure 4.8. Open circuit voltage at 305 Hz

Similarly, shaker was stopped and resistance was introduced in the circuit to measure the circuit voltage at this frequency. The shaker was then turned on and let to reach the required speed to calculate the voltage. There was decrease seen in the open circuit voltage because of the introduction of the resistance. The voltage measured was 0.176 V as shown in the figure 4.9.

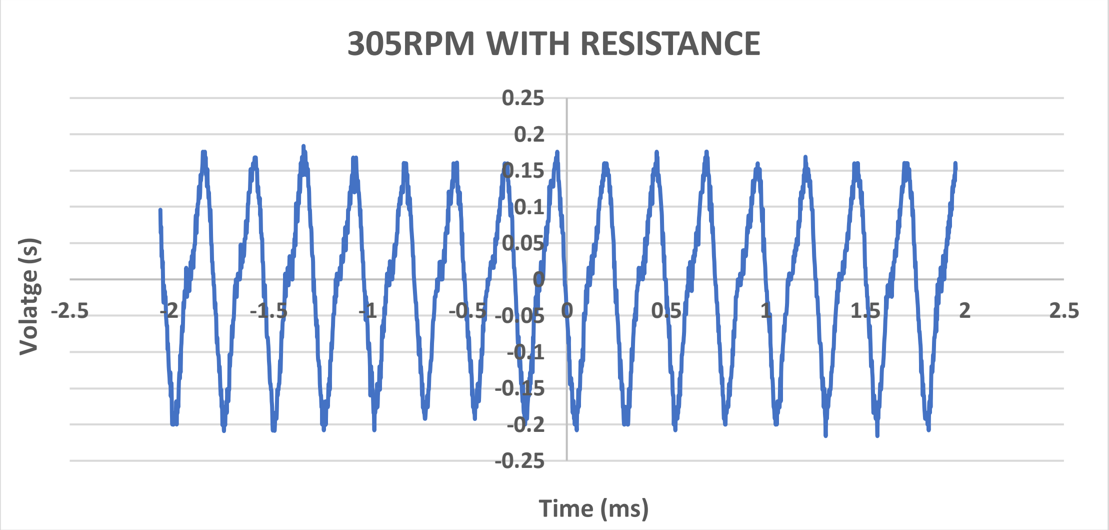

Figure 4.9. Voltage at 305 Hz with resistance

4.2.3. At a Frequency 370 Hz

When the frequency of the shaker was set to be 370 Hz, the magnets moved faster. The inertia is increased so voltage is expected to be greater than before. The new voltage measured to be 0.56 V. This represented in the figure 4.10.

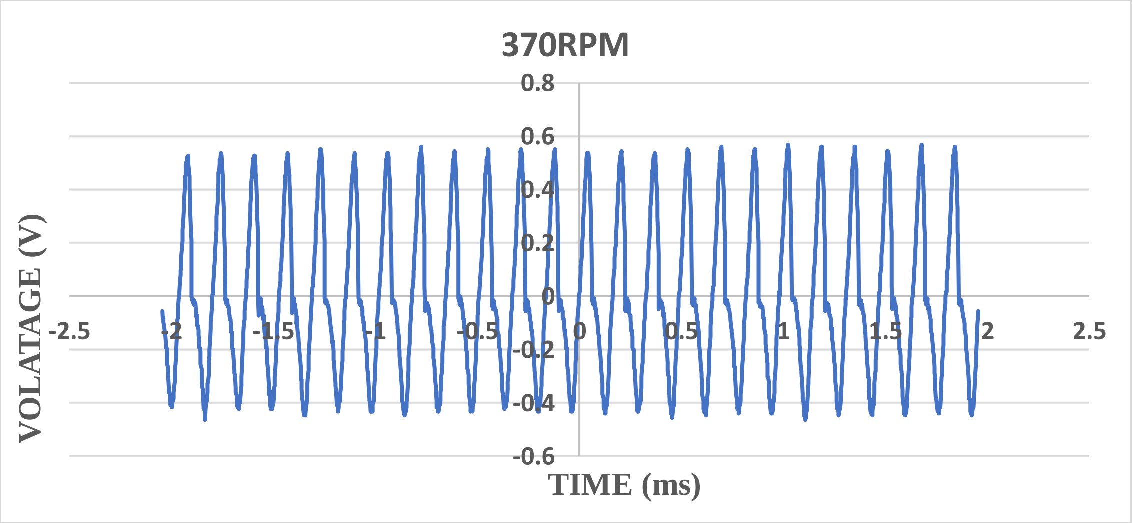

Figure 4.10. Open circuit voltage at 370 Hz

There was decrease in the voltage with the introduction of resistance in the circuit at this frequency. The reduced open circuit voltage measured with the help of oscilloscope was found out to be 0.296 V. This is shown in the figure 4.11.

