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The Harvesting of the Energy from the Piezo-Electric Materials Using Sounds

Master thesis

Study programme: N2301 – Mechanical Engineering
Study branch: 2302T010 – Machines and Equipment Design

Author: **Amar Mallappa Sarwad**
Supervisor: prof. Ing. Karel Fraňa, Ph.D.

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Master Thesis Assignment Form

The Harvesting of the Energy from the Piezo-Electric Materials Using Sounds

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Identification Number:	S17000486
Study Programme:	N2301 Mechanical Engineering
Specialisation:	Machines and Equipment Design
Assigning Department:	Department of Power Engineering Equipment
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Rules for Elaboration:

Energy should harness from piezoelectric material by conducting series of experiment on piezo electric material by inducing sound through a speaker and obtain the energy harness from piezoelectric transducer. The wheat-stone bridge circuit will be used. To get full optimal energy from the material it should be conducted the experiment bycreating a sound wave of 98 Db at 528 Hz frequency. Experiment should be conducted in two methods by moving the position of piezoelectric transducer and changing the angle of piezoelectric transducer.

Scope of Report:	up to 50 pages
Thesis Form:	printed
Thesis Language:	English

List of Specialised Literature:

[1] WEBB, Ralph L. a Nae-Hyun KIM. *Principles of enhanced heat transfer.* 2nd ed. Boca Raton: Taylor & Francis, 2005. ISBN 9781591690146.

[2] RAHMAN, Arifur & Md. Emdadul HOQUE. Harvesting Energy from Sound and Vibration. *International Conference on Mechanical, Industrial and Materials Engineering 2013* (ICMIME2013) 1-3 November, 2013, RUET, Rajshahi, Bangladesh.

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Date of Thesis Assignment:	1 November 2018
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30. 4. 2019

Amar Mallappa Sarwad

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Foremost, I would like to express my gratitude for my supervisor **Prof. Ing. Karel Frana Ph.D**, for his guidance during this work. Also, I would like to thank **Mr.Ing. Jan Hůjer** for providing me with the microphone for recording the results of experiment, I would also like to show my gratitude to **Mr Ing. Shehab Ashraf Salem** for his continuous support and guidance regarding the lab work and numerical. Finally, I would like to thank my family and friends with whom I am most fortunate.

Abstract

This work deals with research and development of ambient energy harnessing technology from mechanical vibration. To harness mechanical vibration from ambient energy a piezoelectric material is used. To create a vibration, sound is produced from a portable speaker, The sound produced from portable speaker is induced on piezoelectric material, The frequency of the sound is controlled by laptop by playing a sine wave frequency and it was played at constant volume which was measured by using a microphone, then the series of experiment was conducted on the piezoelectric transducer. To harness the energy from piezoelectric transducer diode bridge circuit was used, and for measuring the output of the circuit voltmeter was used. The experiment was conducted in five case studies, i.e. by moving the position of piezoelectric transducer, changing the angle of piezoelectric transducer, enclosing the setup, changing the area of the enclosure and Connecting two piezoelectric transducers in parallel.

Keywords: Ambient energy, piezoelectric transducer, sound source, diode bridge rectifier

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1 Introduction

As global crisis for energy is increasing consecutively affecting, the awareness for conserving energy and exploring for the alternate sources of energy. Last few decades has seen an immense growth in research of ambient waste energy harvesting.

Energy harvesting is the process by which energy is derived from external sources such as solar power, wind power, thermal power are harvested and stored for small, wireless autonomous devices, like those used in wearable electronics and wireless sensor networks. With the revolution in the wireless industry the source for energy has also changed in the last decade, demanding the change in sources of energy. The demand for energy sources required to operate advanced technologies must be more unconventional as the source needs to be remote and with lower cost to use. This revolution in the technology has brought the attention of researchers and industrialists towards ambient energy harvesting, which has resulted in a surge in the field.

Energy harvesting of ambient waste energy can be performed in many ways as we said earlier. To harvest more convenient, cost effective and keeping clean energy in mind there are few process to harvest in which one of them is harvesting energy through smart material. Basic need to harvest energy through smart material is through vibrating the material. There are three basic mechanisms which converts vibration energy into electrical energy is electromagnetic, electrostatic and piezoelectric transduction [1].

As area of ambient energy harvesting is getting more researched in these days. The vibration based energy harvesting has been the main criteria of ambient harvesting, and research has been conducting on the mechanics, material and electricity circuitry. Due to the research on this three disciplines as increase the energy harvesting literature. The vibration based energy are basically energy harvesting of micro level of energy it's also called micro energy harvesting technologies, this type of energy harvesting is basic principle are based on a mechanical vibration, mechanical stress, mechanical strain, heat from the furnace, room heaters, solar based, heat from human body, chemical reaction or any biological movement sources. Energy generated from this type harvesting will be mill-watt (mW) to micro-watt (μW) [3]. The ultimate goal of all the research held in this field is to give power to the small electronic devices. Due to this we can reduce the need of external power source and as well as the maintenance needed do.

As researcher Lei Zuo and Xiudong tang [14] as said in their research on piezoelectric transducer , In 2008 research and development team of JR East group (East Japan Railway Company, 2008) have installed a piezoelectric series of energy harvesting transducers in floors of Tokyo station's Marunouchi north exit as shown in the Figure 1-1. as their study suggest that they can harvest energy from people walking on the floors can generate 10,000 W s/day, by energy which generate can power up-to 100W bulb for about 80 min, that can be said power which generated can age of power of 5.6 Watt in 24 hours. However, the experiment at the third week the power generation was reduced due to degradation of the piezoelectric transducer in durability.

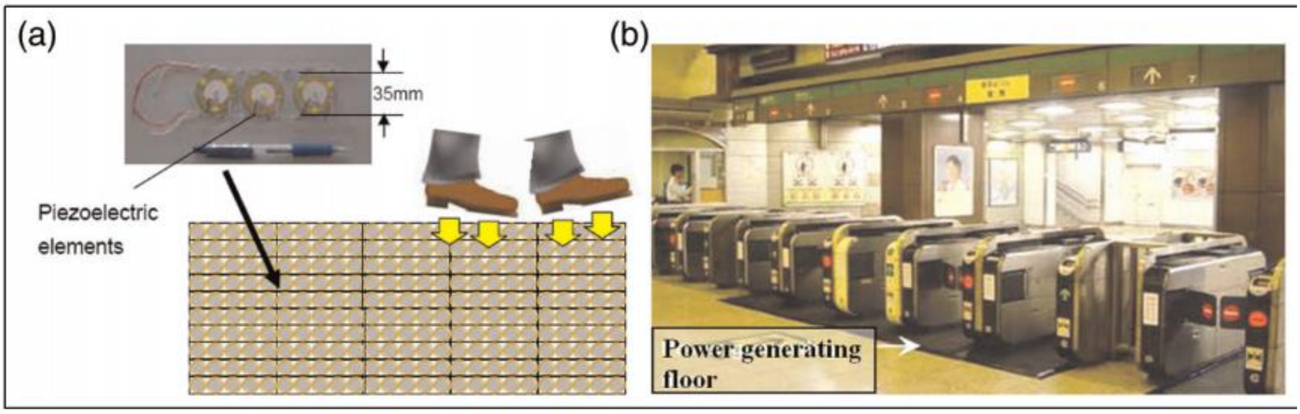

Figure 1-1 Energy harvesting through floor (a) Stacks of piezoelectric harvesting (b) Experiment setup at Tokyo station's Marunouchi North exit (East Japan railway company, 2008) [14].

1.2 Ambient energy harvest from piezoelectric material

As growth of research in ambient energy harvesting, The best method to harness ambient vibration into energy form for a micro system is piezoelectric transduction [1] .The concept of piezoelectric harvesting can be simplified as the ambient energy source example like sound vibration from moving train, vibration of industrial machine, where vibration can be detected from piezoelectric transducer, so piezoelectric transducer will be installed in the place of the vibration. As the vibration take place the piezoelectric will get deflected from the vibration due to the deflection a force or pressure on the piezoelectric material will start fluctuating due to this at molecular level an electric charge will be generated. The electric charge will be harvested by using an AC/DC converter, rectifier and using a storage component, the energy harvested from the piezoelectric will be a micro unit so it will be used to power the small electronic devices. The schematic represent as follows in Figure 1-2 .

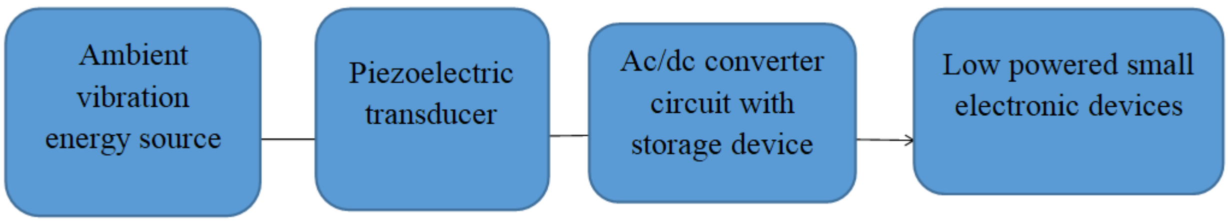

Figure 1-2 Schematic representation of piezoelectric harnessing concept

2 Theoretical background

2.1.1 Fundamentals of Piezoelectric material.

Piezoelectric material is type of smart material. Smart materials can be defined as material which stimulate quickly to a reaction in a specific manner and after the reaction the material will retract back to the previous structure which it was in before the reaction. There are different type of smart material shape memory, alloys magneto-strictness, hydro gels, elector active polymers and several others. Compare to other type source of harvesting energy piezoelectric material covers the larger area of power density to voltage [1] as shown in the Figure 2-1.The word piezo-electricity means electricity resulting from pressure and latent heat. It is derived from the Greek word piezein, which means to squeeze or press.

2.1.2 Working principle of piezoelectric transducers.

Piezoelectric transducer works on principle of piezoelectric effect. When a mechanical stress applies on certain plane of a transducer electricity will be produced which can be measured by electrical device like voltmeter. In piezoelectric there will be symmetric amounts of positive and negative charges as force applied on compression side there will be positive charges and on expanded side there will be negative charges. When a force is relieved the electronics current is produced.

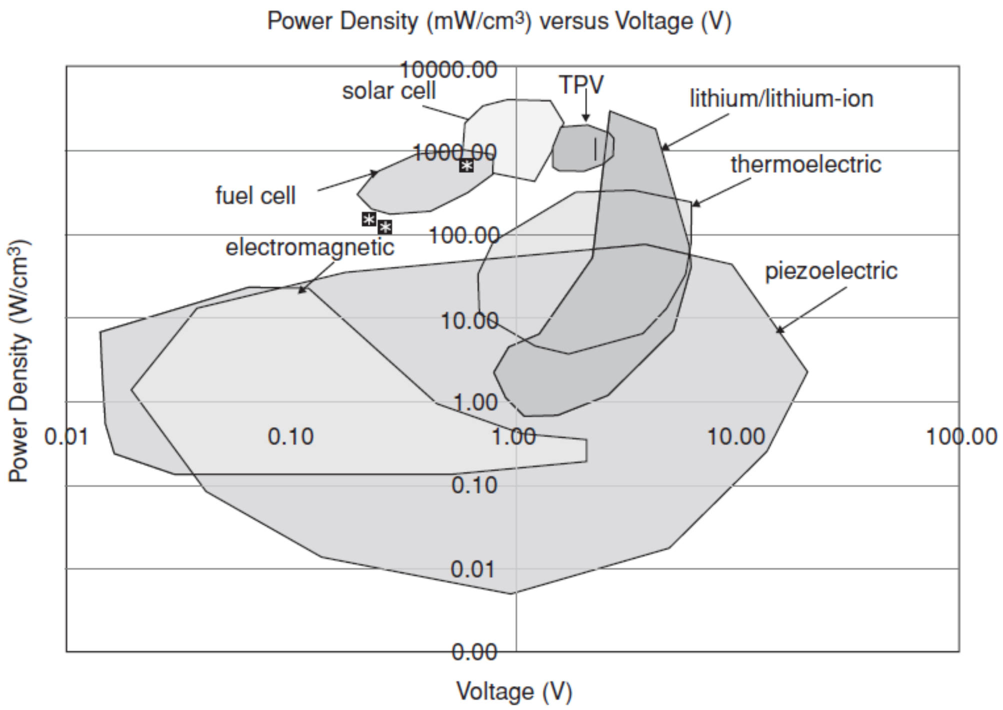

Figure 2-1 power density versus voltage comparison of common regenerative and lithium/lithium-ion Power supply strategies [1].

The three ways we can divide piezoelectric principle of operation.

- Transverse effect
- Longitudinal effect
- Shear effect

- **Transverse effect**

This effect happens when a force is applied along a neutral axis of the piezoelectric material displaces charges along the direction perpendicular to the line of the force applied to the material. The amount of charges depends on the dimension of the material

$$C_x=d_{xy}F_yb/a \tag{2.1}$$

Here C_x is the amount of the charge x is charges along the x axis , y is the neutral axis, a is dimension in with the neutral axis, b is in line with the charge displaced, F is the force applied and d is the corresponding piezoelectric coefficient.

- **Longitudinal effect**

The amount of electric charge displaced from the piezoelectric material is directly depends on the force applied to the piezoelectric material and its independent to the dimension of the piezoelectric material and the shape of the piezoelectric, And adding the multiple elements physically is series and electrically in parallel to improve the charge output.

$$C_x=d_{xx}F_xn \tag{2.2}$$

Here C_x is the amount of the charge, d_{xx} is the piezoelectric coefficient foe a charge, F_x is the a force applied and n is the number of stacked elements

- **Shear effect**

  The amount of charge displaced from the piezoelectric material can directly proportional to the force applied on the piezoelectric material orthogonal and its independent of the size of the piezoelectric material and elements of the piezoelectric, and adding the multiple elements physically is series and electrically in parallel to improve the charge output.

$$C_x=2d_{xx}F_xn. \quad (2.3)$$

Here C_x is the amount of the charge, d_{xx} is the piezoelectric coefficient foe a charge, F_x is the a force applied and n is the number of stacked elements [4]

2.1.3 Piezoelectric in mathematical description.

Piezoelectric transducer can be described in mathematical representation, Reference to Figure 2-2. refers to x axis, 2 represent to y axis, and 3 represent the z axis , the axis 3 represent of the polarization of the piezo-ceramic and axes1,2 are perpendicular to axis 3. The vector-mechanical linear piezoelectric equation can be represented by the equation as follows

$$\mathcal{E}i = S^{E}_{ij}\sigma j + d_{mi}E_m \quad (2.4)$$

$$D_m= d_{mi}\, \sigma_i+ \xi^{\sigma}_{ik}\, Ek \quad (2.5)$$

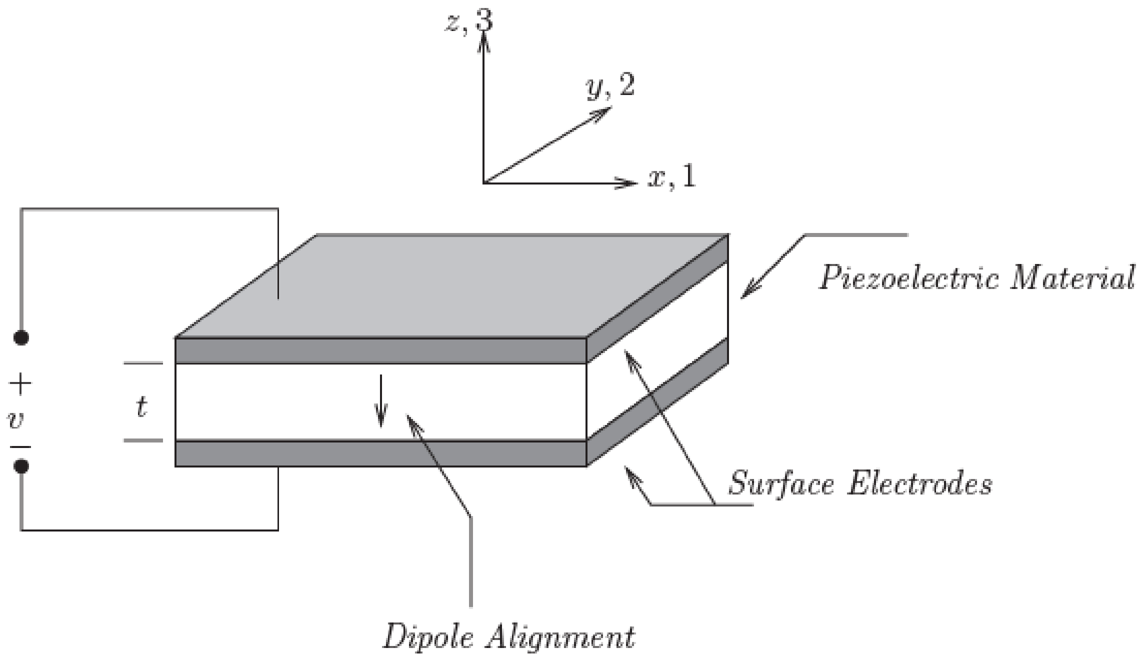

Figure 2-2 show the schematic diagram of piezoelectric transducer[15]

Here index are i , J = 1,2,…,6 and m, k = 1,2,3 refer to axis direction of the material coordinate system of transducer. σ represents the stress vector, Ɛ is a strain vector, E vector of applied electric field, ξ is permittivity, d matrix of piezoelectric strain constants, S matrix of compliance coefficients, D vector of electric constants, g matrix of piezoelectric constants[5].

