

## Harvesting Energy from Sound and Vibration

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### Abstract

Recently, scientist and researcher are trying to seeking new source of energy because energy is needed everywhere and every time. Vibration and sound are one kind of unconventional mechanical energy source which is lost everywhere. Our main goal is to utilize and save this lost energy. In this industrialization, every heavy machines and industrial appliances produce sound and vibration at a time. This paper shows the process of harvesting from these lost energy by using piezoelectric material. Piezoelectric materials have a crystalline structure that provides them with the ability to transform mechanical strain energy into electrical charge and, vice versa, to convert an applied electrical potential into mechanical strain. This property provides these materials with the ability to absorb mechanical energy from their surroundings, usually ambient vibration, and transform it into electrical energy that can be used to power other devices as well as storing in battery.

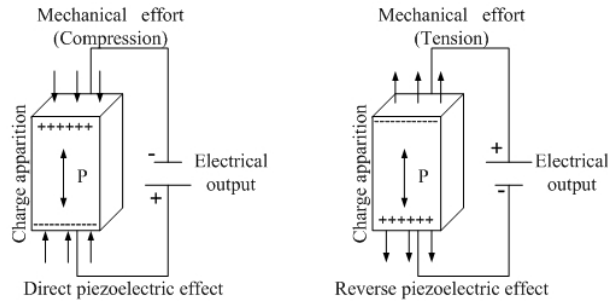
**Keywords:** Vibration, sound, piezoelectric material, harvesting energy, electrical energy.

### 1. Introduction

The increasing desire for completely self-powered electronics has caused the amount of research into power harvesting devices to become progressively larger over the last decade. One early study into power harvesting was investigated the ability to generate energy from the expansion and contraction of the rib cage during breathing. A prototype of the power harvesting system was constructed using polyvinylidene fluoride (PVDF) film and was implemented *in vivo* on a mongrel dog. The prototype was demonstrated to produce a peak voltage of 18V, which corresponded to a power of about 17 $\mu$ W. The discovery of a strong piezoelectric effect in polyvinylidene fluoride (PVDF) polymer, by Kawai in 1969 [1], further added many applications where properties such as mechanical flexibility are desired. With the research into power harvesting devices growing, it was determined that the power found from this system is not so high that is why its power is basically used for portable electronic devices as a self-powered device or it can be saved in battery for later usage [2]. With the recent advances in wireless and MEMS technology, sensors can be placed in exotic and remote locations. Since these devices are wireless it becomes necessary that they have their own power supply. The power supply in most cases is the conventional battery; however, problems can occur when using batteries because of their finite life span. Furthermore, in the case of sensors located on civil structures it is often advantageous to embed them, making access impossible. In this paper, a device has been developed by using fundamental characteristics of piezoelectric effect to utilize and convert the mechanical vibration to electric power.

### 2. Fundamentals of piezoelectric material

The conversion of mechanical energy into electrical one is generally achieved by converters alternator type or commonly known dynamo. But there are other physical phenomena including piezoelectricity that can also convert mechanical movements into electricity. The piezoelectric effect exists in two domains, the first is the direct piezoelectric effect that describes the material's ability to transform mechanical strain into electrical charge and the second form is the converse effect, which has the ability to convert an applied electrical potential into mechanical strain energy as shown in Fig. 1. The piezoelectric materials that exist naturally as quartz were not interesting properties for the production of electricity, however artificial piezoelectric materials such as PZT (Lead Zirconate Titanate) present advantageous characteristics. The piezoelectric strain coefficients describe the relationship between the applied electric field and the mechanical strain produced. Characteristic features [3] of soft piezo ceramic materials are comparably high domain mobility and resulting "soft ferroelectric" behavior, i.e. it is relatively easy to polarize which is used for sound conversion and "Hard" PZT materials can be subjected to high electrical and mechanical stresses which is used for vibration.



**Fig. 1.** Piezoelectric effect

### 3. Sound and noise as energy

Sound is a form of mechanical energy produced by vibrations. A wave is a disturbance that transfers energy through matter or space. It travels in longitudinal (compression) waves and moves much slower than the speed of light. In engineering, noise is defined as a signal that interferes with the detection of or quality of another signal [4]. Basically, noise is unwanted sound. It is a pollutant and a hazard to human health and hearing. Table 1 shows the different sound levels which are usually used. The high intensity sound or noise shown in table 2 has sufficient energy for conversion. There are several terms of measuring sound considered as main factors of EMS like types of sound source, sound intensity, pressure, power, power level, velocity, types of wave, frequency and pitch.

