International Journal of Electronics and Electical Engineering

Volume 2 | Issue 2 Article 13

October 2013

PIEZO BASED ELECTRIC POWER GENERATION USING 3-DIMENSIONAL MECHANICAL VIBRATIONS PRODUCED IN VEHICLES

G.JITHENDRA NAIDU
Department of Electrical Engineering, J.B Institute of Engineering and Technology (Autonomous), Hyderabad, India, jithu.10920821@gmail.com

K.PRANAY KUMAR REDDY
Department of Electrical Engineering, J.B Institute of Engineering and Technology (Autonomous), Hyderabad, India, pranay829reddy@gmail.com

S.SIVA PRASAD
Department of Electrical and Electronics Engineering, J.B. Institute of Engineering and Technology (Autonomous), Hyderabad, India., sshivprasadeee@gmail.com

PIEZO BASED ELECTRIC POWER GENERATION USING 3-DIMENSIONAL MECHANICAL VIBRATIONS PRODUCED IN VEHICLES

G.JITHENDRA NAIDU, K.PRANAY KUMAR REDDY & S.SIVA PRASAD

Department of Electrical Engineering, J.B Institute of Engineering and Technology (Autonomous), Hyderabad, India
E-mail :jithu.10920821@gmail.com, pranay829reddy@gmail.com,[3]sshivprasadeee@gmail.com

Abstract—Due to advancement in the field of technology in recent years, wireless data transmission techniques are commonly used in electronic devices. For powering them we rely upon power supply through wires charging, else power may be supplied from batteries. But while travelling for longer distances continuously we may not be able to obtain power supply for these devices to operate or to recharge their batteries. So in order to operate them continuously we need a power source that provides continuous energy to operate these devices. The mechanical vibrations which are produced by the automobiles can be utilized as a source of energy for generating electrical energy that can be utilized by these electronic equipment to operate. These vibrations are produced by different vehicles around us which is going as a waste. This technique utilizes piezoelectric components where deformations produced by vibrations are directly converted to electrical charge via piezoelectric effect and principle of electromagnetic induction between coil and magnetic field which produces Electromotive force in the coil provided displacement to magnet by the vibrations. The piezoelectric materials and permanent magnets are used as energy conversion devices for converting mechanical vibrations to electrical energy. In this context, we introduced two methods and considered its output performance provided input vibrations, by using piezoelectric materials such as PZT for electro mechanical conversion using Mass-spring system as medium of conversion of force from vibrations applied on PZT materials and by using spring-magnet system where relative displacement of magnet with respect to coil, provided input vibrations generates Electromotive force in coil.

Keywords*:-Piezoelectricity, 3-Dimensional energy conversion, mechanical vibrations, Mass-spring system, Spring-magnet system.*

I. INTRODUCTION

Moving vehicles produce vibrations due to transfer (loss) of energy from the rotating parts to the body of the vehicle. These vibrations are generated either when the vehicle is at standstill (when engine is on) or when the vehicle is moving. These vibrations are maximum when the body of vehicle is in resonance with the rotating parts and the vibrations are more in parts of vehicles which are not mechanically fitted.

These vibrations that are produced are in 3-dimensions (that is along 3 perpendicular axes x,y,z). The generation of vibrations in vehicles is due to many reasons
such as moment of inertia of rotating parts, uneven road surfaces, load on the system. So in order to harness this waste going energy we introduced two methods which uses piezoelectric materials and principle of Electromagnetic Induction for energy conversion respectively.

II. WORKING PRINCIPLE

A. MASS-SPRING SYSTEM

The piezoelectric effect is a special material property that exists in many single crystalline materials [4]. Examples of such crystalline structures are Quartz, Rochelle salt, Topaz, Tourmaline, Cane sugar, Berlinite ($AlPO_4$), Bone, Tendon, Silk, Enamel, Dentin, Barium Titanate ($BaTiO_3$), Lead Titanate ($PbTiO_3$), Potassium Niobate ($KNbO_3$), Lithium Niobate ($LiNbO_3$) ,Lead Zirconium titanate(PZT) etc. Among all these materials PZT is used as energy converting source because it has high electro mechanical coupling coefficient (d_{33}).It represents how much electric charge in columbs generated in material for 1 newton force applied on piezoelectric material. "i" represent poling direction and "j" represent the direction of applied stress on crystal. In this context we are taking d_{33} coefficient for our experimental purpose. The various values of $d_{33}$for different materials is shown.