The linear electrical behavior of the material

$$D=\varepsilon E \quad Di = \varepsilon ij.Ej \tag{2.6}$$

$$\nabla .D=0, \nabla *E=0. \tag{2.7}$$

Hooke's Law for linear elastic materials:

$$S=sT \quad Sij= sijkl\ Tkl \tag{2.8}$$

$$\nabla .T=0, S=\nabla u + u \nabla \ /2 \tag{2.9}$$

$$S=sT+\delta tE \tag{2.10}$$

$$Sij = sijkl\ Tkl + dkij\ Ek \tag{2.11}$$

$$Sij = sijkl\ Tkl + dkij\ Ek \tag{2.12}$$

$$D=\delta T+\varepsilon E \tag{2.13}$$

$$Di=dijk\ Tjk + \varepsilon Ej \tag{2.14}$$

In matrix form,

$\{S\}=[sE]\ \{T\}+ [dT]\{E\}$

$\{D\}= [d]\{T\}+[\varepsilon T]\{E\}$

In total, there are four piezoelectric coefficients, dij, eij, gij and hij defined as follows:

$$dij= (\delta Di/\delta Tj)^{E} = (\delta Sj/\delta Ei)^{T} \tag{2.15}$$

$$eij=(\delta Di/\delta Sj)^{E} = -(\delta Tj/\delta Ei)^{S} \tag{2.16}$$

$$gij= -(\delta Ei/\delta Tj)^{D} = (\delta Sj/\delta Di)^{T} \tag{2.17}$$

$$hij= -(\delta Ei/\delta Sj)^{D} = -(\delta Tj/\delta Di)^{S}. \tag{2.18}$$

2.1.4 Types of piezoelectric material

we can broadly classified as two types natural and synthetic The natural piezo electric are quartz, Rochelle salt, topaz, sucrose tendon silk, enema and several others.

Quartz is a mineral made up of silicon and oxygen atoms chemical composition is silicon-oxygen tetrahedral SiO_4. Quartz exhibit the piezoelectric potential upon applied of the force on the material. The resonant frequency will be changed upon applied mechanical force on it. The application can be found in analog clock.

Rochelle salt is a double salt also knows as potassium sodium tart-rate chemical formula is $KNaC_4H_4O_{6.}4H_2O$. It's commonly used in as transducers.

The synthetic type are Lead zirconate titanate, zinc oxide, barium titanate, potassium niobate and several others.

Lead zirconate titanate it's an inorganic compound type. The chemical formula is $Pb[Zr_xr_{1-x}]O_3$. This is also called as PZT mainly it's used in ultrasonic transducer and piezoelectric resonators, and is the most commonly used in industry as piezo ceramic.

Potassium obstinate it's a Dnepropetrovsk electrify crystals means it has spontaneous electric polarization. Chemical formula is $KNbO_3$ commonly used in making of lasers.

Comparing to natural and synthetic we can say that synthetic are largely displaced and give more electric voltage [2].

Table 1: Sensitivities of piezoelectric materials.

Material	Charge sensitivity s_q(pc/n)	Voltage sensitivity S_v(mV.m/N)
Lead zirconate titanate(PZT)	110	10
Barium Titanate	140	6
Quartz	2.5	50
Rochelle salt	275	90

Piezoelectric materials can also be categorized into two types

- **Piezo-ceramics** and
- **Piezo-polymers**

Piezo-ceramics

Piezo-ceramics are type of ceramics with vividly oriented grains should be ferroelectric to exhibit piezoelectric effect [3]. The macroscopic piezoelectric is a possible only when a texture of polycrystalline non-ferroelectric materials. This type of piezoelectric ceramics have vast electro-mechanical coupling constant and provide high conversation rate, the main disadvantage of this type of transducers are very brittle in nature and cannot be used in general dimension which can be used for the application the examples of piezo-ceramics are Lead zirconate titanate-5H,Lead zirconate titanate-8.

Piezo-polymers

Piezo-polymers are type of polymers it can said that it has nullity charged by bulk polymer and polymer composites, due to this material molecular structure piezoelectric response can be seen. There are two types of piezo-polymers one is amorphous form and another one is semi-crystalline form. The commonly used piezo-polymers are polyvinylidene fluoride(PVDF) and its copolymers such as polyimide and polyvinylidene chloride(PVDC). Due it nullity of charge a piezoelectric effect due to the charge induced by poling of a porous polymeric film. PVDF exhibits piezoelectricity several times greater than quartz but its 5-50 times less than PZT and complete piezoelectric characteristic of Lead zirconate titanate-5H (PZT-5H) Lead zirconate titanate-8 (PZT-8) and polyvinylidene fluoride (PVDF) is discussed in table 2 [6].

Table 2: Piezoelectric characteristics [6]

Coefficient	PZT-5H	PZT-8	PVDF
d_{31}	$-274x10^{-12}$m /V	-97	18-24
d_{32}	$-274x10^{-12}$m /V	-97	2.5-3
d_{33}	$593X10^{-12}$m /V	225	-33
d_{15}	$741x10^{-12}$m/ V	330	-
Relative permittivity e_{33}	3400	1000	-
Free-strain range	-250 to +850	µx	-
Poling field de	12kV/cm	5.5	-
Depoling field ae	12kV/cm	15	-
Density	7500kg/m^3	7600	-
Curie temperature	193^o	300	-
Dielectric breakdown	20kV/cm	-	-
Open circuit stiffness E_{11}	62Gpa	87	-
Open circuit stiffness E_{12}	48Gpa	74	-
Compressive strength	≥517Mpa	≥517	-
Compressive depoling limit	30Mpa	150	-
Tensile strength(static)	75.8	75.8	-
Tensile strength(dynamic)	27.6Mpa	34.5	-

2.1.5 Piezoelectric electrical properties

A piezoelectric transducer it has very high output impedance means it has high resistance to current flow but it can be molded into proportional to voltage source and it can also be used as filter network means it can reduce the unwanted frequency and increase the wanted ones. The voltage received from the piezoelectric can be said it's directly depends on the mechanical force applied to it only if passed through the equivalent circuit as shown in Figure 2-3. To use piezoelectric material as a sensor, the flat region of the frequency is used between the high pass cutoff frequency and the resonant peak.

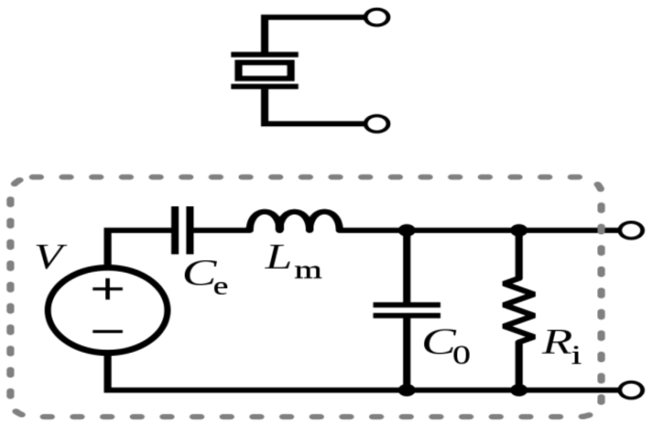

Figure 2-3 : Schematic symbol and electronic model of a piezoelectric sensor[15]

2.1.6 Energy harvesting with piezoelectric material.

Energy harvesting from piezo-ceramics.

In this section, we are going to discuss about energy harness from vibration energy using piezo-ceramics, encompassing coverage of the energy harnessing from piezoelectric transducer and methods of energy harvesting.

Cantilever type

This type of energy harvesting has easily build able structure and give output of a very large deformation under the force of vibration as per Flynn and sander [16]. Can be used to fundamental limitation of lead zicronate titanate (PZT) as per there results the mechanical stress-limited work cycle was 330W/cm^3 at 100kz for PZT-5H.

The commonly used everyday household are used to harvest energy experiment was conducted by Wright et al by using piezoelectric transducer, the experiment was conducted by using microelectronic mechanical system (MEMS) and piezoelectric transducer converters, they have showed the energy harvesting was very high in output and they simulated the a two layer bender mounted as a cantilever which can be harvest energy from low level ambient energy as shown in the Figure 2-4 [9].

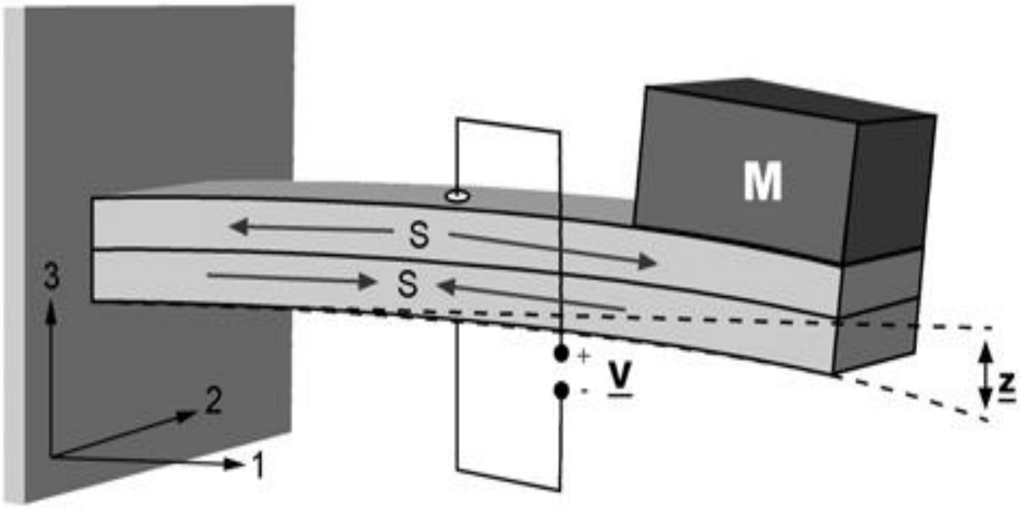

Figure 2-4 A two layer bender mounted as a cantilever [9].

A micro-machined silicon based proof mass were used by Shen [10] to harvest energy from PZT piezoelectric cantilever. The results for average power are 0.32W and power density is 416 W/cm^3. And also they built a series of power harnessing based on thick-film piezoelectric cantilever to get improved power and frequency changing, due to that they achieved the output of 3.98mW and electrical power of 3.93DC output voltage. Resonating at specific frequencies of external source of vibration can harness energy from piezoelectric effect.

M. Alves and J M Dias [17] also researched on piezoelectric device for measurements and power harvesting applications. In their study they conducted experiment using vortex flow on cantilever beam with using vortex mathematical from and vortex flow principle as shown in the Figure 2-5.

$$V = 1/S^{th}.f.d \quad (2.19)$$

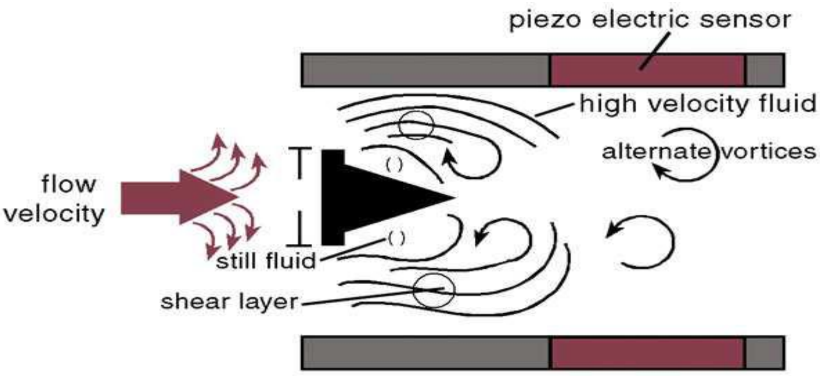

Figure 2-5: vortex flow meter principle using piezoelectric elements [16].

By using vortex as source of vibration on piezoelectric method they have concluded that the direct current voltage drop in each diode (0,7V). They have conducted on two variant of piezoelectric elements 1 with series configuration and another one with parallel configuration as shown in the Figure 2-6 and Figure 2-7.

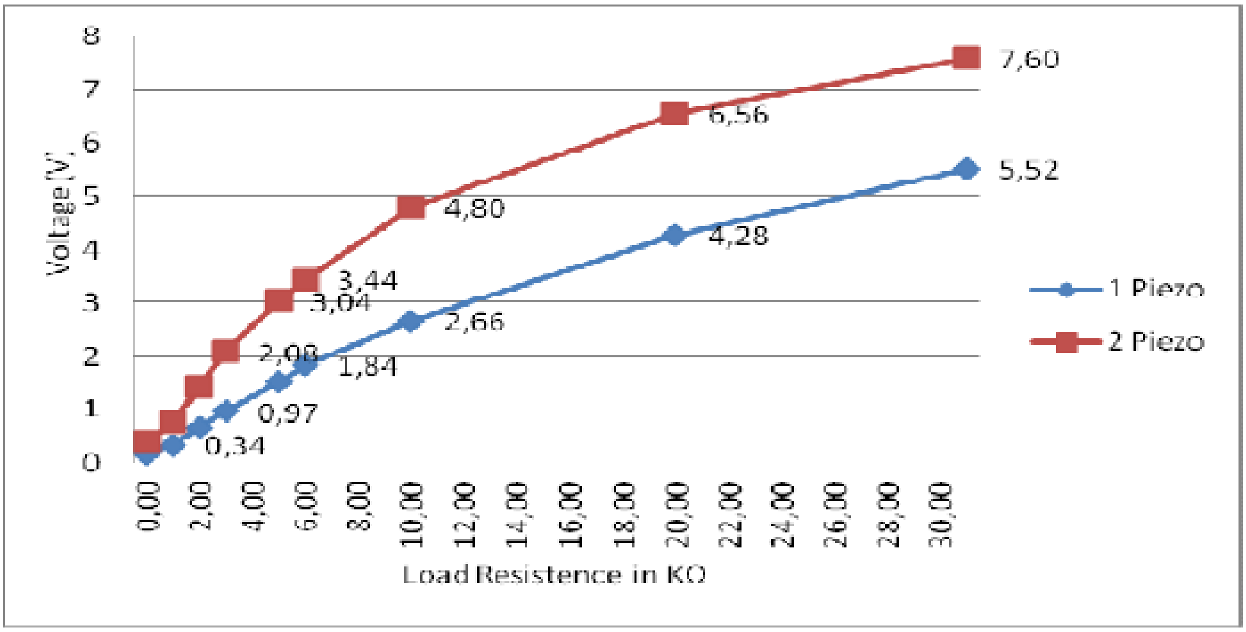

Figure 2-6: Output voltage in function of load value of 1-piezo of series configuration and 2-piezo as parallel configuration [16].

The harvesting behavior as a function of different type of loads impedance, making the amplitude constant. As they conclude change was been evaluated on the assembly beam of single and double bridge of assembled piezoelectric elements. The power increased in three fold for majority of loads.