**Table 1.** Loudness of sound in decibel. **Table 2.** Some sound sources with power [5].

| Sound        | Loudness (dbs) | Hearing damage      |
|--------------|----------------|---------------------|
| Average Home | 40-50          | No                  |
| Loud Music   | 90-100         | After long exposure |
| Rock concert | 115-120        | Progressive         |
| Jet engine   | 120-170        | pain                |

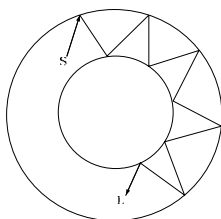
| Situation And Sound source | Sound power Pac watt | Sound power Level $L_w$ db re $10^{-12}$ W |
|----------------------------|----------------------|--|
| Rocket engine              | 1000000              | 180  |
| Turbojet engine            | 10000                | 160  |
| Siren                      | 1000                 | 150  |
| Rock concert               | 100                  | 140  |
| Machinegun                 | 10                   | 130  |

### Energy equation of progressive wave [6]

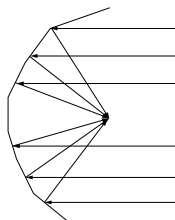
For a particle vibrating simple harmonically, the general equation of displacement,  $Y = a \sin(\omega t + \alpha)$ . Here  $y$  is the displacement and  $a$  is the amplitude and  $\alpha$  is the epoch of the vibrating particle and  $\omega$  is the angular velocity. The total (kinetic + potential) energy of a vibrating particle,  $E = 2\pi^2 m a^2 n^2$ . This energy is supplied by source that is, Energy transfer per unit area per second =  $2\pi^2 \rho n^2 a^2$ .

### 4. Amplification of sound

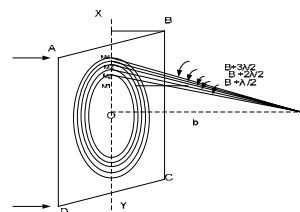
As the high output energy is dependent on the high deflection of piezoelectric material so it can be said that if the source sound intensity and pressure can be raised then energy will be high. There are several methods [7] of amplification of sound. The method of Fig. 2 and 3 is called whispering galleries and Fig. 4 represents the intensity of sound at a point due to a plane wave front. In this method, basically sound waves are redirected at a point which is usable in this experiment to raise sound intensity.



**Fig. 2**



**Fig. 3**



**Fig. 4**

## 5. Mechanical vibration

Vibration is the motion of a particle or a body or system of connected bodies displaced from a position of equilibrium. Most vibrations are undesirable in machines and structures because they produce increased stresses, energy losses, induce fatigue. Vibration occurs when a system is displaced from a position of stable equilibrium. The system tends to return to equilibrium position under the action of restoring forces. The system keeps moving back and forth across its position of equilibrium.

### Energy and power expressions of vibration [7]

This section will review some important ideas in energy and power in mechanical systems. If an increment of mechanical work on a particle of mass  $M$  is denoted as  $\Delta W$ , then this amount of work can be calculated using the force applied to the particle along the incremental change in path,  $dr$ , of the particle as follows:

$$\Delta W = F \cdot dr \quad (1)$$

where the  $\cdot$  denotes a dot product between the force and differential displacement vector. Because the kinetic energy,  $T$ , of a particle is equal to the rate of change in  $\Delta W$  with time, a convenient expression for  $T$  can be derived as follows:

$$\frac{dT}{dt} = \lim_{\Delta t \rightarrow 0} \frac{\Delta W}{\Delta t} = F \cdot \frac{dr}{dt} \quad (2)$$

## 6. Experimental setup and procedure

Figure 5 shows the block diagram of this harvesting process. The wave emits from sound source has no any specific direction. It spreads into several directions around the source. That is why it is very tough to accumulate all sound pressure in a point. In this paper a device has been designed which can focus several waves within its range in a point and increases the sound intensity at a focus point shown in Fig.6 and 7. Its helps to better displacement of piezo material which is kept into focus point as well as better output voltage. Figure 7 shows the dimensions of the design of focusing cone. Sound wave from different direction can be reflected by sound reflector face and the reflected wave is focused on the piezo material. Thus the intensity of sound has been increased by using this device and more energy can be converted.

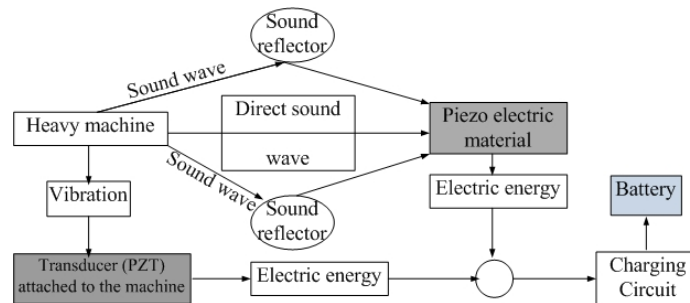


Fig. 5. Block diagram of harvesting energy vibration and sound source.