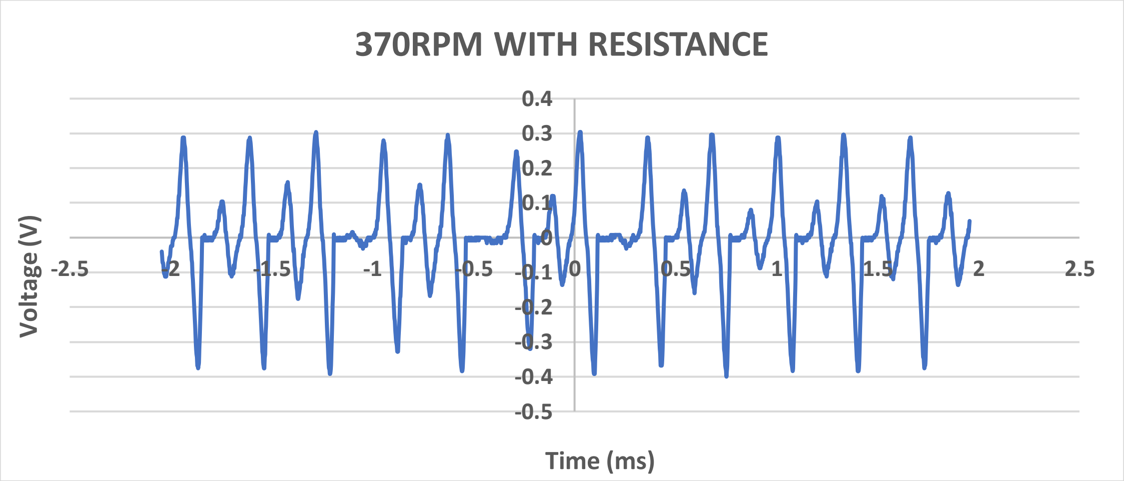

Figure 4.11. Voltage at 370 Hz with resistance

It is seen from the graph that the voltage deviated from a triangular waveform. This may be due to the shaker's unstable motion, profile or a sudden friction increase inside the tube, or an uneven repulsion from the end magnets. This is also making the average voltage not exactly to be zero.

4.2.4. At a Frequency 435 Hz

Shaker's frequency was raised to 435 Hz and it was let some time to stabilize the harmonic motion. it run. When the open voltage circuit was measured at that speed, it was found to be 0.912 V.

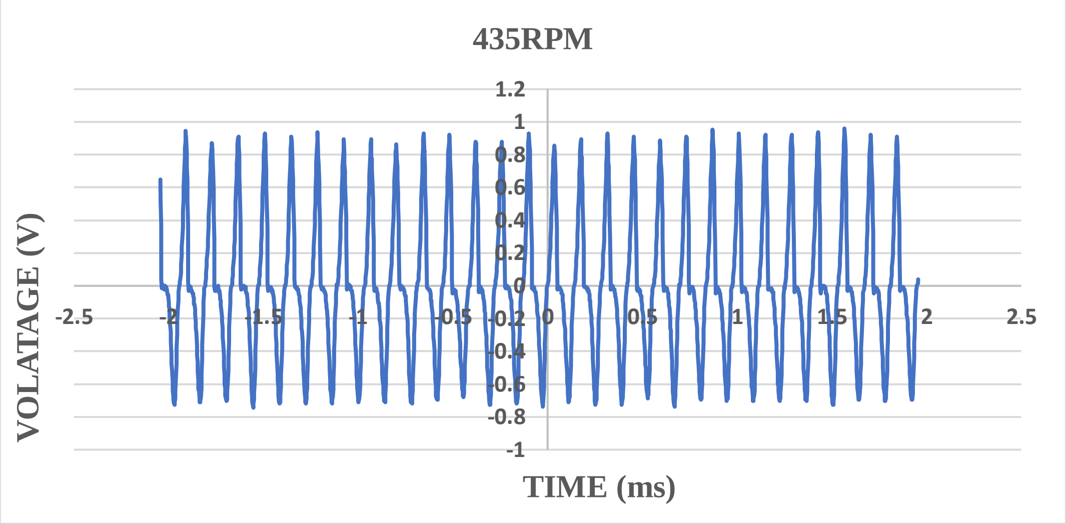

Figure 4.12. Open circuit voltage at 435 Hz

With resistance in the circuit the voltage value was measured again and it follows the same trend as before. The value decreased with the introduction of the resistance in the circuit. The measured circuit voltage with resistance at this frequency was 0.6 V.