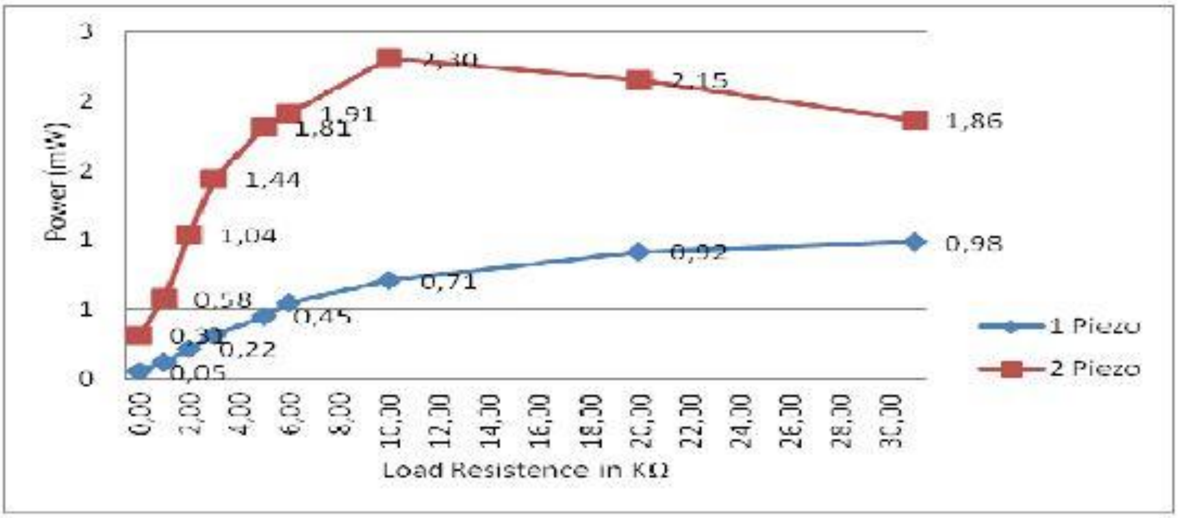

Figure 2-7: Output from harvesting energy from piezoelectric load

Cymbal type

This type of energy harvesting have structure like cymbal type has shown in the figure 5, cymbal type of structure can generate a strain which under a force of transverse from external source, by this force a low level energy harness can be harnessed. Under a cyclic stress cymbal can be a best solution to harness energy from piezoelectric material as shown by Kim [11] by using finite element analysis. They showed two ring type made of piezoelectric stacks, one pair made of elastic plates and a shaft that per-compressed as shown in Figure 2-8.

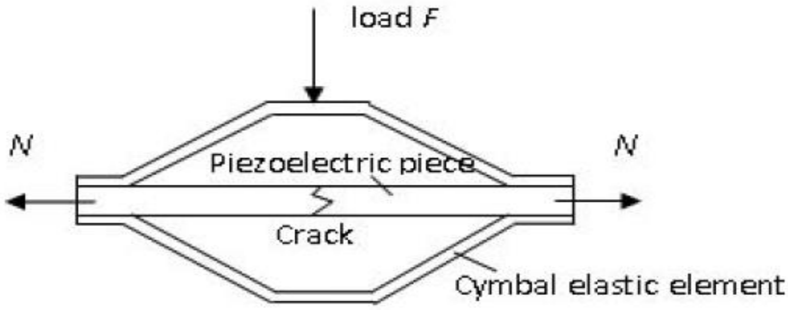

Figure 2-8: Shows cymbal method of harvesting[11].

He as conclude that various thickness of end caps using. The steel cap made of vey thinnest of thickness 0.3mm as given a more voltage output and the force applied on the material was controlled at same intensity. After force of more than 55N is applied on thinner end cap , the result shows that at output of power of 42mW can be harvested 400KΩ resistive load on applying cyclic force of 40N at 100Hz, as shown in the Figure 2-9 and in Figure 2-10.

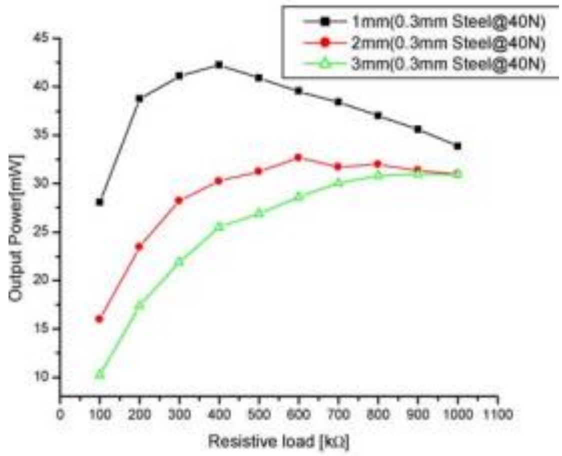

Figure 2-9: shows fixed ceramic thickness and different steel cap thickness

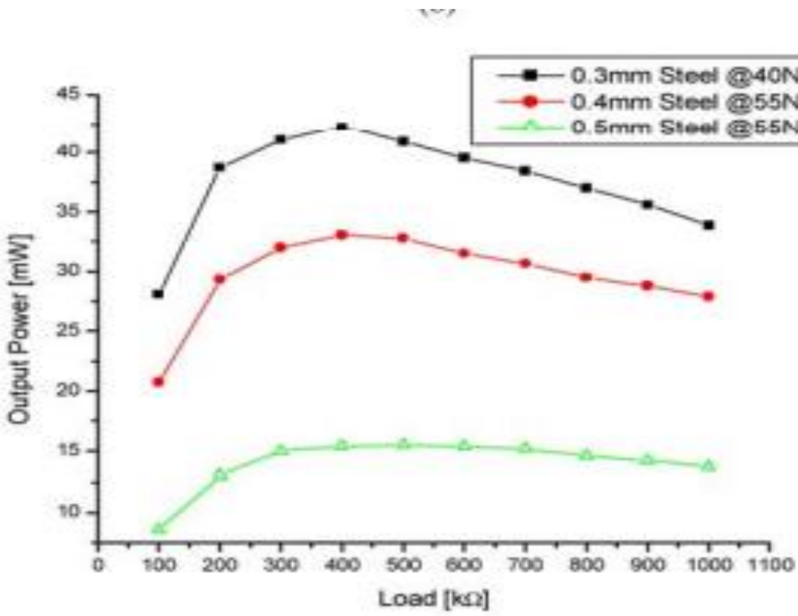

Figure 2-10: shows fixed ceramic thickness and different steel cap thickness

Stack type

Stack type of energy harvesting from piezoelectric has been conducted by Adhikari [18]. As he proposed stacking up of piezoelectric materials in multiple layers, Rather using traditional beam configuration to excitation at resonance and he has conducted two experiment cases one with inductor and another one without inductor in electrical circuit. Also he proposed a synchronized switch damping in energy harnessing from piezoelectric from vibrating structure as shown in the Figure 2-11 and they have results which conclude that stack type will become weak under a lot of stress and mechanical shocks.

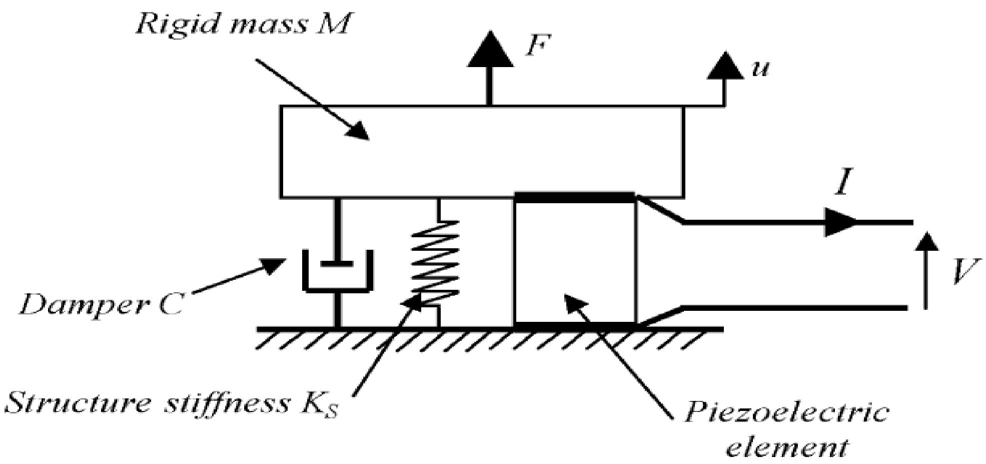

Figure 2-11: Represents of stack type vibrating structure including a piezoelectric element.

Shell type

Shell type of energy harvesting structure can be generate a very huge amount of strain compare to flat plate this experiment was conducted by Yoon [13] , due to strain the energy harvesting from the piezoelectric ceramics has improvised, By using mechanical strain as shown in Figure 2-12, for experiment they have used Lead zirconate titanate-5A (PZT-5A). This element is exposed by a shell shock to gunfire it was performed by using pneumatic shock machine. Results were found the harnessing of piezoelectric is directly proportional to load rate and its constant and energy transfer efficiency was depended on normalize impulse of shell shock.

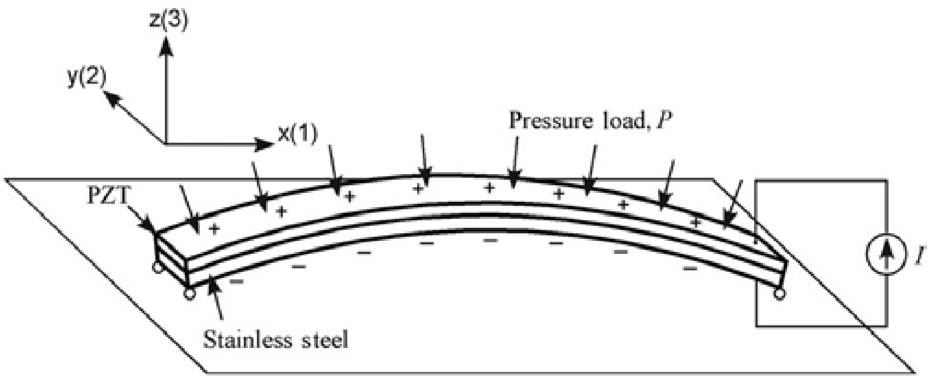

Figure 2-12: Represents a vibrating structure including a piezoelectric element.

As they evaluate that the energy harvested from the PZT-5A thickness is for beam s with similar length and different substance force applied was 22N and 445N and the thickness of material is 0.254mm thick substrate samples as shown in the figure 8, and 0.382mm thick substrate as three sample 1-a of dimension 71 mm in length, 8.45 mm in width, 1-b of dimension of 42.30mm in length, 11.5mm in width and 1-c of dimension of 25.8mm in length, 11.9mm in width samples as shown in the Figure 2-13, Figure 2-14.

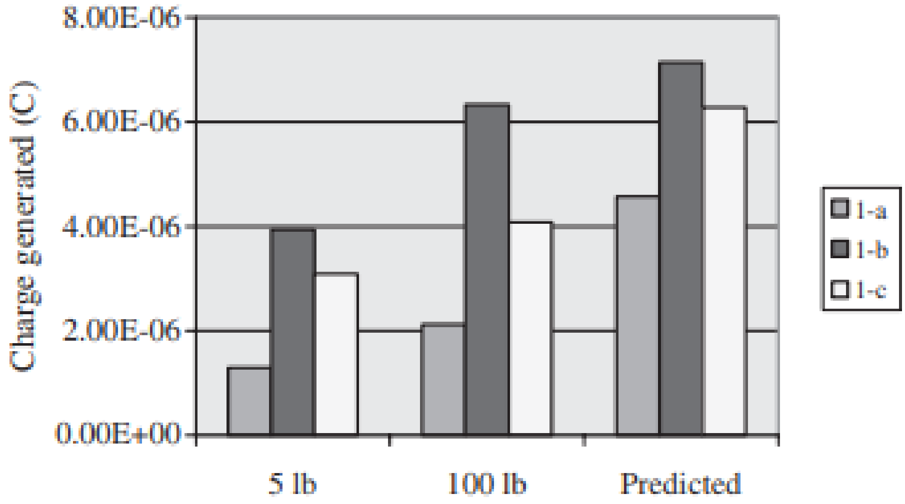

Figure 2-13 : Energy harvested on piezoelectric material of thickness 0.254 substrate sample

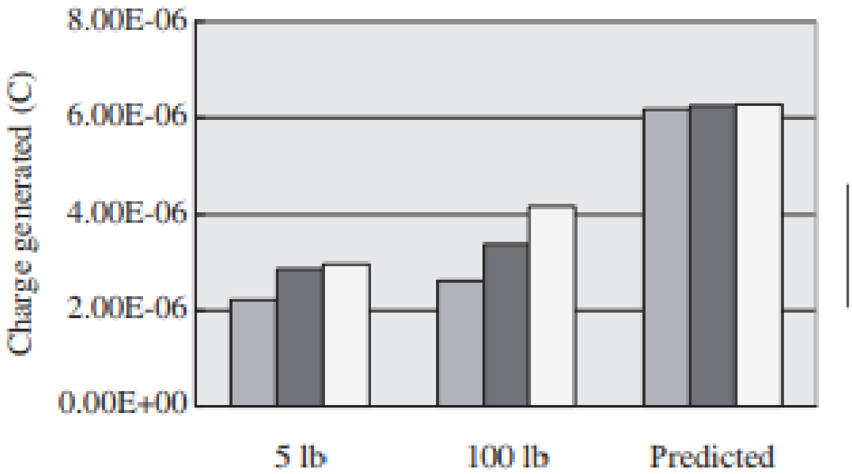

Figure 2-14 : Energy harvested on piezoelectric material of thickness 0.382 substrate samples

Single crystal

This method was conducted by Erturk[19]. In this he as analayzed single crystal of piezoelectric ceramic lead based magnesium niobate-lead zincronate titanate (PMN-PZT) reacts with power generation and shunt damping performance by his result on numerical and experiment based. Another researcher named Karami[28] as conducted experiment on comparison between PMN-PZT , PZT-5H,PZT-5A in a unimorph cantilevered beam and found that best deign for this kind lightweight energy harvesting and proved that single crystal energy harvester can give better result compare to poly-crystalline devices.

Energy harvesting from piezo-polymers.

A piezo-polymer film based power generation

Piezo-polymers are very flexible in nature. So Mateu and Moll[20] are used to harvest energy from it. They have analyzed by using several beams which is used bend like using in shoe inserts and walking-type excitation, and results were obtained on the results of strain for different type of geometrical dimension and material properties. As observed the energy harvesting, the optimum configuration on shoe insert as shown in the figure 2-15. as paper suggest they evaluated piezoelectric type magnitude of the excitation, energy consumed and power gain in voltage , they also conducted on the magnitude of the capacitor and voltage intervals.

Harvesting from backpack Strap from polyvinylidene fluoride(PVDF)

Granstrom, J., Feenstra, J., Sodano, H. A. and Farinholt, K [21] has developed a energy harvest from backpack using PVDF. The backpack can generate energy from the forces of human wearing and the backpack by using PVDF as shown in Figure 2-16. And they also conducted experiment on PVDF and the ionically conductive ionic polymer transducer, the analytical simulation based on spring and mass damper in axial loading and simulation results were evaluated by the experiment results.

Figure 2-15 The piezo-polymer insert in shoe.