Table-1 d_{33} values for different piezoelectric crystals

MATERIAL	***d_{33}(10-^{12}Columbs/Newton)***
Quartz	***2.3***
$BaTiO_3$	***90***
$PbTiO_3$	***120***
PZT	***560***

For PZT, d_{33}=560(10^{-12}Columbs/Newton) Means that 1Newton force applied strain produces 560(10^{-12}Coumbs/Newton) Electric charge.

There are two types of piezoelectric effect, direct piezoelectric effect and inverse piezoelectric effect. The direct piezoelectric effect is derived from materials generating electric potential when mechanical stress is applied and the inverse piezoelectric effect implies materials deformation when an electric field is applied [4]. The energy

harvesting via Piezoelectricity uses direct piezoelectric effect shown in Figure.1.

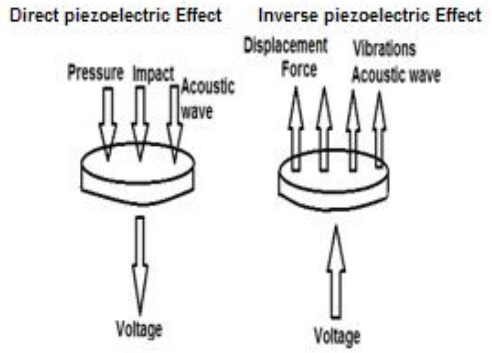

Figure.1. Direct and Inverse piezoelectric effect

Usually the piezoelectric materials are first poled in a specific direction(i.e in 1 or 2 or 3) direction by applying high voltage(about 1800 volts)in order to maintain alignment in Weiss domains(Dipoles), in the absence of electric field. After poling the piezoelectric material works as a capacitor with dielectric medium present in it. This material produces a charge when a force is applied on the material. When an external force is applied the distance between two charged plates decreases and the internal dielectric force with charge accumulated on surface breaks, result in movement of charge in external circuit. This charge is then collected to storage devices(batteries)[4].

B. SPRING-MAGNET SYSTEM

The principle of Electromagnetic Induction states that whenever there is a relative motion between a conductor and a magnetic field then an Electromotive force is induced in the conductor according to Faraday's law.

III. METHODS FOR GENERATION OF ELECTRICITY USING PIEZOELECTRIC MATERIAL

A. POWER GENERATION ON PAVEMENTS

In this model a sheet of piezoelectric material is placed underneath the pavement so that when the pedestrians walk on the pavements produces a harmonic stress on material result in generation of electricity which can be stored in batteries and used for other purposes [7]. But the amount of input vibrations produced is limited since the concrete pavements absorb most of the vibrations result in less transfer of vibrations to material.

B. POWER GENERATION ON ROADS

Innowattech an Israel based research lab got success in generation of electricity by using piezoelectric generators placed underneath the road. When vehicles passed on these materials energy is produced based on force acted by vehicles on piezomaterials which is sufficient for electrifying traffic lights.

C. POWER GENERATING SHOES

In United States Defense Advance Research Project Agency (DARPA) initiated an innovative project on Energy harvesting which attempts to power battlefield equipment by piezoelectric generators embedded in soldiers' boots. However, these energy harvesting sources put an impact on the body. DARPA's effort to harness 1-2 watts from continuous shoe impact while walking[6] were abandoned due to the discomfort from the additional energy expended by a person wearing the shoes.

D. POWER GENERATION ON SITTING CHAIRS AND VEHICLE SEATS

The weight of human body which acts as source of energy is used for generation of electricity. in this method a piezo sheet is placed on chair which converts potential energy(human weight) to electric power[6].

IV. PROPOSED METHODS

METHOD-1VIBRATION BASED PIEZO GENERATION IN 3-DIMENSIONS USING MASS-SPRING SYSTEM

Since the vibrations produced by moving vehicles are continuous and this vibrational energy is wasted continuously [1]. In order to utilize this energy efficiently we need to develop a system which converts these vibrations into useful electrical energy, which is stored in rechargeable batteries used for other purposes.