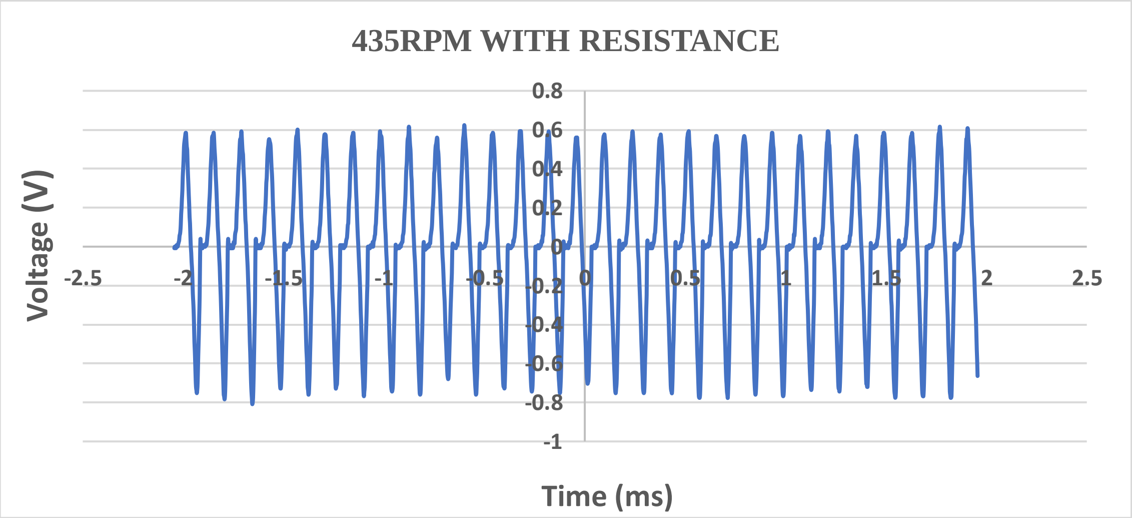

Figure 4.13. Voltage at 435 Hz with resistance

Similarly, at this high frequency we see that again there is some deviation from the triangular shape in the output with both open circuit voltages. This may be cause by the same reason explained above.

4.2.5. At a Frequency 500 Hz

Shaker was then moved to its highest frequency which is 500 Hz. We see the highest waveform at the oscilloscope than the previous frequencies. The voltage measured at the highest speed was found to be 1.16 V.