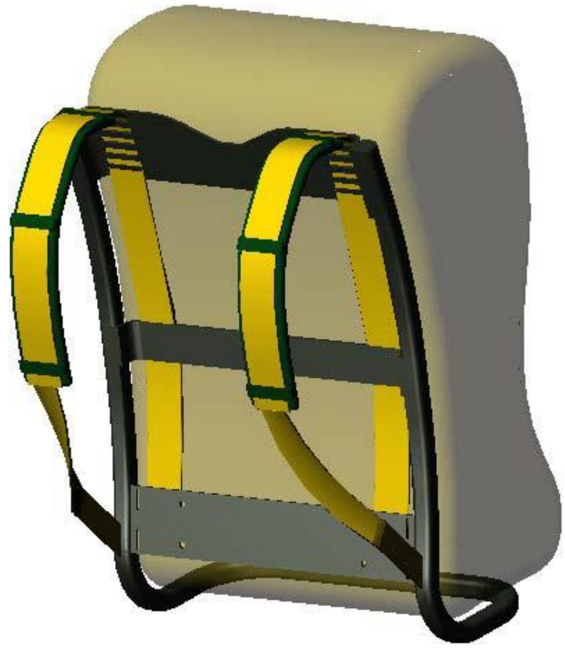

Figure 2-16: schematic of the backpack with piezo-polymer strap

Energy harvesting from Aluminum nitrate thin films

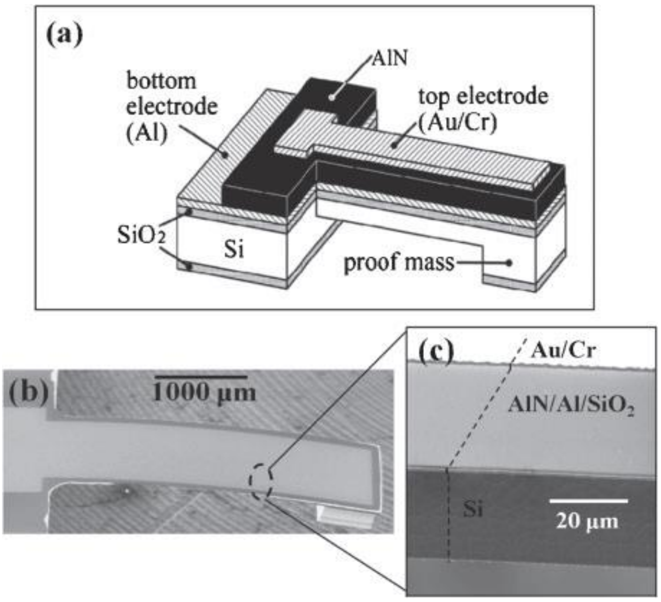

Figure 2-17 (a) Schematic view (b) general image and (c) lateral image of AIN energy harvesting

Aluminum nitrate(AIN) thin films are used to generate energy by Zhang, J. Y[22]. A AIN thin films on silicon substrates with diverse bottom electrodes containing of copper/chromium, lead/titanium to harvest energy form ambient energy by micro-machining process for converting environmental vibration to usable energy as shown in the Figure 2-17. And they also had experiment on PVDF and they come to conclusion that energy generated by unpacked in vacuum is almost twice the results of packed in vacuum at 0.5g acceleration.

Energy harvesting from PVDF nano fibers

Chang[23] used electro spinning's to PVDF nano fibers to harvest ambient energy. They have studied how to conserve a ambient energy into electrical energy, They conducted test to on two variant of PVDF film and PVDF fiber. They had several tests and experiment have conducted on this material in mechanical stretch and electrical poling characteristic as shown in the Figure 2-18, they have concluded that mechanical stretching, nano generators have significance of repeat ability and consistent voltage output with energy conversion efficiency this research shows that PVDF has lower magnitude compare to nano fibers [15].

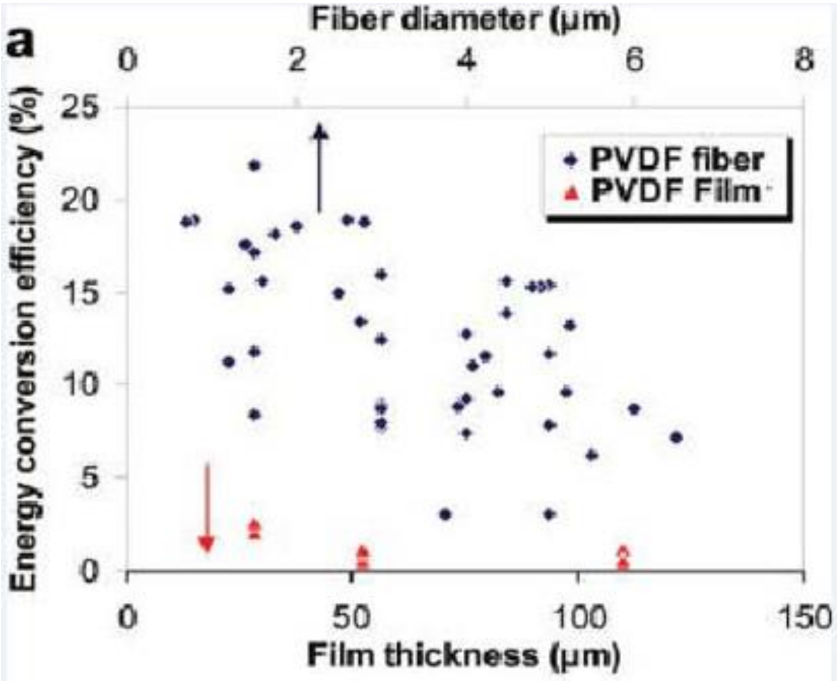

Figure 2-18 : Characteristic of energy conversion efficiency of a piezoelectric PVDF nanogenerator.

Energy harness from piezo-polymer using wind power

Researcher Oh [24] as built and simulated piezo-elastica energy harvester in laboratory. Using numerical simulation process and experimental measurements about tree based structure power system using PVDF to build leaf structure element, and to manufacture trunk of the tree PZT has been used as shown in the Figure 2-19. As wind blows the trees leaves will start waving, due to this motion energy has been harvested. And koyama and Nakamura[25] researched on polyuria thin film. Which coverts effectively a small vibration into electrical energy by using numerical element analysis of cantilever configuration.

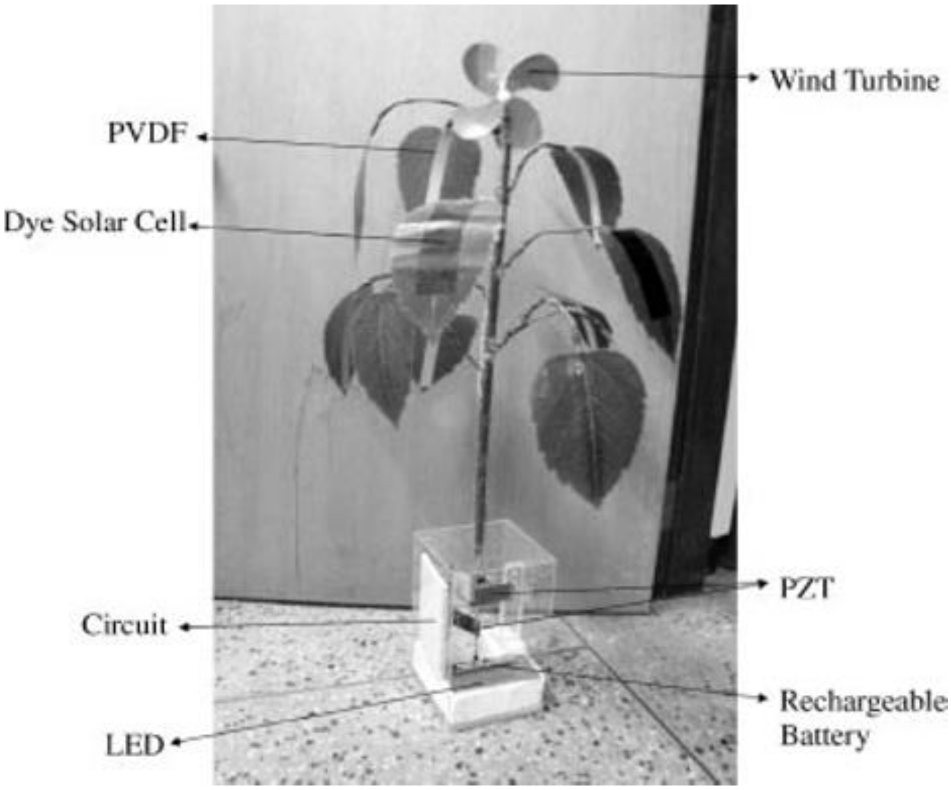

Figure 2-19: A Tree structured energy harness from piezo-polymers.

2.1.7 Piezoelectric transducer design

As per the application of the sensor the design of the sensor will be made. Commonly uses of sensor are to determine the pressure and the acceleration.

For measuring the pressure a thin membrane will be applied on massive base. To ensure that the load applied on the sensor will be uni-direction towards the element. For measuring the acceleration ,a proof mass will be applied on to the crystal element , when the material experience the acceleration using the Newton's second law of motion F=ma. The acceleration will be determined.

2.1.8 Piezoelectric application

The application of piezoelectric is vast in industries and manufacturing; main advantage of piezoelectric material is due to its low weight and small size factor.

High voltage and power source

Piezoelectric is used as high voltage due to its capacity of generating potential difference of thousands of volts. To generate a spark in gas stoves and cigarette lighters the piezoelectric crystals are used. Piezoelectric material is used in transformer, it's used to replace conventional transformers magnetic coupling between input and output by using acoustic coupling.

Sensor

Piezoelectric are used in sensor due to it can transfer the physical dimension into a force acts on two opposing faces of the sensing element. Detection of the pressure variation in the sound wave is the most widely used sensor application Microphones, acoustic guitars, contact microphone. And it's also used for diagnosis in medical field for non-destructive testing.

Actuators

Piezoelectric are used in actuators for its response to very small variation in the size of the element can lead to very high electric field. It's used in loudspeaker due its ability to covert electrical signal into mechanical movement.

Frequency standards.

Quartz crystals are used to make standard correction of quartz clock, this types of clocks uses direct and converse piezoelectricity to generate an array of electrical pulses that is can generate that can be marked preciously. The same principles are used to create clock pulse in computers and radio transmitters.

2.1.9 Energy harvesting circuit.

The method to create a optimized method to harvesting vibration energy from piezoelectric materials is very critical to develop a clean energy device. In nature of vibration piezoelectric energy harvesting devices are work on the force created from a mechanical vibrations with changing its amplitude of force, gives output of alternate current (AC) from piezoelectric transducer.

In recent time the attempt to use piezoelectric energy harvesting devices, energy output must be designed with a rectifier. There are several rectifier have researched and evaluated example vacuum tube diodes, mercury arc valves, silicon based switches and solid state diodes. The best way to rectify the alternative current input is to connect the transducer with P-N junction diode which can carry out function easily and only in half input wave [26].

To gain full-wave rectification of vibrating based piezoelectric harnessing device, a bridge-type with four numbers of diodes is placed in circuit. In order to improve the output of the device there are several studies have made by using buck-boost DC-DC converter which can track the power generators dependence with force induced by acceleration and vibration frequency as the study suggest the efficiency has increased by 84% as shown in the Figure 2-20.Also to improve the conversion efficiency of this kind bridge-type rectifying circuit, a synchronized charge was used also with inductor. Resulting the increase output of the energy harness by power factor of 4 as shown in Figure 2-21

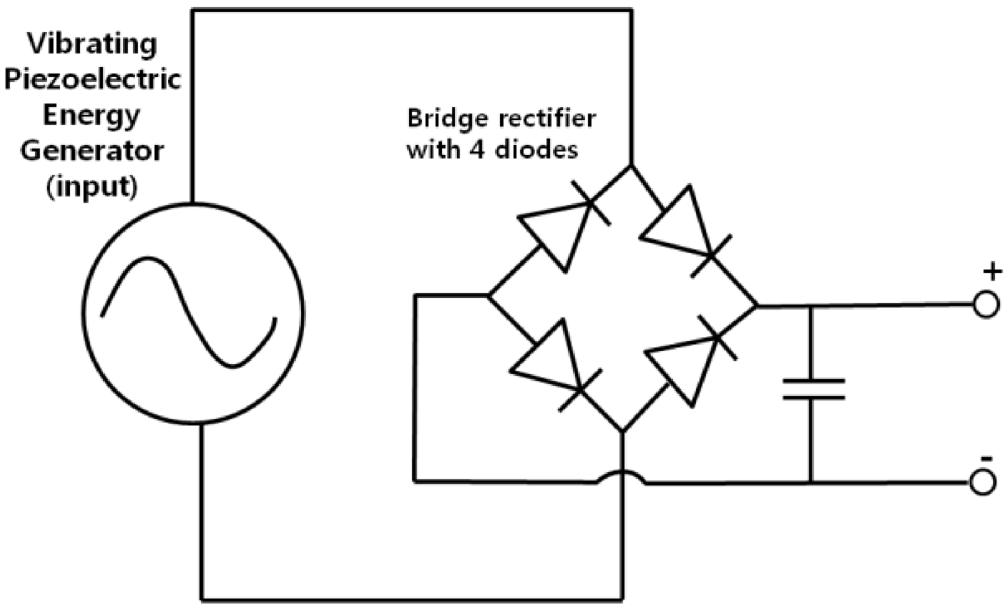

Figure 2-20: Full wave-bridge circuit[26].

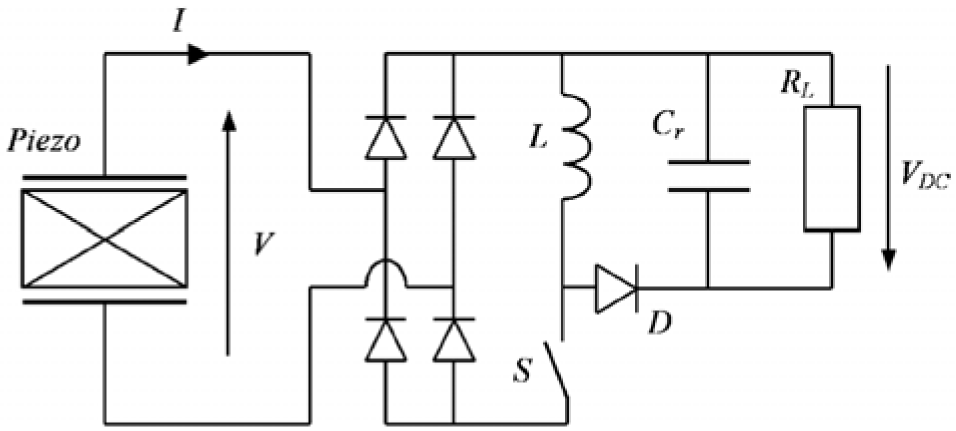

Figure 2-21 : Synchronous charge extraction with induct-or and switch[26].

Synchronized switch harvesting on Inductor.

A research named Guyomer[27] had researched about the real flow of energy that usually left in several energy conversion techniques like parallel synchronized switch harvesting on Inductor (SSHI) and series of SSHI of harvesting ambient energy of thermal variation called pyro electric effect this effect is energy harvesting from thermal source and converting it into the electrical power as shown in As he suggest 1.7mW is sufficient enough to carry a power for low power consumption sensors from spring- mass damper model as shown in the Figure 2-22.

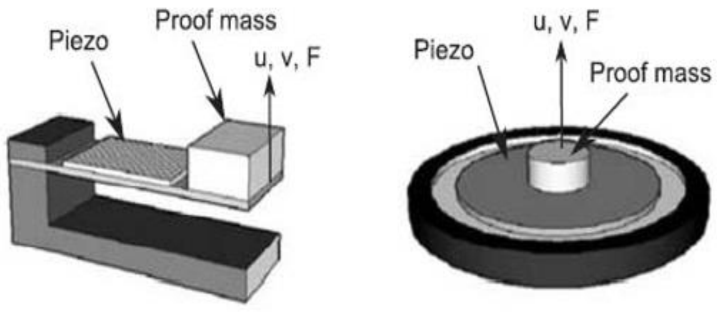

Figure 2-22: Electro-mechanical structures

2.1.10 Circuits and storage

Ayers[29] have conducted studies on PZT ceramics to store electrical energy and described the equation for piezoelectric. The energy capacitor can also be used as storage and rechargeable batteries was also discussed and evaluated were made for better and effective usage of battery recharging.

Guan and Liao[30] had researched on resistances leakage of the resistance of the energy storage capacitor. They said the most dominate factor of storage devices leakage can be influence the charging and discharging criteria, they have found an easy test method to conduct case study the charging and discharging efficiency of the storage devices using super capacitors.

Recent study on the storage rectifier of piezoelectric energy harvesting devices circuit been proposed by Kim[21]. He suggested the circuit the easy way and desirable, can give a output of more than 71% of conversion efficiency as shown in the Figure 2-23.