The vibrations that are produced by moving vehicles possess in 3-dimensions .These vibrations are efficiently used for harvesting energy by using PZT material .The piezoelectric generator we have proposed consist of a spring mass system used as interconnection for applying vibrations produced, to PZT material. The system consists of five weights, five piezoelectric materials(PZT) and five friction less springs. One of the mass-spring system(M1,K1) is hanged from the vibrating body by using a string (S1)which acts as main part of the system. Let the plane of hanging system be Z plane. A nonmetallic shield is placed around the hanging system. A PZT material (P1) is placed on the base of shield such that the vertical mass (M1) exerts a force on PZT material [1]. Then by keeping S1 as centre of axis we place two mass-spring systems(M2,K2) (M3,K3) in horizontally on smooth surfaces in opposite direction with reference to string1 so that the masses are free to slide. Let the plane of these two mass-spring systems be X plane (i.e one in positive X axis other is in negative X axis) and these two mass-spring systems are connected to the hanging system S1using two auxillary strings as shown in Figure.3. Let these strings be (S2) and (S3).The end connections of the

strings are designed such that if force exerted in positive X axis direction does not affect the negative X axis mass-spring system as shown in Figure.2. Two more mass-spring systems are placed on smooth surfaces in opposite with reference to hanging system such that their plane is perpendicular to X plane. Let this plane be Y plane and two mass-springs are(M4,K4) (M5,K5).These two Y systems are connected to hanging system using auxillary strings(S4)and(S5) as shown in Figure.3.These string ends are also designed such that if force exerted in positive Y direction does not affect the negative Y direction mass-spring system.

Four PZT materials (P2, P3, P4, P5) are placed on the outer shield of hanging systems such that each PZT occupies a face of other two planes as shown in Figure.4.When the vehicle moves on plane surface the amount of vibrations produced are less. Let the vibrations produced be only along Z axis. Then the main hanging system vibrates in Z plane without disturbing other plane systems exerting time variable force on the PZT P1.This force produces a charge in PZT material which is stored in storage devices (Batteries).

When the vehicle is moving on a irregular surface or during acceleration of the vehicle or when brakes are applied, along with vertical displacement (Z axis) there is also a force acting in X and Y planes. So a 3-Dimensional power is obtained (i.e through 3 piezos placed along 3 axes).So an efficiency of about 3 times more is obtained than using single mass-spring system for generation of power. The energy generated will be continuous as long as the vehicle keeps moving and the conversion is more efficient since we are using friction less springs, as a result maximum amount of energy is obtained.