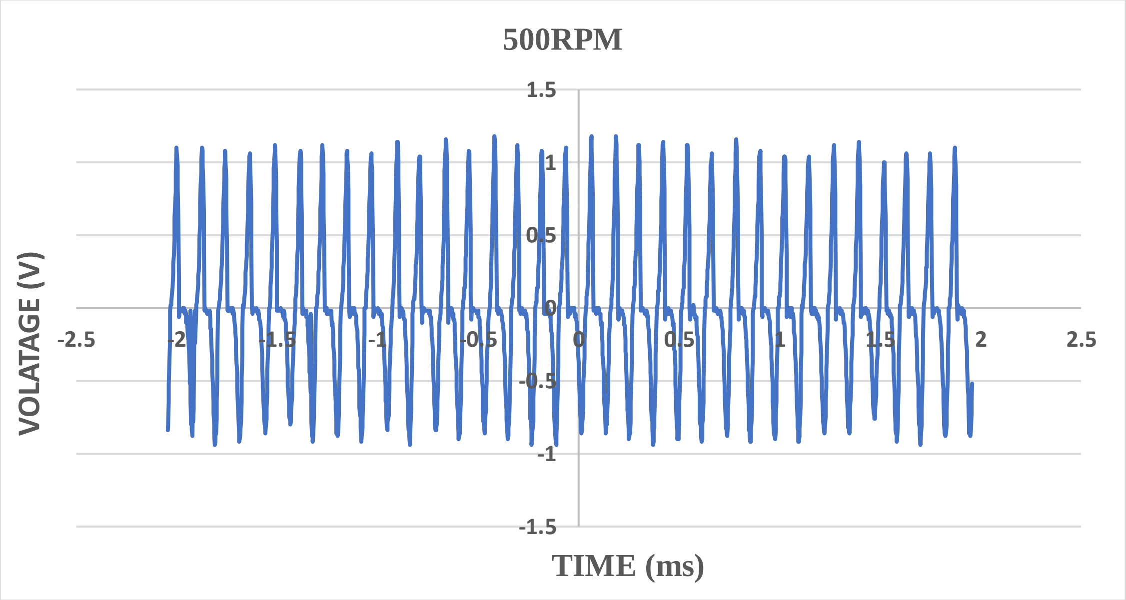

Figure 4.14. Open circuit voltage at 500 Hz

By introducing the resistance in the circuit and voltage was measured with the help of oscilloscope. It followed the same trend and we saw the value decreased with the resistance. The circuit voltage measured at this frequency was 0.7 V.

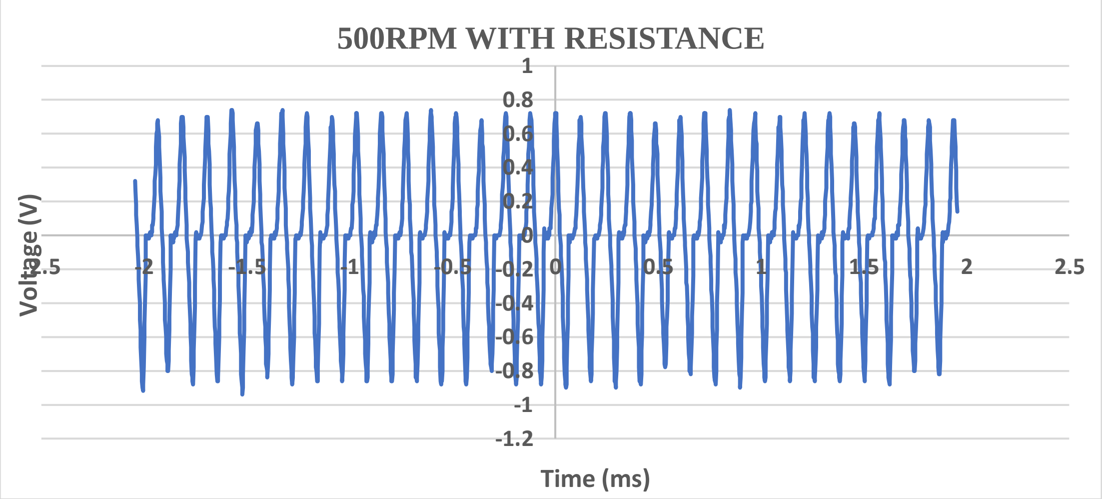

Figure 4.15. Voltage at 500 Hz with resistance

4.2.6. Discussion

The voltage calculated for all these frequencies were compared. We see an increase in the value of the voltage as the frequency increased. The higher the shaker frequency, and therefore the faster motion is the voltages have been. The value of open circuit voltage without resistance at the lowest frequency was 0.248 V while it increased to around 1.12 V at the highest frequency of the shaker. This shows the graph is not linear as it is not following the straight line. Similarly, when resistance was introduced in the circuit the voltage decreased according to without resistance at the exact same frequency. Both the graphs are not linear due to nonlinearities that may exist in the shaker motion or magnet friction because they are not following the straight line. As shown in table 4.1.