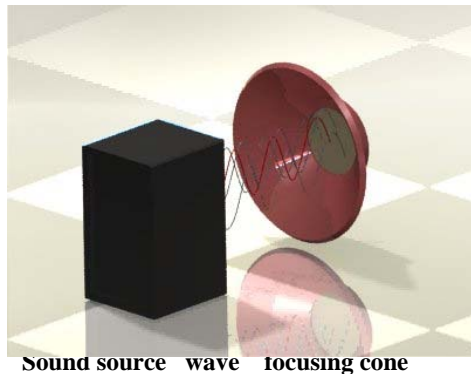


Fig. 6. Striking the piezo material by sound pressure (Solid works drawing)

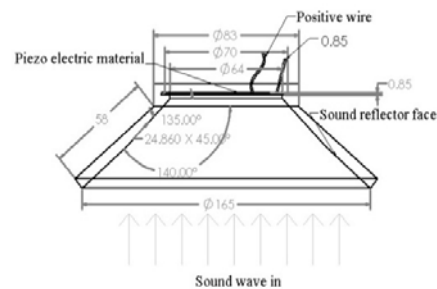
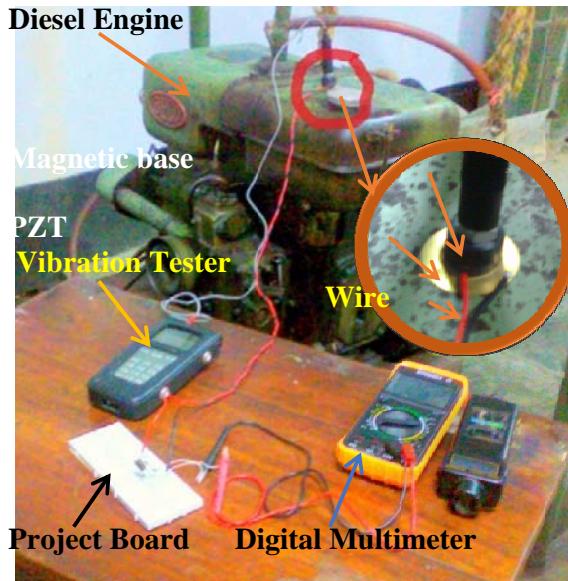


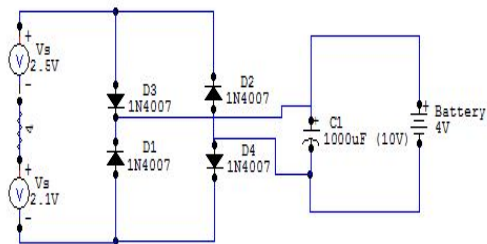
Fig. 7. Piezoelectric device (focusing cone) for converting sound to electric energy.

Figure 8 shows experimental set up which depicts that a heavy machine like diesel engine releases mechanical energy means of sound and vibration at a time. These two energy is our target for transducing. Sound waves which emit from machine spread around the ambient so it needs to be concentrated in a point to increase its intensity which is described in theory previous. For this reason, our designed focusing cone is used to capture sound wave and to redirect the sound wave in a specific point on piezoelectric material for getting higher sound pressure. This focusing cone is placed in front of machine in several positions so that it can capture several sound waves. When the higher intensity sound strikes piezoelectric material in focusing cone, then it produce comparatively high electric energy.

At the same time machine creates vibration which is undesirable and loss of energy. Figure 8 also shows the 7.5 Hp Beco Diesel Engine as a vibration source running at 1100 rpm. A vibration tester was used to measure the displacement, velocity, acceleration of the vibration. Piezoelectric material which is attached on the machine produces voltage. These two voltages found from sound and vibration is sum up through charging circuit (Fig. 9) and finally stored on battery.



**Fig. 8.** Experimental setup on 7.5 Hp Beco Diesel Engine.



**Fig. 9.** Circuit diagram of charging battery.

## 7. Analysis of charging circuit and connection

Due to stress and strain caused by vibration to the piezoelectric material, dual polarity of charge results in an alternating current (AC), which is then converted into direct current (DC) by a full bridge rectifier. The rectified current is then used to charge a capacitor or a battery, which can hold energy. The maximum power transfer technique will be used to design the circuit for this energy conversion. AC-DC converter [8] is used to maximize the power transfer to the load. The reason to use AC-DC converter is to convert a variable input voltage into a constant output voltage. Figure 9 shows the circuit diagram including full bridge rectifier. The optimal power transfer is achieved when the operating rectifier output voltage is half the open circuit voltage; this assumption allows the effective loss factor of the system to be dependent only on the coupling coefficient. If the device number can be increased then the output voltage may be found in satisfaction level in spite of dropping some voltage.