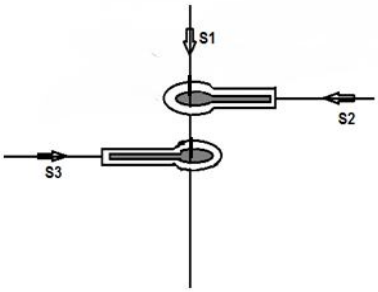

Figure.2.End connections of auxillary strings with main string

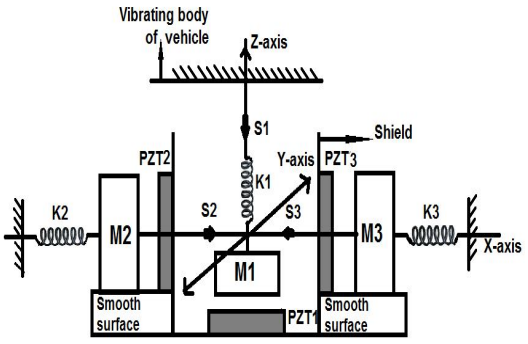

Figure.3.Front view of 3- dimension mass-spring based PZT energy harvester

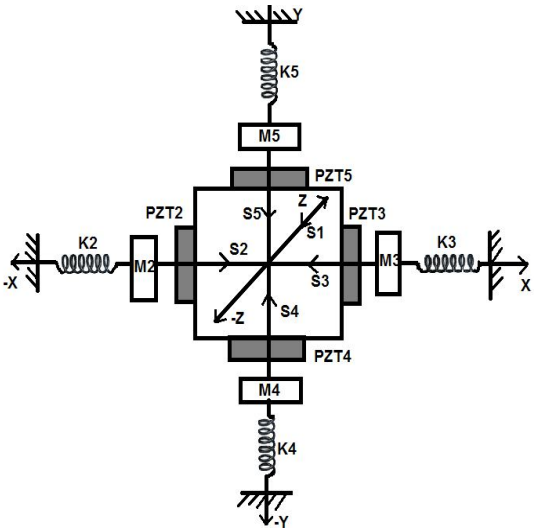

Figure.4.Top view of 3-Dimensionalmass-spring based PZT energy harvester

METHOD-2 SPRING-MAGNET SYSTEM

Along with the 3-Dimensional power produced by spring mass system we can also produce power by using spring-magnet system. In spring-magnet system instead of using PZT as energy conversion device here we are using principle of electromagnetic induction. In this method three permanent magnets, three frictionless springs and three coils are used as energy converting devices. Two magnets (M2,M3) are placed in an alignment such that they are placed along the same axis with a distance between them The polarity of magnets are placed in such a way that the two magnets tend to repel each other(i.e same poles are adjacent to each other).The distance between the magnets should be such that there should be a repulsive force acting between two magnets. Let the axis of these two magnets be X axis. The two magnets are connected to rigid surfaces by using two springs as shown in Figure.5. These two springs are arranged in such a way that the two magnets are free to move along X axis only. A third magnet (M1)is placed in such a way that its axis is perpendicular to the axis of the other two magnets and the pole of third magnet which comes into field of other two magnets must be of opposite polarity with respect to leading poles of other two magnets. Let the axis of third magnet be Y axis .The other end of magnet is connected to a vibrating body by using a spring such that the magnet is free to move along Y axis. Three coils (C1,C2,C3) are wounded across three magnets as shown in Figure.5 such that when a relative motion occurs between magnet and coil an Electromotive Force is induced in coil. Now when the vibrating body vibrates along Y axis the magnet M1 moves along its free axis, thus creating a relative motion between M1 and C1. So an Electromotive force is induced in coil C1 [5]. Since the magnet moves in the field of other two magnets and the polarity of magnet in field is of opposite polarity with respect to polarity of field

poles, thus creating an attractive force between vibrating magnet with other two magnets. So the two magnets in X plane tend to move towards the axis of third magnet. But the connected springs exert a reaction force such that it prevents the adjoining of two magnets with the vibrating magnet. When the vibrating magnet leaves the field of adjacent magnets a repulsive force is created between the two magnets M2andM3 because of same polarity. So the two magnets move away from the axis of third magnet. Now when the vehicle is accelerating or when brakes are applied the two magnets along X axis experience a force due to law of motion without any interference of third magnet. This results in creating a relative motion between magnet and coil. This process repeats, since the vibrations produced in vehicles during motion are continuous. So a relative motion develops between (M1,C1),(M2, C2) and (M3,C3). This results in generation of an Electromotive Force in coils C1, C2 and C3. So power can be generated in 3 coils simultaneously

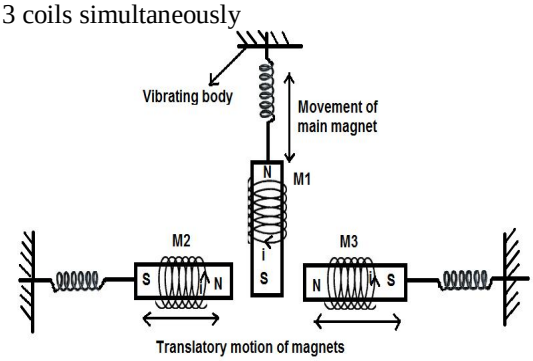

Figure.5.Spring magnet system and translatory motion of magnet

V. INTENSITY OF INPUT VIBRATIONS PRODUCED IN VEHICLES THAT EFFECTS MASS - SPRING SYSTEM

In 3-Dimension mass-spring system the auxillary mass-spring systems are excited by a force which is given by main mass M1 and the horizontal X direction vibrations. This force produces a displacement in auxillary masses whose kinetic energy is used by PZT materials for conversion of energy [1]. Figure.6 shows the displacement of horizontal mass provided a force by two sources acting in same direction. This results in more efficient displacement of mass which provides high input to the PZT.