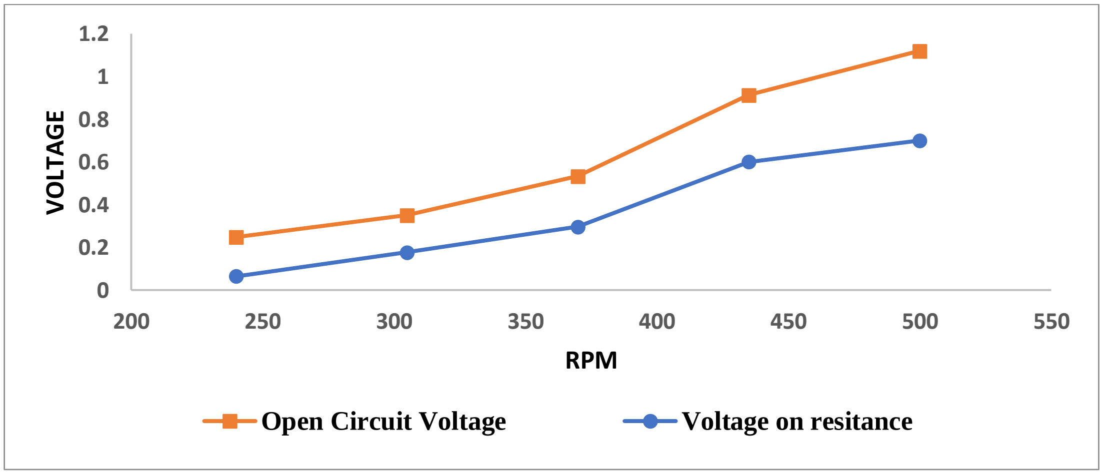

Figure 4.16. Circuit voltage with and without resistance

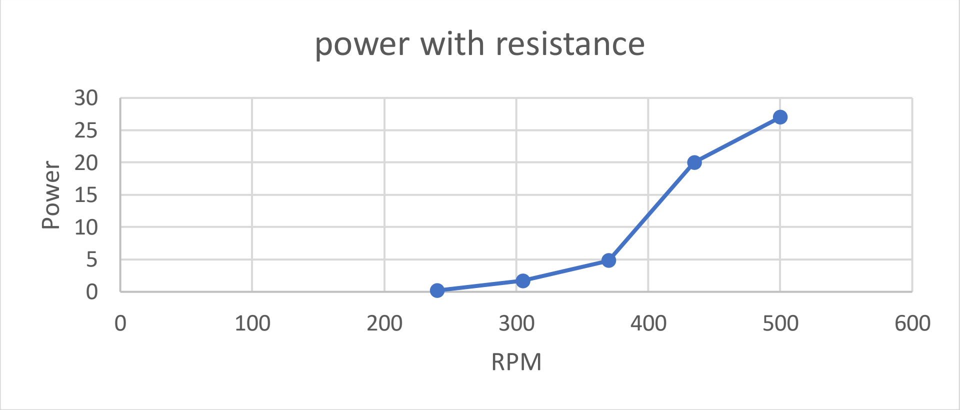

Figure 4. 17. Power on resistance (mW) v shaker RPM

Table 4.1. Voltages with & without Resistance

RPM	**Open circuit voltage (V)**	**Voltage on resistance (V)**	**Power**
240	0.248	0.064	0.2mW
305	0.352	0.176	1.7mW
370	0.532	0.296	4.8mW
435	0.912	0.6	20mW
500	1.12	0.7	27mW

The resistance of the coil was calculated to be 18 ohms. The values of open circuit voltage with resistance also increases with the increase in the frequency but they are decreased almost half in contrast to the values without resistance. The voltage at the lowest frequency of 240 Hz in the experiment was measured to be 0.064V. At the highest frequency of the shaker which is 500 Hz the voltage increases to 0.7 V.

The power is also calculated for both open circuit voltages which is shown in the table 4.1. The number of turns used at the device are 400 and when we multiply these number of turns with the voltage, we got from simulation for number turns 3.36mV. We get the result 1.34V which is close to the open circuit voltage obtained at 500RPM.

5. CONCLUSIONS

5.1. Conclusion

The hunt for alternatives is sparked by batteries' short lifespan and the influence they have on the environment during production and recycling. Systems for harvesting energy are created to produce electricity from environmental sources. Power can be produced by a variety of sources, including motion, radio frequency, and the sun. One of these sources, human body motion, can be used to provide electricity, especially for wearing electronic equipment. Kinetic motion of humans can be utilized to generate electricity as it is not being used seriously so it is mostly being wasted.