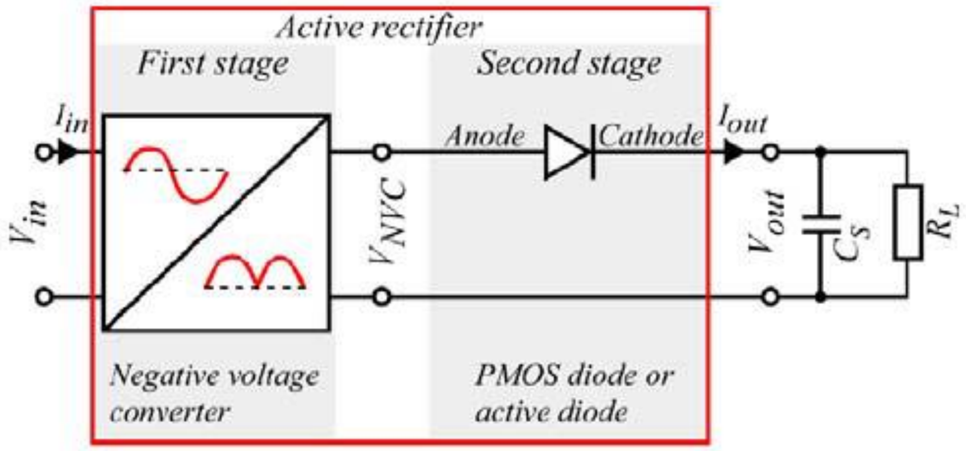

Figure 2-23: Two stage rectifying circuit for ultra-low input piezoelectric voltage

Peters[31] have suggested the stage two concept which have passive stage and one active diode, this achieve rectification of tens of micro-volts with higher efficiency up to 90% as shown in the.

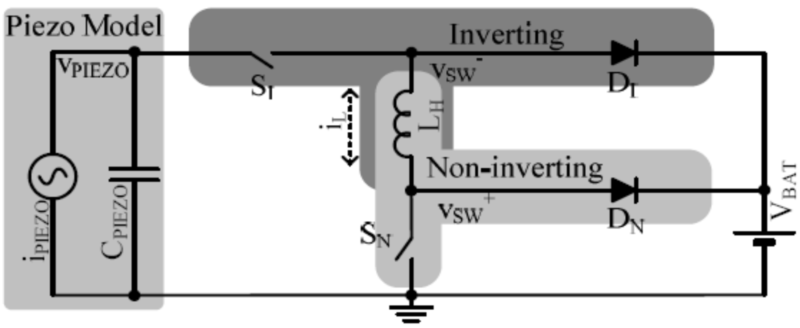

Figure 2-24: Represents a schematic circuit of rectifier- free piezoelectric energy harvesting.

2.2 Sound as energy

Sound is also known as acoustics, it is a form of mechanical energy produced by vibration. A sound wave is a propagation of oscillatory elastic and compression of wave which can be transferred the energy through matter or space. Sound wave can be a formed by vibration of a object it can said as a mechanically generated acoustic. Sound need medium to propagate such as air, water and solid, it travels in a longitudinal waves and transverse wave.

Longitudinal waves are waves which flows in the direction of the medium or opposite direction of the wave propagation and it's also called as compression wave, because they produce by compression when traveling through medium due to this they produce high and low waves due to low and high waves they produce decrease and increase in pressure. Transverse waves are a wave which flows in the perpendicular direction of the medium or right angle direction of the wave propagation and it also called as shear wave.

The behavior of sound propagation can be affected by three relationships.

- A relationship of density and pressure can be affected by temperature and the speed of sound in the medium which sound is travelling.
- The movement of medium can also determine the sound behavior , the movement can increase or decrease the speed of sound depends on the direction of movement of the medium.
- Viscosity of the medium. Sound can be affected due to the viscosity of the medium it can decrease the speed of the sound.

2.2.1 Speed of sound

The speed of sound depends mainly on the wave which its propagating through, the speed of sound in a particular substance was equal to the square root of the pressure acting on it dived by its density was said by Isaac Newton

$$c=\sqrt{p/\rho} \quad (2.20)$$

Here p is pressure, c is the velocity of sound and ρ is the density

The equation was later improvised by Laplace.

$$c=\sqrt{\gamma . p/\rho} \quad (2.21)$$

$$c=\sqrt{K/\rho} \quad (2.22)$$

Here k is elastic bulk modulus

2.2.2 Sound energy mathematical definition

Sound energy density can be denoted w

$$w = pv/c \quad (2.23)$$

Here p is pressure, v is velocity and c is speed of sound.

Sound energy density can be defined as the ratio of sound incidence as a sound energy value in comparison to reference level

$$L(E)= 10 \log_{10}(E_1/E_0) \text{ dB} \quad (2.24)$$

Here L(E) is energy produced by vibration , E_1 and E_0 are the energy densities, dB is the density level in decibel

Reference of sound energy density of

$$E_0=10^{-12} \text{ J/m}^3 \quad (2.25)$$

Sound intensity can define as product of pressure and particle velocity.

$$I=pv \tag{2.26}$$

Here I is intensity of sound, p pressure and v is velocity.

Sound intensity level can be defined as

$$L_I=1/2 \ln (I/I_0)dB \tag{2.27}$$

Here I is sound intensity, I_0 is the reference sound intensity, Np is neper.

2.2.3 Amplification of sound

As we already discussed the power output of piezoelectric transducer is directly proportional on the pressure or force applied to it. For study we are sound as source of vibration to create a pressure or force on piezoelectric. So to improve the output of piezoelectric transducer there are several methods are there to amplification the sound. The methods are whispering galleries, Echo focusing, Room acoustic.

Whispering galleries are type of sound amplification is mostly constructed in the form of circular walls and it allows sound wave to flow from one place to another point in the side of the circumference and this type of waves are called whispering gallery waves as shown in the figure 2.25. This type of acoustic waves are used to inspect in nondestructive type of testing

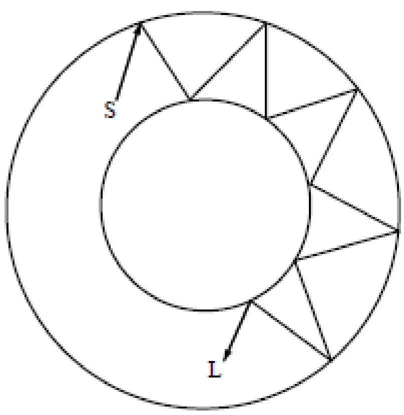

Figure 2-25 the whispering galleries.

Echo focusing is another type of sound amplification method. In this method the sound waves are focus in coherent plane waves by using a parabolic reflector. Parabolic reflector is a type of reflector it collects the energy from the source and reflects back by making coherent wave, parabolic reflector will be designed in circular parabola shape as shown in figure 2.26.

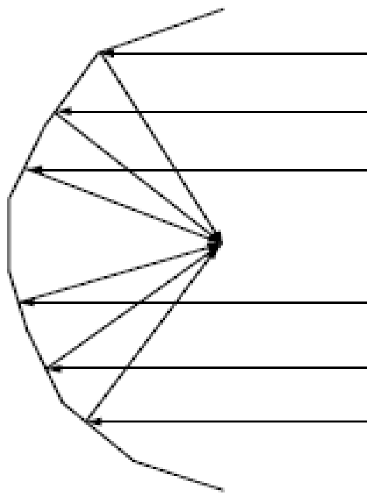

Figure 2-26: Echo focusing.

3 Experimental work.

As discussed before, the purpose of this experiment is to harness energy from the piezoelectric transducer using sound as source. To do so, sound was induced on piezoelectric buzzer by using a speaker. The induced sound pressure level was measured by a microphone, while the voltage generated by the transducer was measured by means of voltmeter with help of full wave rectifier circuit. Experiment setup arrangement as shown in the Figure 3-1, actual setup at laboratory is represented by Figure 3-2.

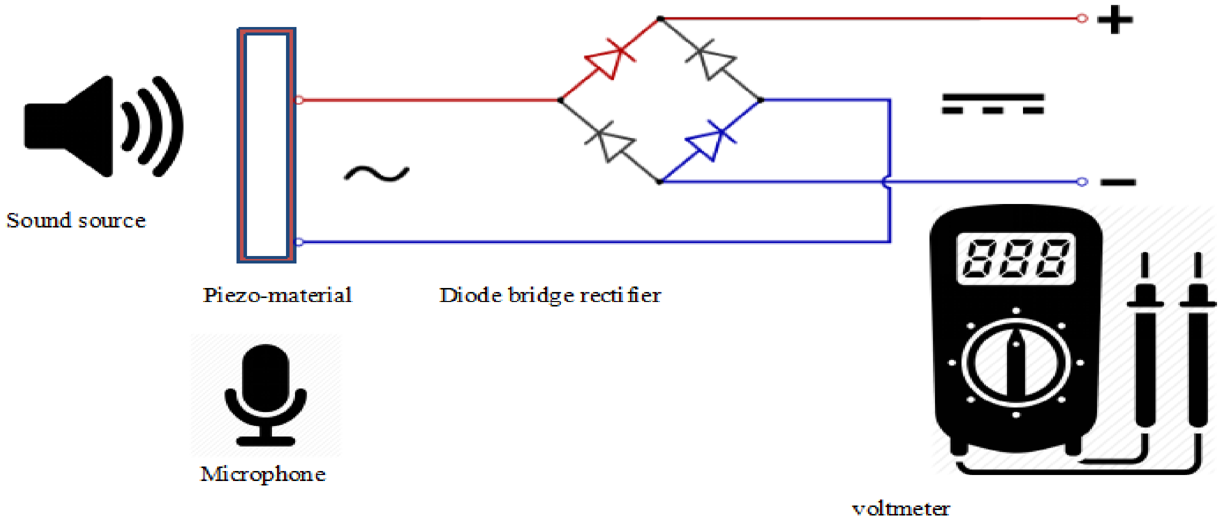

Figure 3-1 : Schematic representation of experiment setup

Figure 3-2: Actual setup layout in the laboratory.

3.1 Experiment setup.

3.1.1 Piezoelectric material specification

The experiment has been conducted using piezodelectro buzzer element made up of brass which had a dimension of 50mm diameter round as shown in the Figure 3-3and Figure 3-4 . The weight of the element had 3 gram. Resonant impedance of 3500 ohm max, the maximum input voltage 30V and resonant frequency at 1.2±0.2 KHz.

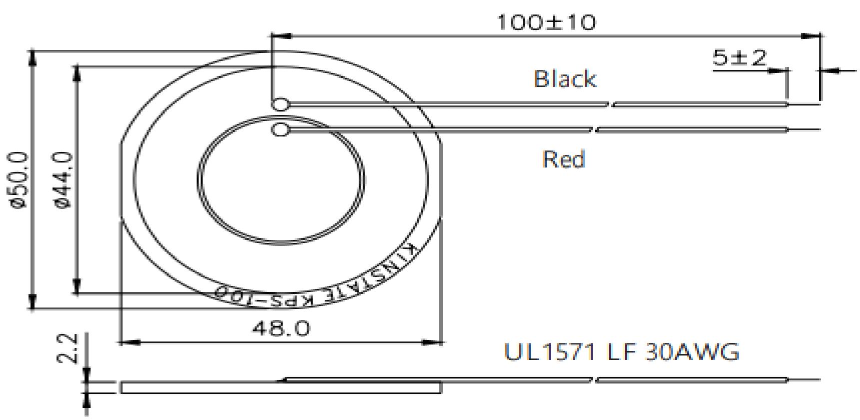

Figure 3-3: shows the appearance drawing.

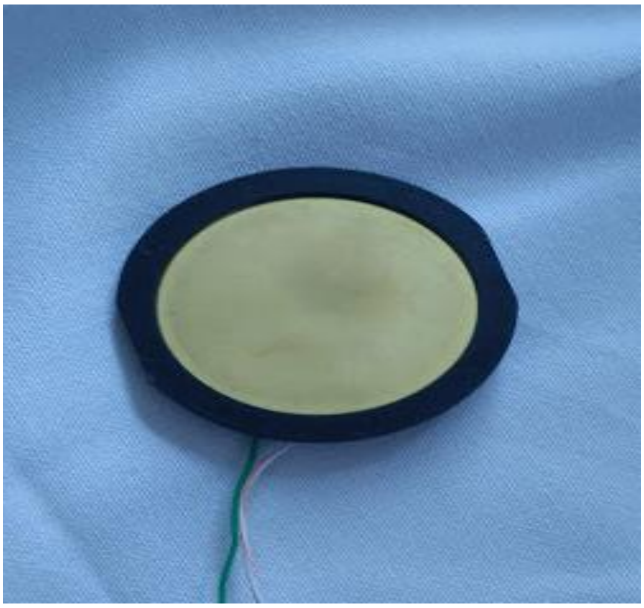

Figure 3-4: The piezdelecto buzzer element:Brass

3.1.2 Piezoelectric transducer holder

To hold the piezoelectric transducer a holder had been designed and manufactured to have accurate measurements. Design was made in auto-cad, Holder had précised position to held piezoelectric transducer, it had the stand structure to support the piezoelectric transducer to stand still at midair opposite to sound source as shown in the Figure 3-5 and Figure 3-6.

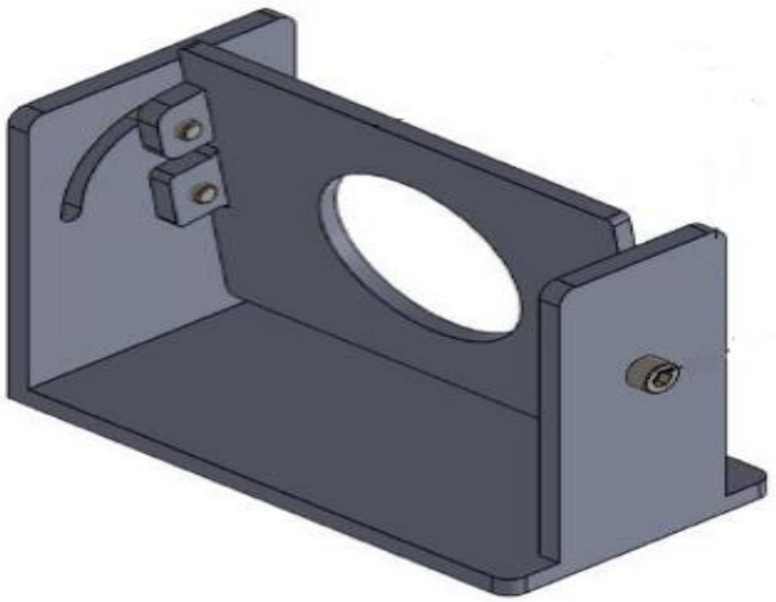

Figure 3-5 : Holder cad designed

Figure 3-6 : Holder manufactured

The construction of the holder had two main parts, Stand and piezoelectric holder.

The stand of the holder was constructed in shape of U, it had two holes which can hold the piezoelectric holder in fixed place at a single fixation and above the single fixation a indexing slot cut was made, This slot was made to have access to index the piezoelectric element as per the condition of the experiment, another advantage of this slot was to a hinge mechanism so it can piezoelectric can be rotated at in singular fixation and can fixed at variation angle needed for the experiment as shown in the Figure 3-7 and Figure 3-8 Dimension of the holder was 150mm in width, 106 mm in height, 80mm length and it was manufacture by using 5mm thick mild sheet metal.

Piezoelectric holder has dimension 130mm in width, 100mm in length and it was manufactured by using 5mm thick mild steel metal. The piezoelectric holder had three wings kind a structure two of them were aligned in same axis this axis was bolted in singular fixation of stand and one wing kind structure had M6 tapped hole which was used to operate the holder in indexing slot. As Shown in the Figure 3-9 and Figure 3-10.