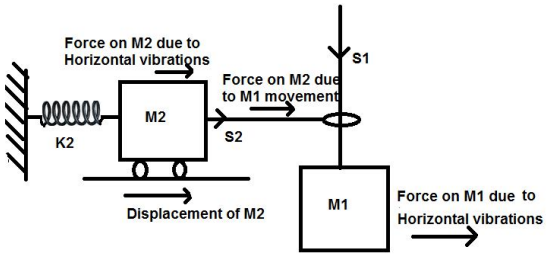

Figure.6.Displacement of horizontal mass

The accelerations produced by the vibrating bodies along3-dimensionsis calibrated using an Accelerometer[1] and is shown graphically below.

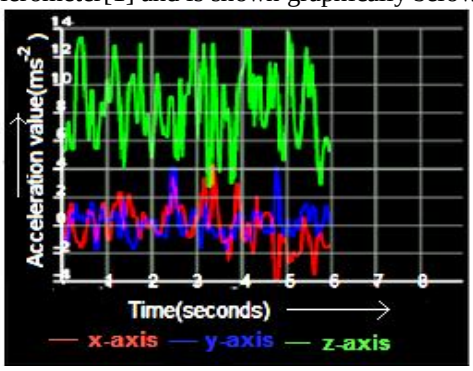

Figure.7.showing vibration intensity in vehicles along 3-Dimensions

The accelerations produced in vertical mass-spring system [1] along 3-Dimensionsis shown graphically.

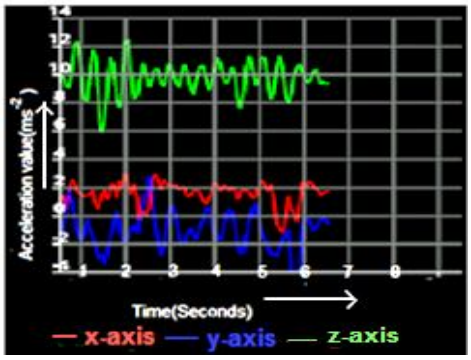

Figure.8.Displacement of mass with input vibrations in main mass-spring system

This mass M1 applies a force(F) on PZT1 crystal given as F=Mass (M1)*acceleration of mass along Z axis. This applied force generates a power in the PZT1 crystal [2].Now along with Z direction displacement there is also a displacement of mass M1 in Y axis and X axis as shown in Figure.8. So this exerted force is useful for the displacement of auxillary masses along with vibration force exerted on them as shown in Figure.7.The displaced mass exerts a force on auxillary PZTs[3]whose relation is given as F=Mass(auxillary)*acceleration of mass along X or Y axis. So at a given instant simultaneously 3 PZTs(two auxillary along 2 axes and other is the main crystal) can deliver power to the load which is about 3 times more efficient comparing to single system .

VI. MAGNITUDE OF 3- DIMENSIONAL VIBRATIONS PRODUCED AT DIFFERENT LOCATIONS IN THE VEHICLE

The magnitude of vibrations produced will be different at different locations in the moving vehicle. So, in order to have maximum output power we have to know the location where the vibration

intensity is more by comparing the magnitudes of vibrations produced at different locations in the vehicle graphically. For this purpose we are taking a loaded bus as a test vehicle which is moving at a constant speed of 30kmph. In order to measure the vibrations produced in it using an accelerometer. We have chosen 3Locations in bus to measure vibrations by keeping the speed of the bus constant and running the bus on same route repeatedly for measuring the vibrations at different locations.

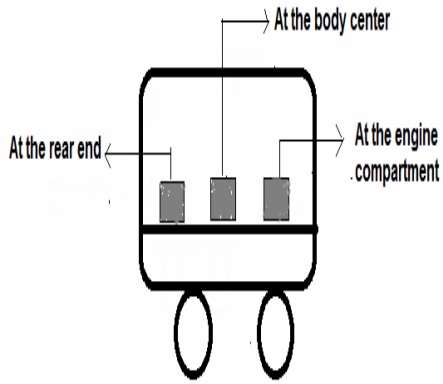

Figure.9 The vibrations measured at different locations of the bus.

The intensity of vibrations at different locations in bus are shown below.