We developed a system to use the arm movement of the human notion in this thesis to power the wearable electronics, especially wrist worn electronic devices. Software used for the simulations was COMSOL as it offers fully connected modeling capabilities for both single-physics and Multiphysics. The output voltage we got during the simulation was volts. For performing the experiments, a device was developed with the help of 3D printing and has small permanent magnets on each end of its lid. Coil was wrapped around it and two magnets were placed inside the 3D tube. The magnets are placed in such a way that the permanent magnets on each side of the lid repel the magnets inside the tube. It is then placed on a shaker to get arm like movement to get the results. Shaker was run at different frequencies and open circuit voltage was calculated for all of those frequencies. 0.248 V was produced at the frequency of 240 Hz and it keeps on increasing as we increase the speed of the shaker. The voltage increases to the value of 1.12 V at highest speed. The resistance of the coil was measured and then the same resistance was introduced in the circuit. When open circuit voltage was calculated for the circuit with the resistance attached, it was found to be 0.064 V. It reaches the value of 0.7 V at the highest speed of the shaker.

This device can be used for wearable electronic devices and it can continuously recharge their batteries. It has advantage than the ones that use solar cell as it doesn’t depend on the weather. As it utilizes human motion so it can be used inside the rooms during normal chores like writing or eating and it can also be worn while walking or running outside. Further work on this will develop future for wearable electronic devices that do not require battery replacement or do not require battery at all. The device is very easy to make and very inexpensive which makes it more advantageous than other devices which require a very complex model. This device does not need any complex material or component we just need magnets and a 3 D printed tube to perform the experiment and get voltage. This can then be rectified or boosted as required to our needs to utilize.

This device can also be utilized in biomedical industry in the future. Sometimes the doctor a patient that they have to wear a device to check the blood sugar lever or heart rate but they are not the always close to the power source and battery can run out any time. So, this device can potentially help those patients to not worry about that and just continue their normal work. They can just wear this and as they are doing their work and moving their arms, the battery is getting charged in their device or the device can run directly from i

REFERENCES

Articles

Beyaz, M. (2019). Piezoelektrik Yama Dönüştürücülerle Diz Hareketinden Enerji Hasadı. *Academic Platform Journal of Engineering and Science*, *7*(2), 255–260. https://doi.org/10.21541/apjes.449102

Cai, M., & Liao, W. H. (2021). Enhanced electromagnetic wrist-worn energy harvester using repulsive magnetic spring. *Mechanical Systems and Signal Processing*, *150*, 107251. https://doi.org/10.1016/j.ymssp.2020.107251

Cai, M., Liao, W. H., & Cao, J. (2019). A smart harvester for capturing energy from human ankle dorsiflexion with reduced user effort. *Smart Materials and Structures*, *28*(1). https://doi.org/10.1088/1361-665X/aaed66

Contributors, W. (2021). Wind power - Wikipedia. In *Wikipedia, The Free Encyclopedia*. https://en.wikipedia.org/wiki/Wind_power

Donelan, J. M., Li, Q., Naing, V., Hoffer, J. A., Weber, D. J., & Kuo, A. D. (2008). Biomechanical energy harvesting: Generating electricity during walking with minimal user effort. *Science*, *319*(5864), 807–810. https://doi.org/10.1126/science.1149860

Energy harvesting - Wikipedia. (2021). https://en.wikipedia.org/wiki/Energy_harvesting

Hayashida, J. Y. (2000). Unobtrusive Integration of Magnetic Generator Systems into Common Footwear by. *, BS Thesis, Dept. of Electrical Engineering and MIT Media Laboratory, Massachusetts Institute of Technology*.

Kornbluh, R. D., Eckerle, J., & McCoy, B. (2011). A scalable solution to harvest kinetic energy. *SPIE Newsroom*, *June 2015*. https://doi.org/10.1117/2.1201106.003749

Maharjan, P., Cho, H., Rasel, M. S., Salauddin, M., & Park, J. Y. (2018). A fully enclosed, 3D printed, hybridized nanogenerator with flexible flux concentrator for harvesting diverse human biomechanical energy. *Nano Energy*, *53*, 213–224. https://doi.org/10.1016/j.nanoen.2018.08.034

Materials, S., Hoffmann, D., & Becker, P. (2015). *Energy harvesting from human motion : Exploiting swing and shock excitations*. *February*. https://doi.org/10.1088/0964-1726/24/2/025029

Omar, M., & Sifuentes, E. (2020). *Energy Harvesting from Fingers Motions Using a Wearable System : An Experimental Analysis*. 866–873.

Rantz, R., Halim, M. A., Xue, T., Zhang, Q., Gu, L., Yang, K., & Roundy, S. (2018). *Architectures for wrist-worn energy harvesting*. *27*.