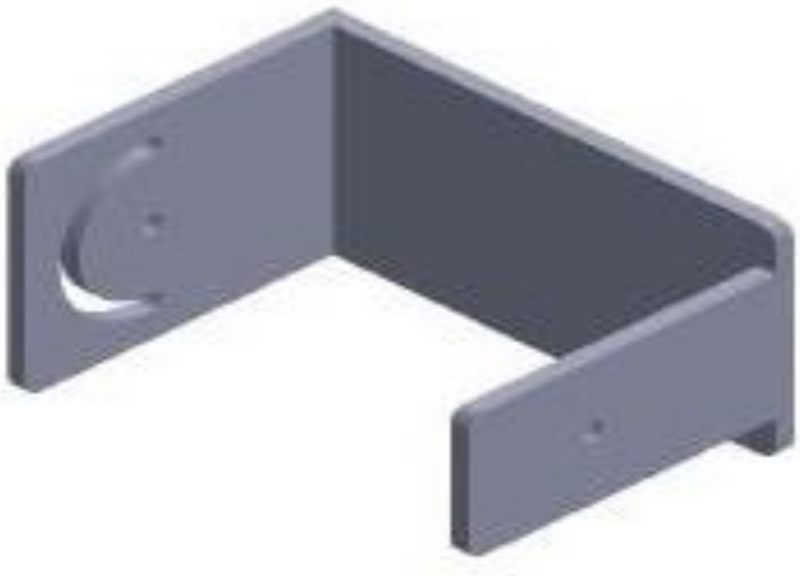

Figure 3-7 Cad model of the stand

Figure 3-8 : Manufactured part of the stand

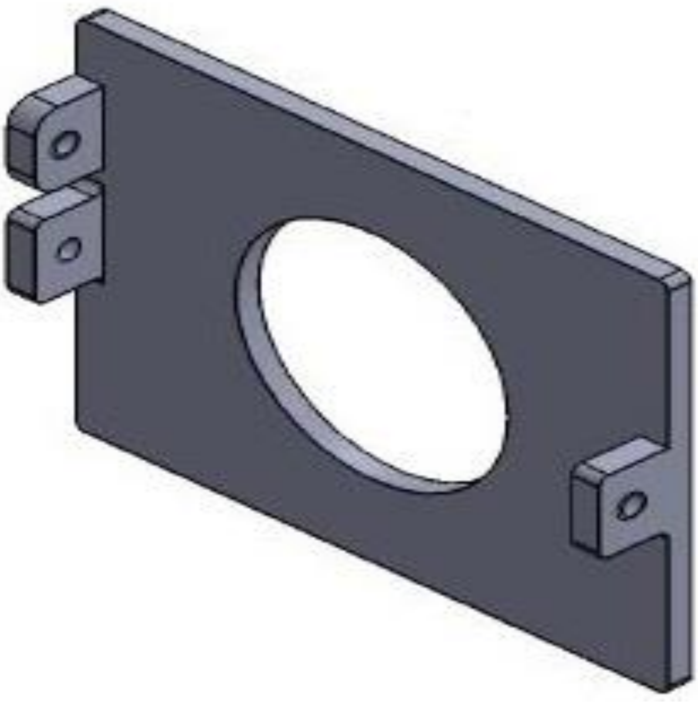

Figure 3-9 : Cad design of piezoelectric holder

Figure 3-10 Manufactured part of piezoelectric holder

3.1.3 Sound source

As we discussed about the sound and using sound as source of vibration to harvest energy from the piezoelectric. To obtain optimum energy from the piezoelectric Jbl charge3 a portable bluetooth speaker had been used which had transducer 2 times of 50mm diameter , frequency response of 65Hz to 20kHz, signal to noise ratio of greater than 80dB, dimension of 213mm in width, 87 in diameter, 88.5 in height as shown in the Figure 3-12. Study had been conducted by playing a particular sine wave frequency at full volume of speaker from laptop using frequency generator [18]. Finally, to measure the sound a microphone of a Bruel and Kajer 2250 was mounted as shown in the Figure 3-11.

Figure 3-11: Brüel & Kjær type 2250

Figure 3-12: Shows the Jbl super charge Bluetooth portable speaker

3.1.4 Amplification of sound.

It was interesting to study the effect of sound amplification by the reflection on the results. There we have used an egg tray to enclose the experiment setup. two types of en-closer has been used first setup with dimension of width of 285mm, height of 285mm and length of 285mm as shown in Figure 3-13, and second setup had a dimension of width of 570mm, height of 285m and length of 285mm as shown in the Figure 3-14.another main advantage of en-closer is noise cancel of surrounding noises.

Figure 3-13 En-closer

Figure 3-14 : Enlarged size of an en-closer setup

3.1.5 Electric circuit.

To harness voltage from piezoelectric transducer, As voltage output of transducer is very less and to eliminate polarity, Due to this reason we had used a full wave rectifier circuit, the circuit is an arrangement of four diodes in a form of bridge circuit, this configuration gives the output of same polarity to the given polarity input and it also converts the alternating current to direct current. This is an open circuit type in this we can generate only voltage, which means no energy is generated, the schematic representation is as shown in the Figure 3-15.

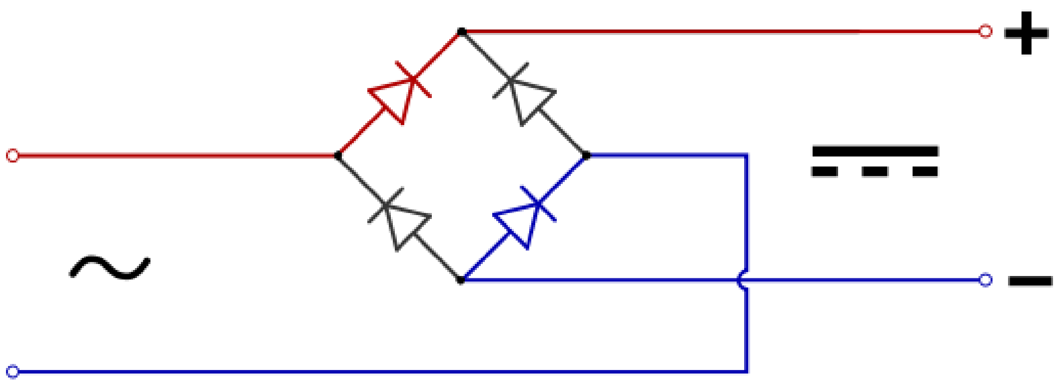

Figure 3-15 Schematic representation of full wave rectifier.

3.2 Experiment procedure

As was discussed before, sound was played from a laptop, pressure level was measured by microphone and the voltage was measured by voltmeter. The performance of piezoelectric buzzer depends on the frequency of incident sound. Therefore, the piezoelectric buzzer material was experimented at different frequency and we have found that at 529 Hz output voltage was at optimum.

The experiment conducted at studying the effect of each case as follow:

- Piezoelectric transducer is set away from sound source at ascending distance by 10mm.

  This case was studied to study the performance of transducer material. By keeping the transducer material step by step distance of 10mm from the source of sound

- Piezoelectric transducer is rotated at different angle.

  In this method we try to understand the material output voltage by changing the material orientation angle towards the source of sound.

- Piezoelectric transducer is set away from sound source at ascending distance by 10mm by capsuled in an en-closer

  An en-closer method was used in this case to increase the reflection of the sound towards transducer and to study the result.

- Piezoelectric transducer is set away from sound source at ascending distance by 10mm by capsuled in an enlarged size of an en-closer.

  In this case the en-closer was enlarged in size to know whether reflection of the sound would increase the piezoelectric output due to the enlarged size.

- Two piezoelectric transducers are connected in parallel in en-closer.

  In this case two piezoelectric transducers is used in an enclosed to obtain optimum value of a transducer by using en-closer

3.2.1 Case 1: Piezoelectric transducer is set away from sound source at ascending distance by 10mm.

As discussed before this case was conducted to study the piezoelectric buzzer at varying distance from sound source. To do so the frequency, sound intensity level and angle of piezoelectric buzzer were kept constant throughout the study and procedure is as follows.

Preset-up of experiment.

1. Sound source was kept 20mm away from the piezo material.
2. Frequency of the sound was played at 529Hz frequencies.
3. Sound source was played at maximum volume at 98 dB which was measured by microphone.

After preset-up of experiment conducted is done as above. From speaker sound was produced by playing through laptop. Piezoelectric buzzer was distanced from the source at an incremental of 10mm from sound source at each incremental voltage was measured from voltmeter as shown in the Figure 3-16 .

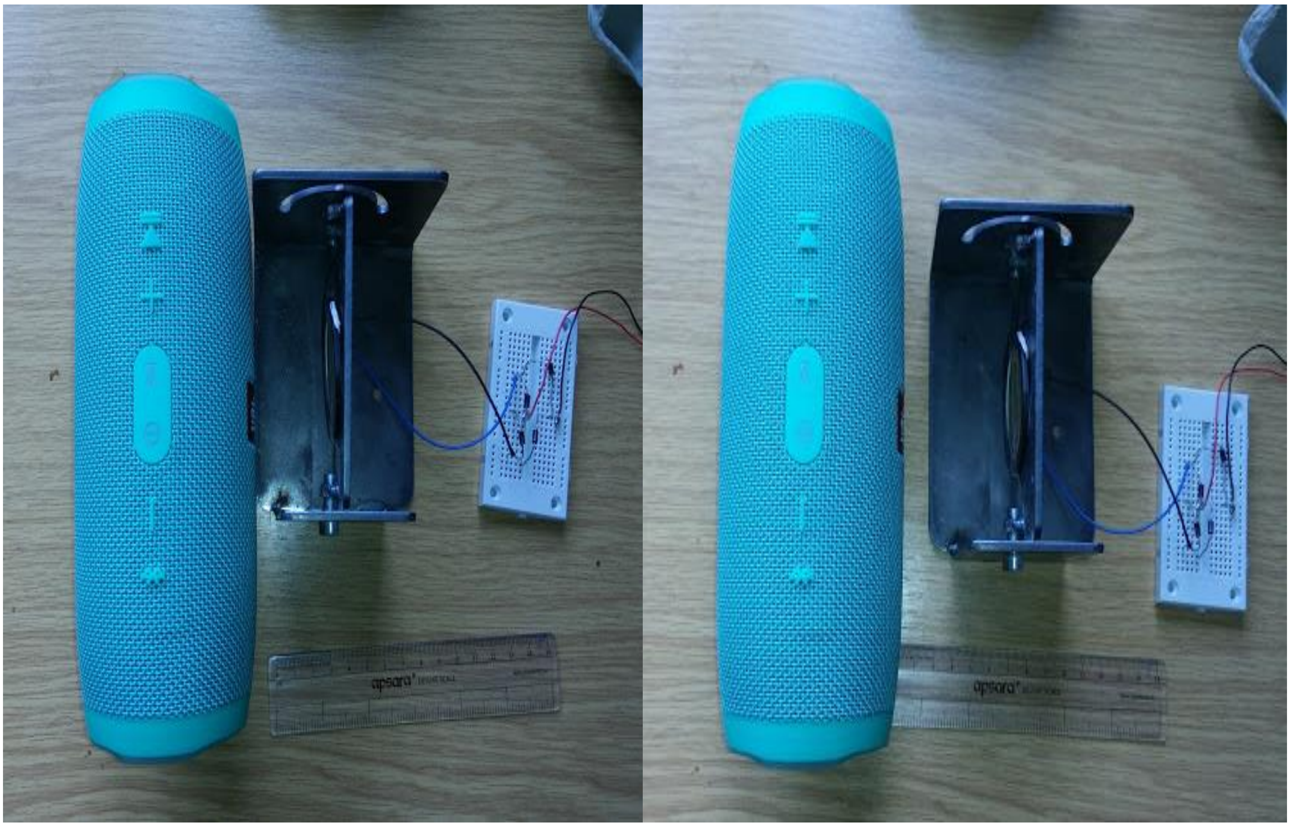

Figure 3-16 : Experiment setup of piezoelectric buzzer with ascending distance from sound source.

3.2.2 Case: 2 Piezoelectric material is rotated at different angle

As discussed before this case was conducted to study the piezoelectric buzzer at varying angle towards source of sound. to do so the frequency, sound intensity level and distance of transducer from sound source were kept constant throughout the study and procedure is as follows.

Preset-up of the experiment

1. Sound source was kept 20mm away from the piezoelectric buzzer.
2. Frequency of the sound was played at 529Hz frequency.
3. Sound source was played at maximum volume at 98 dB which was measured by microphone.

After the preset-up of the experiment is done as per above conditions. Sound was produced from the speaker with the help of the laptop. Piezoelectric transducer was tilted by incremental of 22.5 degree from 45 degree normal towards source to 135 degree away from the source. To tilt the piezoelectric transducer used the knob provided in the stand. At each incremental of the piezoelectric buzzer of 22.5 degree the voltage is measurement was noted down using voltmeter as shown in the Figure 3-17.

Figure 3-17: Piezoelectric buzzer change in its angle of tilts.

3.2.3 Case 3: Piezoelectric transducer is set away from sound source at ascending distance by 10mm by capsuled in an en-closer.

As we said earlier this case is studied to understand the piezoelectric buzzer performance under an en-closer, the enclose was used to increase the reflection of the sound, to do so frequency, angle and sound level was kept constant and the procedure was conducted as follows.

Preset-up of the experiment

1. Sound source was kept 20mm away from the piezoelectric buzzer
2. Frequency of the sound was played at 529Hz frequency.
3. Sound source was played at maximum volume at 98 dB which was measured by microphone.
4. En-closer should be set up by closing all the six sides of the experiment setup as shown in the Figure 3-18.

After the preset-up of the experiment is done as per above conditions. Sound was produced from the speaker with the help of the laptop. Piezoelectric buzzer was distanced from the source at a incremental of 10mm from sound source at each incremental voltage was measured from voltmeter. For each incremental reading the en-closer was opened, changed the position of the piezoelectric buzzer and closed the en-closer before stating the experiment.

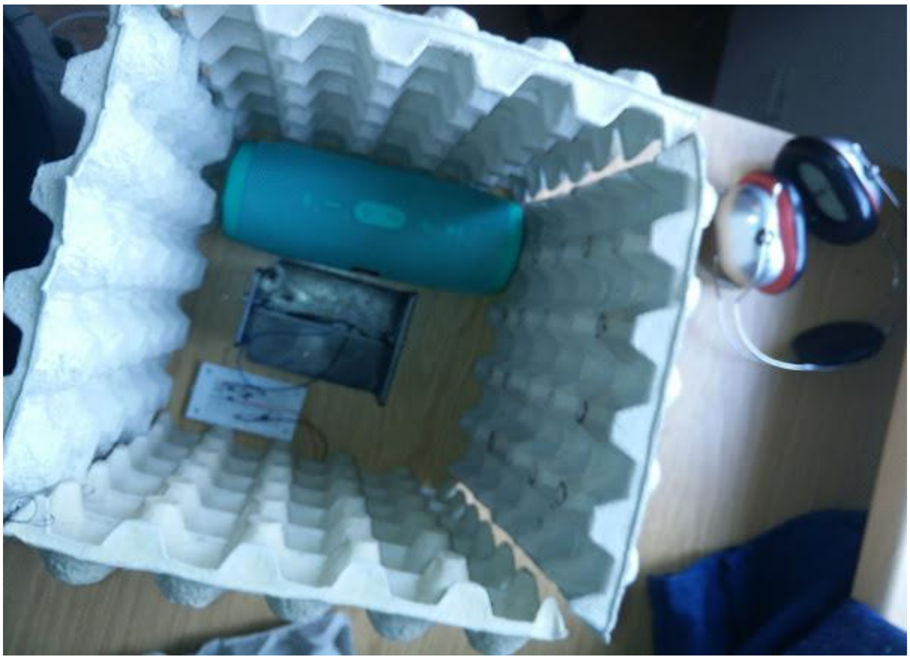

Figure 3-18: Piezoelectric buzzer in an en-closer with change in its position

3.2.4 Case 4: Piezoelectric transducer is set away from sound source at ascending distance by 10mm by capsule in an enlarged size of an en-closer.

As we discussed earlier this case was conducted by increasing the en-closer size, to understand the performance of piezoelectric buzzer. To do so, the experiment was conducted at constant angle of piezoelectric buzzer, frequency and sound level was kept constant, And procedure is as follows.

Preset-up of the experiment

1. Sound source was kept 20mm away from the piezoelectric buzzer.
2. Frequency of the sound was played at 529Hz frequency.
3. Sound source was played at maximum volume at 98 dB which was measured by microphone.
4. Enlarged size of an en-closer should be setup by closing all the six sides as shown in the Figure 3-19.

After the preset-up of the experiment is done as per above conditions. Sound was produced from the speaker with the help of the laptop. Piezoelectric transducer was distanced from the source at an incremental of 10mm from sound source at each incremental voltage was measured from voltmeter. For each incremental reading the en-closer was opened, changed the position of the transducer and closed the en-closer before starting the experiment.

Figure 3-19: Piezoelectric buzzer in an enlarged en-closer setup.

3.2.5 Case 5: Multiple Piezoelectric transducers is connected in parallel and it is set away from sound source at ascending distance by 10mm by capsuled in an en-closer.