### Parallel and series connection of piezoelectric film

Since the power output from a single piezo-film was extremely low, combination of few piezofilms was investigated. Two possible connections were tested - parallel and series connections. The parallel connection did not show significant increase in the voltage output. With series connection, additional piezo-film results in increased voltage output but not in linear proportion [9]. This may be due to the non-linear modification of internal impedance of the system. Further investigation is required to explain this non-linearity occurrence. If this is understood, an artificial modification could be added into the system to achieve the ultimate goal of producing high voltage output with high current density.

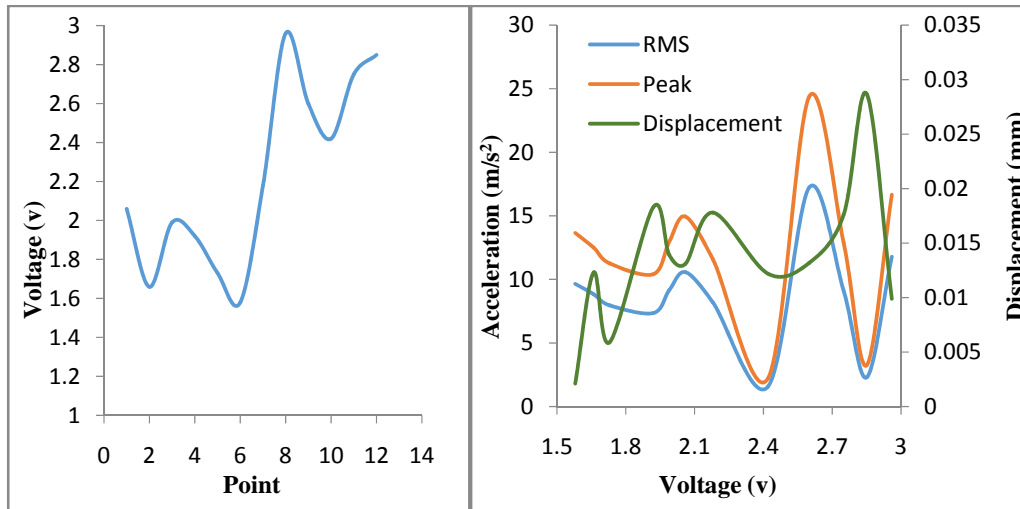
## 8. Experimental results and discussion

The output voltage which is the result of deflection of piezoelectric material fluctuates in the range about 1.5-3.0 volt. At the same time the amount of current is very low in mA ranges that are the power harvested from this experiment is small in amount. The material was placed in several positions on diesel engine. As the vibration rate of engine is not same at different places so the voltage found varies with respect to position. Table 3 shows the acceleration of rms and peak value, velocity, displacement and voltage. Data from table has been presented in graph which depicts clearly. In fig. 10(a), high voltage 2.96v is found at point 8 on the machine as well as the high voltage is recorded at high acceleration at the same point on the machine.

**Table 3.** Acceleration, velocity, displacement and voltage on different point of diesel engine.

| point | Acceleration $m/s^2$ |       | Velocity $cm/s$ | Displacement $mm$ | Voltage $v$ |
|-------|----------------------|-------|-----------------|-------------------|-------------|
|       | Rms                  | Peak  |                 |                   |             |
| 1     | 10.57                | 14.95 | 0.489           | 0.0131            | 2.06        |
| 2     | 8.84                 | 12.50 | 0.191           | 0.0123            | 1.66        |
| 3     | 9.17                 | 12.98 | 0.489           | 0.0139            | 1.99        |
| 4     | 7.36                 | 10.41 | 0.431           | 0.0183            | 1.92        |
| 5     | 7.96                 | 11.26 | 0.204           | 0.0059            | 1.73        |
| 6     | 9.65                 | 13.65 | 0.189           | 0.0021            | 1.58        |
| 7     | 8.18                 | 11.57 | 0.335           | 0.0178            | 2.18        |
| 8     | 11.78                | 16.66 | 0.462           | 0.0099            | 2.96        |
| 9     | 1.56                 | 2.20  | 0.179           | 0.0122            | 2.42        |
| 10    | 9.11                 | 12.89 | 0.471           | 0.0176            | 2.75        |
| 11    | 2.30                 | 3.25  | 0.191           | 0.0287            | 2.85        |