A. AT THE ENGINE COMPARTMENT

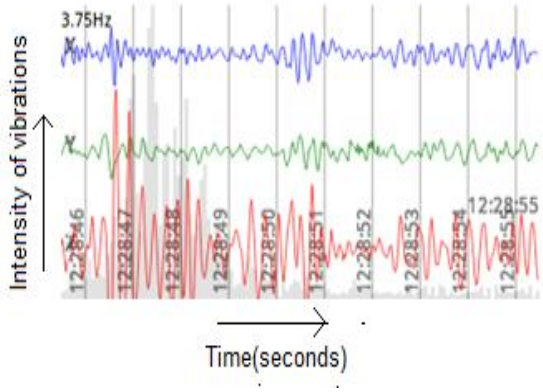

Figure.10.3-Dimensional vibrations at the engine compartment

B. AT THE BUS CENTER

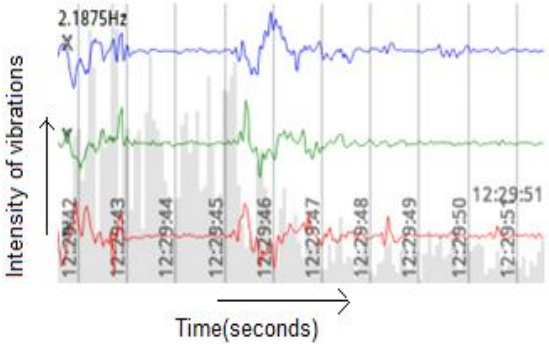

Figure.11.3-Dimensional vibrations at the bus center

C. AT THE REAR END OF THE BUS

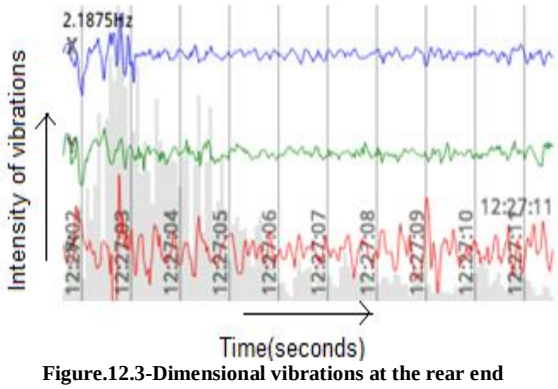

Figure.12.3-Dimensional vibrations at the rear end

From the above analysis we can conclude that the vibration intensity is more and continuous at the engine compartment comparing to remaining two locations. So by placing the above system at these locations we can obtain maximum power [2].

VII. EXPERIMENTAL ANALYSIS

A. MASS-SPRING SYSTEM

Experiment has been done on piezo crystal and it is tested using a Light emitting diode (LED). LED electrodes are connected to PZT output terminals and it glows with full intensity. The weights taken for experimental purpose is of order 0.5kilograms and PZT material of length 10centimetres and width 5cm.The output voltage and current of the 3 crystals have been measured whose peak values are found to be 6.5 volts and 131micro amperes in main PZT and 3.5 volts and 70 microamperes in each of auxillary PZTs. So by using these 3 dimension vibrations we can get a maximum power of 1.34milli watts can be obtained. These PZTs can be connected in series or parallel according to the requirement of load. But the amount of power obtained exists instantaneously. So this output power has to be stored into a battery in order for further usage.

B. SPRING-MAGNET SYSTEM

Experiment has been conducted for determining the output power on spring-magnet system by connecting a load across the coil terminals and by measuring output voltage. Since this system requires high amplitude and low frequency vibrations, these vibrations are provided when this spring-magnet system is connected at locations of vehicle where intensity of vibrations is more(at engine compartment). If the input vibration frequency is of order 4Hertzs [3]as given in Figure.10, then an output voltage of about 2.5Volts from each coil is obtained which is ten turns each whose output alternating power can be converted into unidirectional by using rectifiers and stored in batteries.