This case was studied to understand the optimum output of two same piezoelectric buzzers at an en-closer. In this method the piezoelectric buzzer angle towards sound source, frequency and sound level was kept constant, And experiment procedure as follows.

Preset-up of the experiment

1. Sound source was kept 20mm away from the two piezoelectric buzzers connected in parallel.
2. Frequency of the sound was played at 529 frequency.
3. Sound source was played at maximum volume at 98 dB which was measured by microphone.

Enlarged size of an en-closer should setup by closing all the six sides as shown in the figure 3-20.

After the preset-up of the experiment is done as per above conditions. Sound was produced from the speaker with the help of the laptop. complete multiple piezoelectric transducer was distanced from the source at an incremental of 10mm from sound source at each incremental voltage was measured from voltmeter. For each incremental reading the en-closer was opened, changed the position of the transducer and closed the en-closer before starting the experiment.

Figure 3-20 : Multiple transducers were placed in en-closer setup.

4 Results

4.1 Case 1

The results of case 1 obtained are as shown in the Table 3. For the result obtained from data, distance and voltage graph were plotted and it is worth to mention that measurements were interpolated and used to fit a curve of second order as shown in the Figure 4-1. The interpolations of points are increased at the longer distance this due to the uncertainty of measurement device. Comparing this results with Xiao and Cheng[32] they have harvested maximum output of 28mV at 99dB. We can say that the output generated is approximately identical.

Table 3 shows characteristic of piezoelectric obtained for case 1.

Frequency [Hz]	Voltage [mV]	Sound [dB]	Distance[mm]	Angle[°]
529	21.3	98	0	90
529	17.5	98	10	90
529	12.3	98	20	90
529	10.5	98	30	90
529	7.5	98	40	90
529	3.3	98	50	90
529	3	98	60	90
529	3	98	70	90
529	3	98	80	90

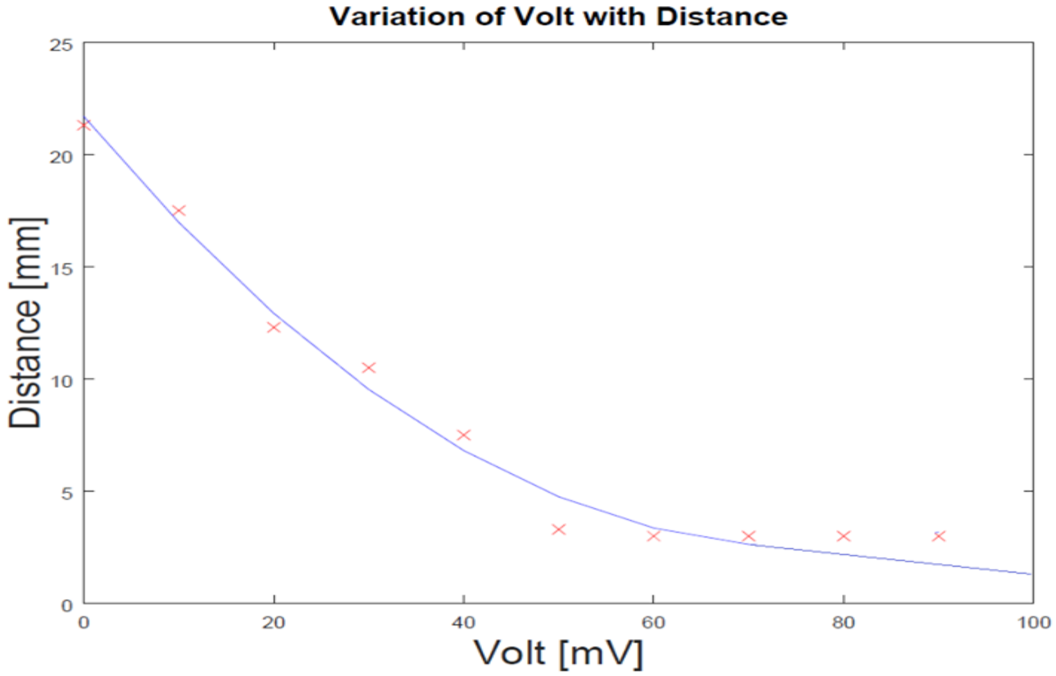

Figure 4-1: Graph of variation of voltage with Distance of piezoelectric transducer of case 1.

4.2 Case 2

The result of case 2 is obtained measurement was noted down as shown in Table 4. From the measurement graph was plotted as shown in the Figure 4-2 .we obtained highest output of 62 mV at 77.5 degree angle and least of 3mV at 135 degree.

Table 4 : shows characteristic of piezoelectric obtained for case2.

Frequency [Hz]	**Voltage [mV]**	**sound [dB]**	**Distance [mm]**	**angle**
529	42.1	98	0	45
529	62	98	0	77.5
529	18.5	98	0	90
529	39	98	0	112.5
529	3	98	0	135

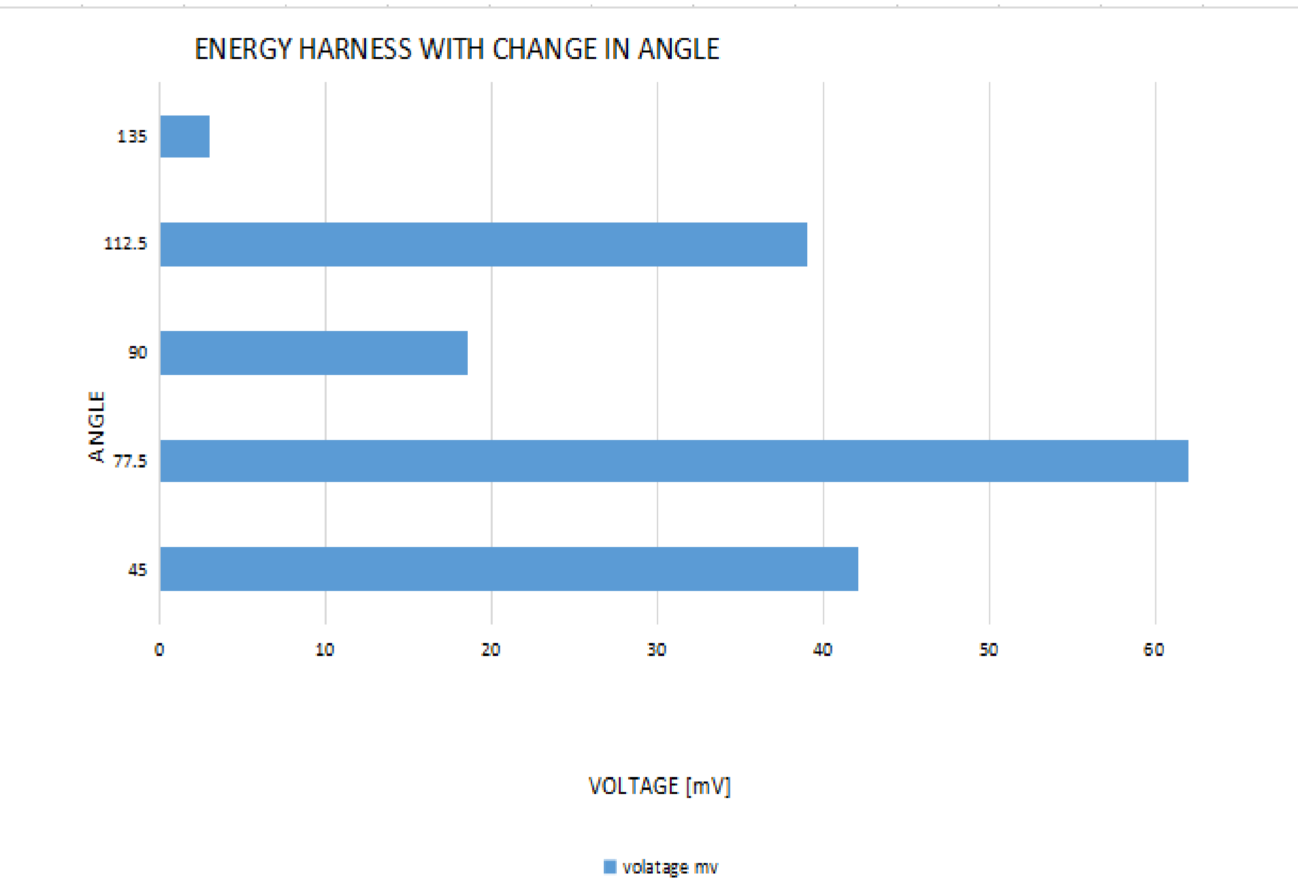

Figure 4-2: Represent voltage with respect to angle of piezoelectric transducer of case 2.

4.3 Case 3

In case 3 enclosed setup is used. Measurement was noted down as shown in the Table 5, by the data of measurements graph was plotted similar to that of case 1.Even in this case as the transducer moved at longer distance from the sound source and voltage should be reduced, due to uncertainty of measurement device it as increased as shown in the Figure 4-3. Comparing results with Hee[33] its significantly less. He has obtained maximum output of 190mV at 100db but he has used Helmholtz resonator, this resonator increases the vibration of the en-closer.

Table 5: Shows characteristic of piezoelectric obtained for case 3.

Frequency [Hz]	Voltage [mV]	sound [dB]	Distance [mm]	angle
529	109	98	30	90
529	114	98	40	90
529	60	98	50	90
529	45.6	98	60	90
529	14.5	98	70	90
529	16.5	98	80	90
529	18.9	98	90	90
529	7.2	98	100	90
529	12.3	98	110	90

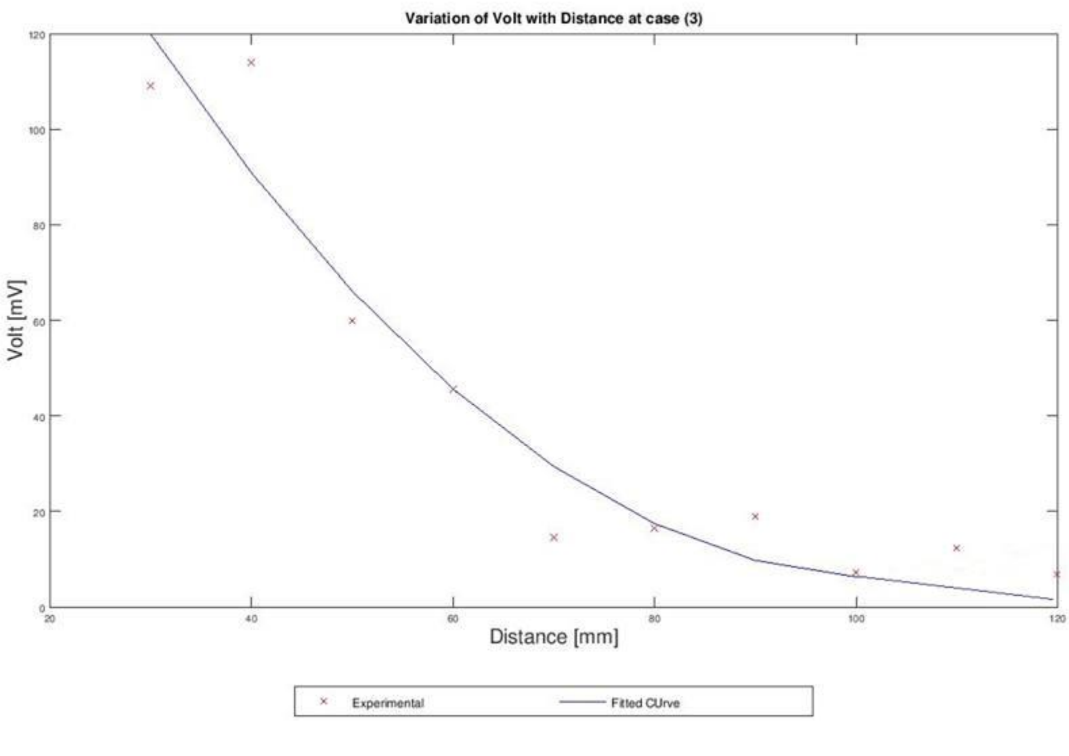

Figure 4-3: Graph of variation of voltage with distance of piezoelectric transducer of case 3.

4.4 Case 4

This case was conducted with same procedure as case 1 with an enlarged dimension of an en-closer was used. The graph was plotted similar to that of case 1 as shown in the Figure 4-4. And uncertainty of measuring instrument as similar to last cases. Here the voltage was reduced dramatically by 80% compare to case1 and case2 but declination was similar to case1 and case2.

Table 6: Shows characteristic of piezoelectric obtained for case 4.

Frequency [Hz]	Voltage [mV]	sound [dB]	Distance [mm]	angle
529	60	98	30	90
529	42.4	98	30	90
529	20.4	98	30	90
529	18.3	98	30	90
529	16.4	98	30	90
529	12.7	98	30	90
529	10.8	98	30	90
529	6.5	98	30	90
529	6.3	98	30	90
529	8.5	98	30	90

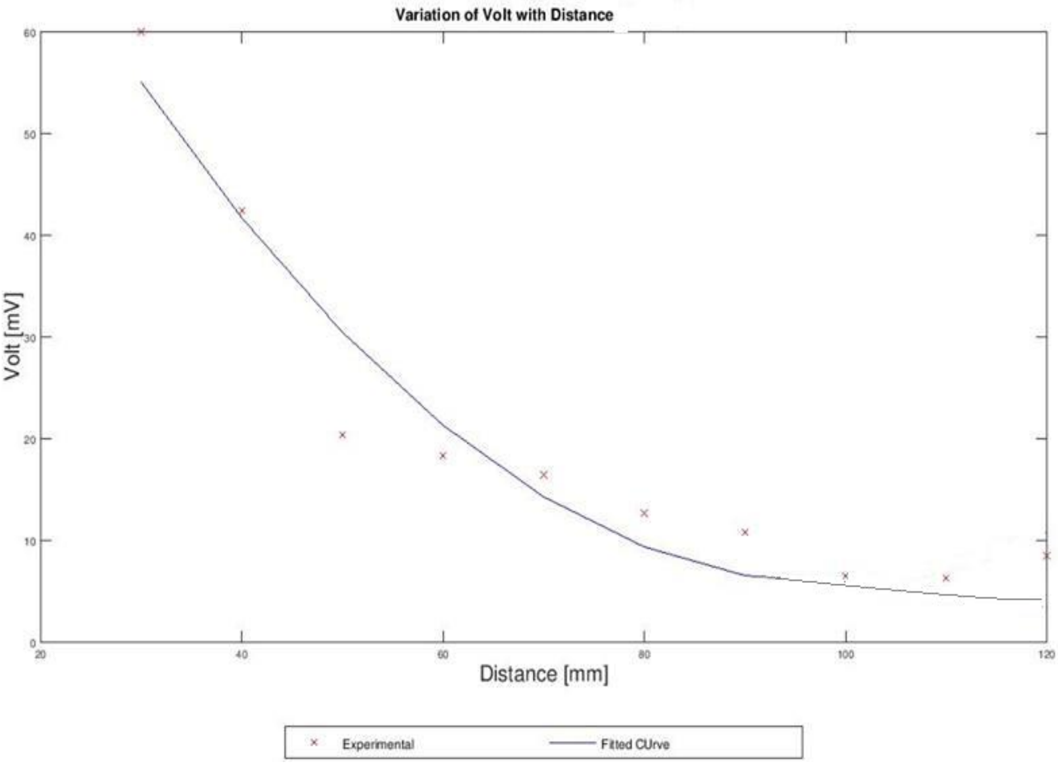

Figure 4-4: Graph of variation of voltage with distance of piezoelectric transducer of case 4.

4.5 Case 5

This was conducted with same procedure as of case2 but in this case two of similar transducer was connected in parallel. Measurements are done as shown in Table 7. The graph was plotted similar to case1 as shown in the Figure 4-5 in this case uncertainty of the measurement device is reduced significantly but in this case voltage was increased by twice compare to case 3 this is due to use of two piezoelectric transducer in parallel but declination was steady and linearly of second order throughout the experiment. Comparing these results with case 3 we can say that output was increased by 50%.