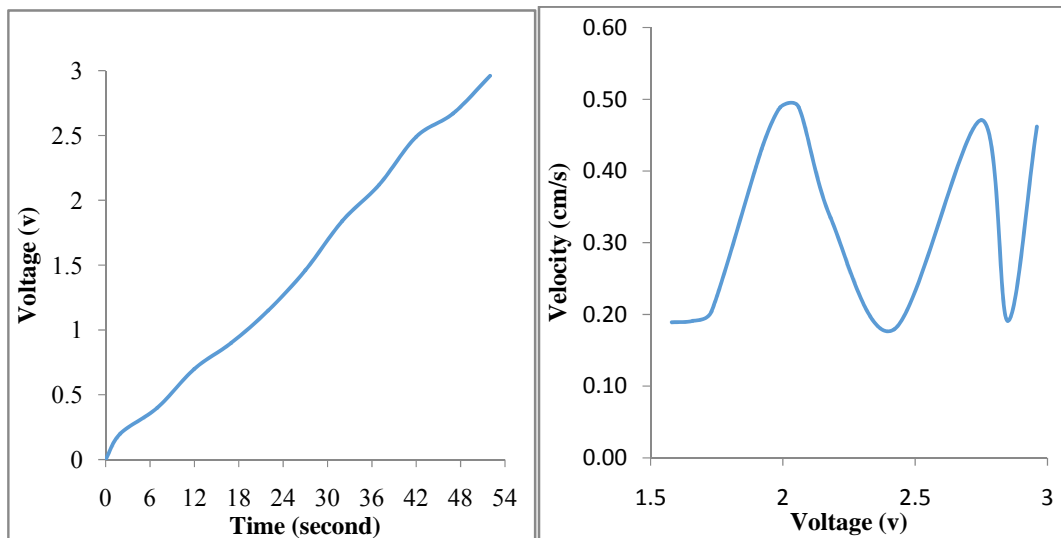
It is very clear from Fig. 10(b) that acceleration and displacement over voltage fluctuates very rapidly. In the region of voltage 2.6 to 3, Acceleration and displacement is high. From data table, at point 8 the voltage is high and at this point the voltage is gradually increasing with respect to time as shown in Fig. 11(a). There is no any abrupt fluctuation of voltage at the same time it is nonlinear voltage. Figure 11(b) follows the ideal curve of velocity and maximum velocity found in this experiment is 0.489 cm/s. The data recorded only on the basis of vibration. The harvesting energy from sound is very sensitive and complex. The method is mentioned above about sound and a prototype is also modeled which can transduce sound into electric energy. Finally this two energy is sum up in a circuit and stored in battery or used in MEMS. The major limitations facing researchers in the field of powerharvesting revolve around the fact that the power generated by piezoelectric materials is far too small to power most electronics.



(a) Voltage vs Point

(b) Acceleration and Displacement vs Voltage

**Fig. 10.** Output voltage at different point on the diesel engine.



(a) Voltage vs time at point 8

(b) Velocity vs voltage

**Fig. 11.** Output voltage representation over time at a fixed point and velocity at different point.

Therefore, methods of increasing the amount of energy generated by the power harvesting device or developing new and innovative methods of accumulating the energy are the key technologies that will allow power harvesting to become a source of power for portable electronics and wireless sensors. However, the rechargeable battery can be charged and then used to run any number of electronic devices for an extended period of time while being continuously charged by ambient motion. Innovations in power storage such as the use of rechargeable batteries with piezoelectric materials must be discovered before power harvesting technology will see widespread use.

## 9. Conclusion

In this paper a system has been developed which can transduce vibration and sound into electrical energy. In this project, the converted energy is measured in a voltage by proper experiment. The maximum voltage was found 2.96 volt. This paper shows the result found from only vibration which was practically done in lab on diesel engine. Different machines vibrate at different level and release energy at also different level. So this technology can be used in higher vibration sources for transducing higher energy. However, the research topic is also related to sound. For this reason a prototype model has been designed for converting sound energy to electric energy. This research has developed a model and process to generate power through the vibration and sound of any heavy machine using piezoelectric elements. The electrical energy harvested from ambient vibration and sound can then be used to power other devices or stored for later use. Despite some limitation of arrangements and materials the model was verified using experimental results and proved to be very accurate independent of excitation frequency. Further research is also necessary to implement both sound and vibration converting technology largely and integrate them in a structure for better future success of this project.

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