VIII. OUTPUT STAGE OF PIEZO ENERGY CONVERSION SYSTEM

The output power of the piezoelectric material is alternating in nature which is not suitable for storage in batteries. So in order to store the electrical energy into energy storage devices it is first converted from bipolar to unipolar direction. A full wave rectifier is used for converting Alternating current output to Direct current [4]. But the output Direct current waveform is not smooth. It again contains pulses which is not efficient for storage in batteries. So in order to smooth the output waveform a capacitor in parallel with load is placed. But the value of capacitor[3] is chosen such that the value of load capacitance is equal to source capacitance(i.e internal capacitance of unstressed piezoelectric material).

IX. CONCLUSION

The proposed methods which are used to convert mechanical vibrations produced in vehicles to useful electrical energy is to use a PZT material as an energy converting device in method-1 and using principle of electromagnetic induction in method-2. The obtained output power is utilized to power other devices or it can be stored in batteries. The vibrations produced in moving vehicles are along 3-dimensions and is continuous but this vibration energy is going as a waste. So in order to harness this waste going energy we have introduced two models in which one uses Piezoelectric effect and the other uses principle of electromagnetic induction. Implementation aspects focuses on the practical work carried out in the field of Piezoelectric Energy Harvesting using mass-spring system and Electromotive force induction using spring-magnet system which can efficiently convert 3-dimensional vibrations at any part of the vehicle. Maximum power from two systems can be obtained by choosing locations in the vehicle where intensity of vibrations is more. These vibrations along 3-dimensions results in power obtained from three sources (PZTs) along with three coils which is desirable. The combination of these two systems electrically (series and parallel) will result in obtaining required voltage and current according to load requirement. This idea of 3-Dimensional piezoelectric energy conversion along with Electromotive Force induction will efficiently solve the problem of charging the batteries while we are in journey. This concept will help to power up any low power device even when we are travelling through some areas where there is no source of power.

X. REFERENCES

[1] C.B. Williamst, A. Pavic, R.S. Crouch, and R.C. Woodst "FEASIBILITY STUDY OF VIBRATION-ELECTRICGENERATOR FOR BRIDGE VIBRATION SENSORS", 16th International Modal Analysis Conference (IMAC XVI), pp. 1111-1117, Santa Barbara, CA, USA, February,1998.

[2] G. Staines, Helmut Hofmann, Josef Dommer, L.L. Altgilbers, Ya. Tkach "COMPACT PIEZO-BASED HIGH VOLTAGE GENERATOR – PART I:QUASISTATIC MEASUREMENTS" Electromagnetic Phenomena 2003, Vol.3, No. 3(11),pp. 373-383.

[3] Stephen R. Platt, Shane Farritor, and Hani Haider"ON LOW-FREQUENCY ELECTRIC POWER GENERATION WITH PZT CERAMICS" IEEE/ASME TRANSACTIONS ON MECHATRONICS, VOL. 10, NO. 2, APRIL 2005, 10(2),pp. 240-252.

[4] TanviDikshith, DhavalShrivastava, Abhijeetgorey, Ashishgupta,Paragparandkar,Sumanthkatiyal"ENERGY HARVESTING VIA PIEZOELECTRICITY", Proceedings of the 4th National Conference; INDIACom-2010 Computing For Nation Development, February 25 – 26, 2010, Volume-2,Issue-2, pp. 2558–2561,BharatiVidyapeeth's Institute of Computer Applications and Management, New Delhi.

[5] "APPARTUS FOR CONVERTING VIBRATING ENERGY INTO ELECTRIC POWER",Kesatoshitakeuchi,suwa (JP), APP. no 10/125, 567, Publication number: US 2002/0172060 A1 Filing date: Apr 19, 2002, Issued patent: US7009315 , Issue date Mar 7, 2006.

[6] "ANALYTICAL MODELS TO PREDICT POWER HARVESTING WITH PIEZOELECTRIC MATERIALS", Master's Thesis by timothy eggborn, etd-05192003-150202 ,May 2003, Blacksburg, Virginia .

[7] Ahola J, Särkimäki V, Ahonen T, Kosonen A, Tiainen R, Lindh T., "DESIGN CONSIDERATIONS OF ENERGY HARVESTING WIRELESS SENSORS FOR CONDITION MONITORING OF ELECTRONIC MOTORS", Proc. 5th Int. Conf. ConditionMonitoring & Machinery Failure Prevention Technologies 15–18 July 2008, Edinburgh, UK.