Rathod, J. (2019). RF Energy Harvesting - Converting Radio Frequency into Electrical Energy. In *Digi-Key*. https://circuitdigest.com/article/rf-energy-harvesting-converting-radio-frequency-into-electrical-energy

Resources- SolarPath Sun Solutions. (n.d.). http://www.solarpathusa.com/resources/

Riemer, R., & Shapiro, A. (2011). *Biomechanical energy harvesting from human motion : theory , state of the art , design guidelines , and future directions*. 1–13.

Seebeck Effect Theory - Inst Tools. (n.d.). https://instrumentationtools.com/seebeck-effect-theory

Serdijn, W. A., Mansano, A. L. R., & Stoopman, M. (2014). Introduction to RF Energy Harvesting. In *Wearable Sensors: Fundamentals, Implementation and Applications*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-418662-0.00019-2

Sodano, H. A. (2009). *Harvesting Energy from the Straps of a Backpack Using Piezoelectric Materials*. 431–432. https://doi.org/10.1007/978-0-387-76464-1

Tang, L., Yang, Y., & Soh, C. (2012). *Journal of Intelligent Material Systems and Structures*. https://doi.org/10.1177/1045389X12443016

Wang, Y., Gao, M., Williams, T., Bouazza-marouf, K., Liu, T., & Pierre, R. S. (2015). *Piezo-magnetic energy harvesting from movement of the head Piezo-magnetic energy harvesting from movement of the head*. https://doi.org/10.1088/1742-6596/660/1/012120

Wang, Y., Shi, Y., Mei, D., & Chen, Z. (2017). Wearable thermoelectric generator for harvesting heat on the curved human wrist. *Applied Energy*, *205*(May), 710–719. https://doi.org/10.1016/j.apenergy.2017.08.117

Wikipedia. (2018). *Daniell cell - Wikipedia*. https://en.wikipedia.org/wiki/Daniell_cell

Wikipedia. (2019). *Solar power - Wikipedia*.

Williams, A. J., Torquato, M. F., Cameron, I. M., Fahmy, A. A., & Sienz, J. (2021). Survey of Energy Harvesting Technologies for Wireless Sensor Networks. *IEEE Access*, *9*(August), 77493–77510. https://doi.org/10.1109/ACCESS.2021.3083697

Yang, B., & Yun, K. S. (2011). Efficient energy harvesting from human motion using wearable piezoelectric shell structures. *2011 16th International Solid-State Sensors, Actuators and Microsystems Conference, TRANSDUCERS'11*, 2646–2649. https://doi.org/10.1109/TRANSDUCERS.2011.5969874

Yeo, H. G., Xue, T., Roundy, S., Ma, X., Rahn, C., & Trolier-McKinstry, S. (2018). Strongly (001) Oriented Bimorph PZT Film on Metal Foils Grown by rf-Sputtering for Wrist-Worn Piezoelectric Energy Harvesters. *Advanced Functional Materials*, *28*(36), 1–9. https://doi.org/10.1002/adfm.201801327

Zhang, S. L., Jiang, Q., Wu, Z., Ding, W., Zhang, L., Alshareef, H. N., & Wang, Z. L. (2019). Energy Harvesting-Storage Bracelet Incorporating Electrochemical Microsupercapacitors Self-Charged from a Single Hand Gesture. *Advanced Energy Materials*, *9*(18), 1–7. https://doi.org/10.1002/aenm.201900152

Zhao, J., & You, Z. (2014). *A Shoe-Embedded Piezoelectric Energy Harvester for Wearable Sensors*. *July*. https://doi.org/10.3390/s140712497

Thesis

Hayashida, J. Y. (2000). Unobtrusive Integration of Magnetic Generator Systems into Common Footwear by. , BS Thesis, Dept. of Electrical Engineering and MIT Media Laboratory, Massachusetts Institute of Technology.

Website Resources

Energy harvesting - Wikipedia. (2021). https://en.wikipedia.org/wiki/Energy_harvesting

Contributors, W. (2021). Wind power - Wikipedia. In Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/wiki/Wind_power

Wikipedia. (2018). Daniell cell - Wikipedia. https://en.wikipedia.org/wiki/Daniell_cell

Wikipedia. (2019). Solar power - Wikipedia.

Seebeck Effect Theory - Inst Tools. (n.d.). https://instrumentationtools.com/seebeck-effect-theory