Table 7 : Shows characteristic of piezoelectric obtained for case 5

Frequency [Hz]	Voltage [mV]	sound [dB]	Distance [mm]	angle
529	160	98	30	90
529	179.2	98	40	90
529	180.8	98	50	90
529	120	98	60	90
529	98	98	70	90
529	73.5	98	80	90
529	65.8	98	90	90
529	40	98	100	90

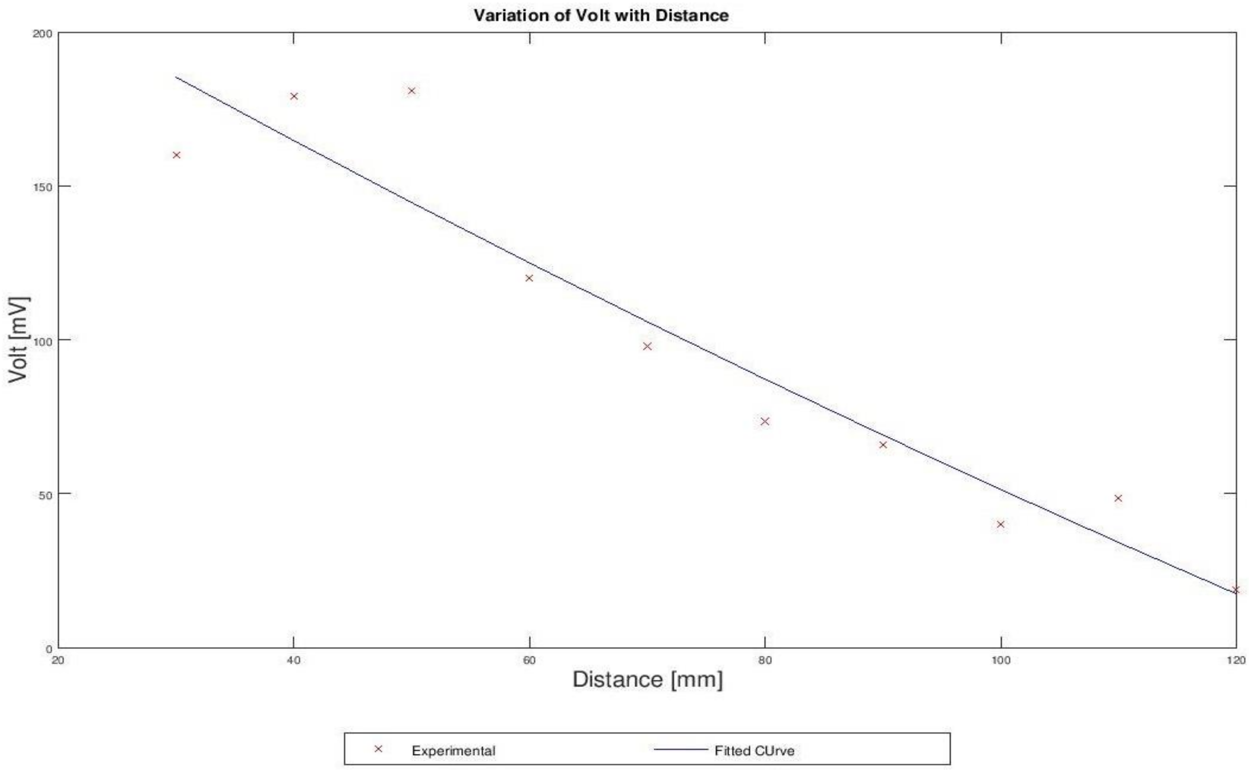

Figure 4-5 : Graph of variation of voltage with distance of piezoelectric transducer of case 5.

5 Conclusion:

Overall conclusion of the experiment we can say that piezoelectric transducer output harnessing will Be depend on the distance of source of sound, as in the experiment we can see that as piezoelectric transducer is at shorter distance the output of harness will be at its optimum. As the distances were longer the output will be reduced.

As per the en-closer the experiment can generate a maximum voltage of 114 mV. Which is five times higher compare to openly conducted experiment and comparing with enlarged enclose the voltage reduced by 80%, so we say that in confined environment the harvesting of energy form sound can improve the harvesting device.

Piezoelectric transducer angle direction towards source will also play major role in harvesting of the energy as we can see in case 2 the energy harvested at 77.5 degree we have harnessed maximum output which is higher compare to the 90 degree but the transducer was very near to sound source, so maximum output we can measure is at 90 degree.

Using multiple transducers in parallel connection can increase the energy harvesting in an en-closer by 50% compare to energy harvesting using single transducer in same en-closer.

The transducer material which is piezdelecto buzzer element of brass has generated voltage maximum voltage of 189mV is a great material compare to energy harvest output of 32mV by piezoelectric transducer of acrylic based [33]

6 Future work

- The future work of this thesis can be conducting an experiment by using echo focusing on piezoelectric transducer and conducting series of experiment by changing the angle of the transducer towards sound, including position changing of transducer and combining the echo focusing and room acoustic.
- The energy harvesting piezoelectric device in application form like absorbing the vibration energy from a Heavy industrial machine like milling machine, drilling machine
- Harvesting energy from traffic noise and using the energy to power up the traffic lights using piezoelectric transducer
- Harvesting energy from day to day household or office noise using piezoelectric transducer

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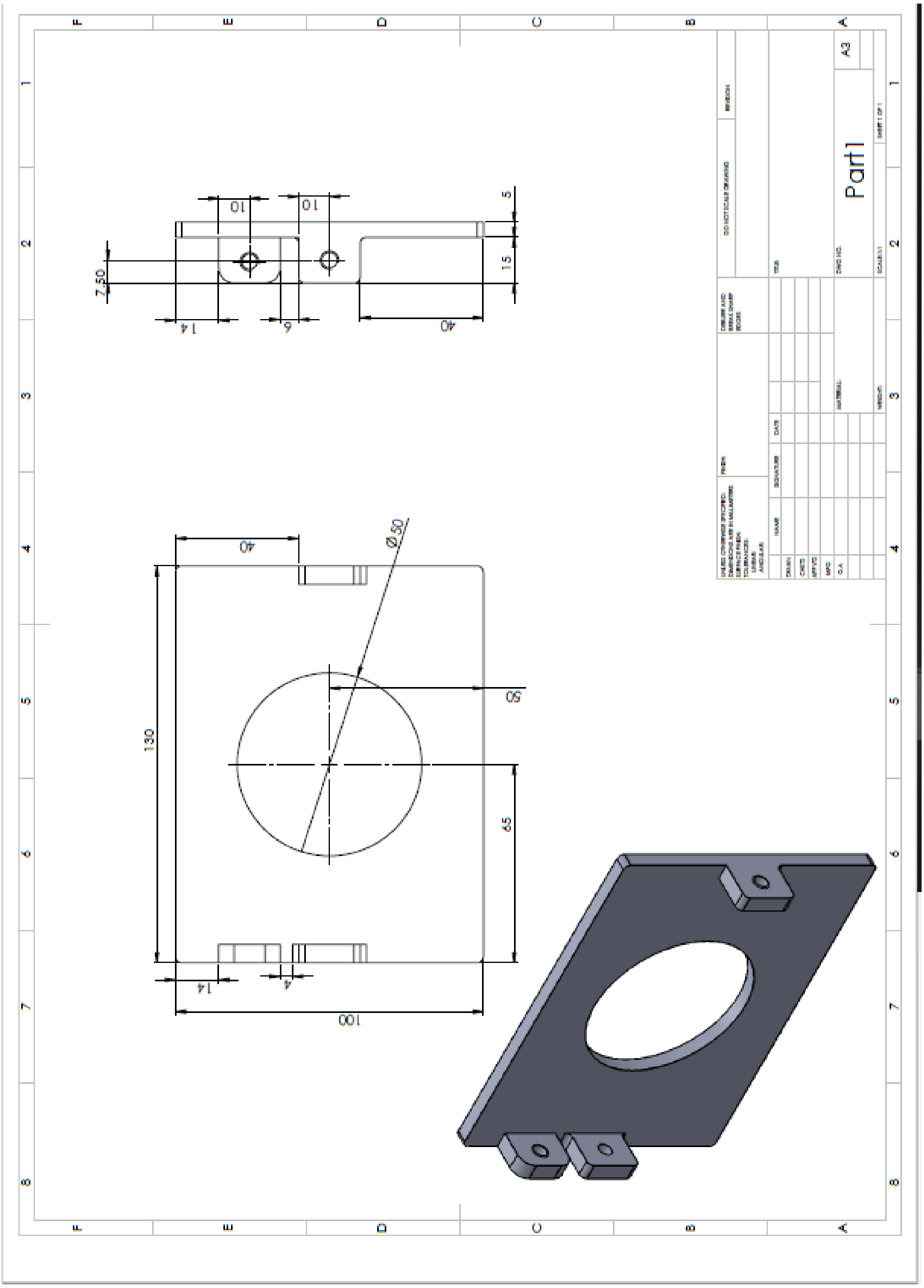
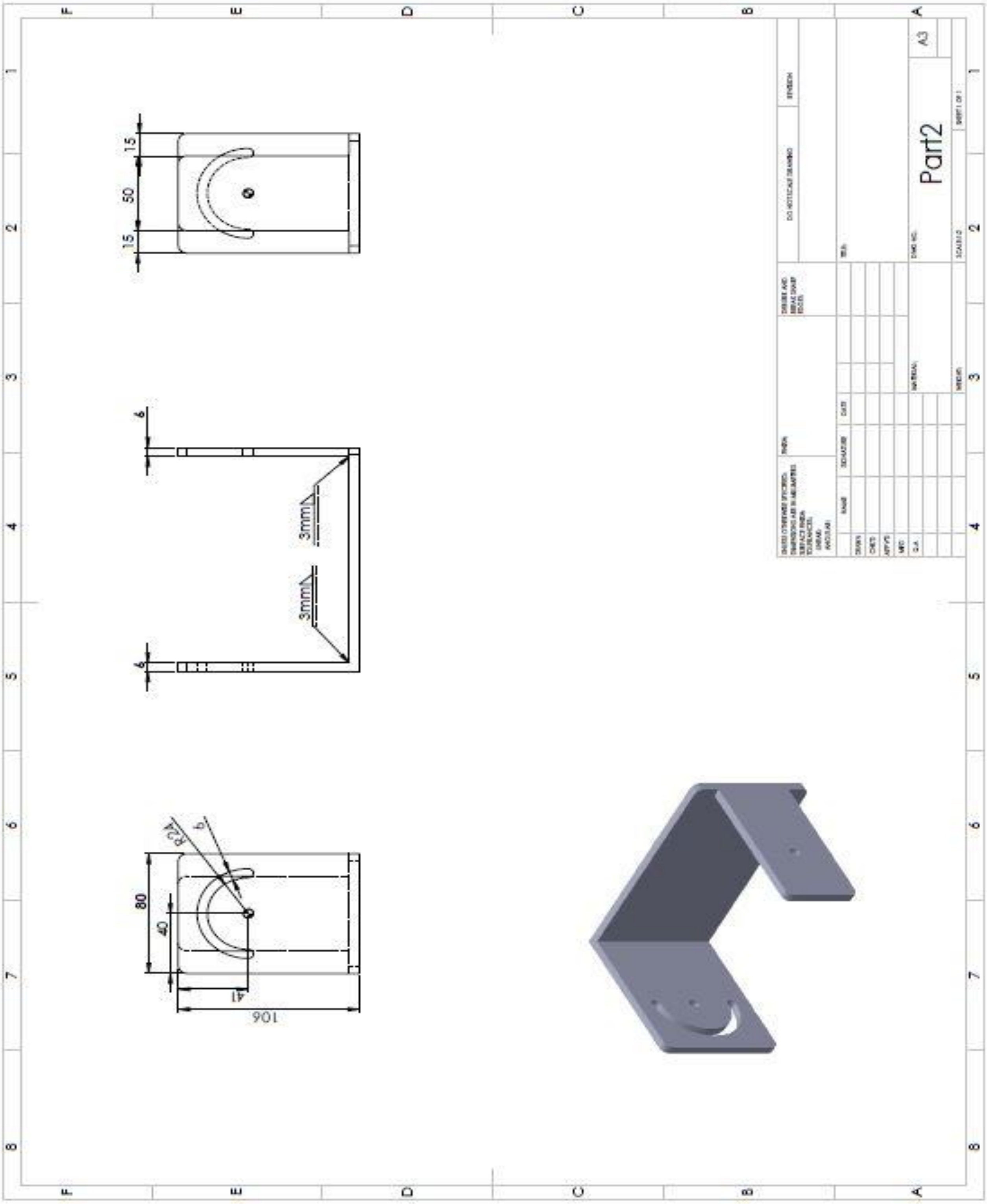
Appendix





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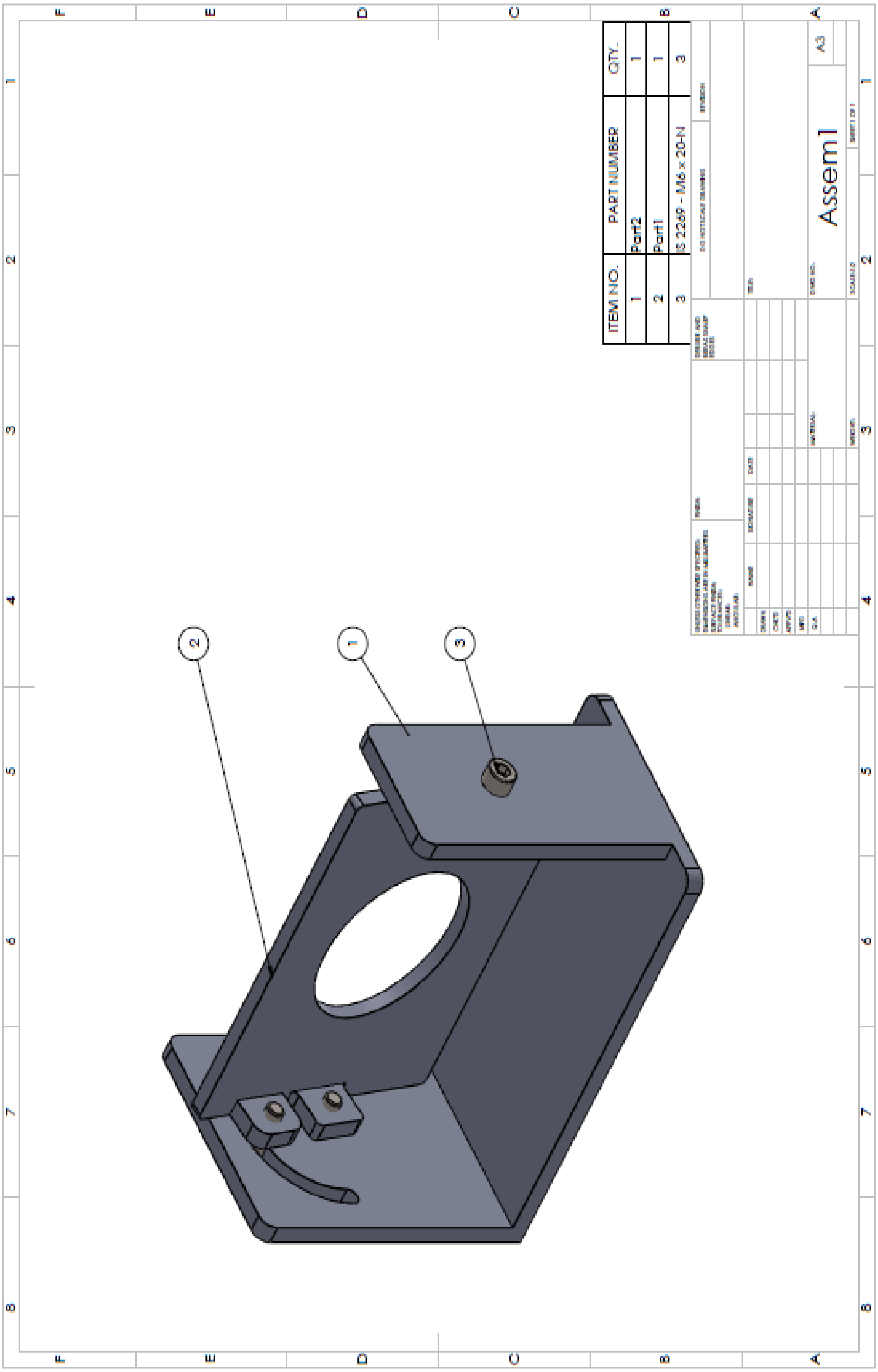
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