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Power harvesting from vibration

Sri. Sengupta A[1,☼], Solanki SS[2]

1. Final Year, M.E. Student, Department of Electronics & Communication Engineering, Birla Institute of Technology, Mesra, India,
2. Associate Professor, Department of Electronics & Communication Engineering, Birla Institute of Technology, Mesra, India, sssolanki@bitmesra.ac.in

☼*Corresponding author:* Final Year, M.E. Student, Department of Electronics & Communication Engineering, Birla Institute of Technology, Mesra, India, Mail: senguptaabhilash@gmail.com, Mobile No: +919830754726

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ABSTRACT
Harvesting of power from the energy dissipated during machine operation is a major thrust in the study of non-conventional energy resources. Voltage generation from the vibration and its various modes, forms, the controlled conditions, and current status of development are being described with historical chronology. The finding and experience of the present author group are also being shared. The major hindrances in the purposeful application of the device are low amplitude current/voltage generation, problem of stabilized and standardized output etc. Further researches are needed to address all these issues.

Key Words: Power Harvesting, Vibration Generator, Induction Generator, Piezoelectric Generator.

Vibration Generator:
A Vibration Generator or vibration powered generator is a type of transducer that converts kinetic energy derived from vibration to electrical energy.

1. INTRODUCTION
The energy need in the modern society is constantly rising. In present day India, in her current scenario, there has been massive increase in energy consumption. This may result from the large scale turnkey project, moderate scale industrial growth to small scale recharge devices at the user level. To maintain this growing need, every country draws a large amount of energy from a variety of sources. These sources can be categorized as conventional and non-conventional source of energy. The main sources are Fossil Fuel Energy, Hydraulic Energy and Nuclear Energy. Out of these, the fossil fuels are used to generate energy in more than 85% of all energy sources. However all these sources have their own hindrances. Hydraulic Energy system has got a high setup cost, while Nuclear Energy involves a high risk, and Worst of all; there has been a rapid depletion and exhaustion of fossil fuels globally, for last few decades. At this rate of expenditure the storage of fossil fuel will be exhausted within a few decades. In this review, we shall present the scope of vibration based energy generator as a tool for power harvesting. In the area of energy conservation, an important aspect is utilization of wasted energy drawn from various conventional and non conventional sources. During machine operations, a part of energy is lost due to friction and vibration and dissipated as unused heat. These byproducts of operations can be suitably used to generate power. The main aspect of energy harvesting is to recover energy wasted in a process and to store and reuse that energy in another process. In order to harvest the energy transformed into vibration during machine operation, researches have been conducted for a long time. The main two approaches are (1) Electromagnetic/Inductive:- Here a coil is moved through a magnetic field, which causes a current flow into the coil (Figure 1) and (Figure 2) Piezoelectric:- Differential pressure in a Piezoelectric material causes a voltage generation across it(Figure 2). Researches are being carried out on these two areas for a considerable period of time.

2. HISTORY OF ENERGY HARVESTING THROUGH VIBRATION
The trend of research to use vibration as an energy source indirectly started with the use of vibration sensor. In the year 1997, C. B. William *et al* (Willium et al. 1998) performed a study of vibration on the Stradbroke Road bridge and the Prince of Wales Bridge in Sheffield U.K. The main goal was to observe the vibration profile of those bridges and prepare a damage report. In order to do so, the scientists used a vibration to energy convertor and tabulated the data.

$$V = \frac{j\omega \frac{2c_p d_{31} t_c}{a\varepsilon}}{j\omega\left(\omega^2 k_{31}^2 + \frac{2\zeta\omega}{RC_b}\right) - 2\zeta\omega^3} \frac{A_{in}}{k_2} \quad (1)$$

$$P = \frac{1}{2\omega^2} \frac{RC_b^2 \left(\frac{2c_p d_{31} t_c}{k_2 a\varepsilon}\right)^2 A_{in}^2}{\left(4\zeta^2 + k_{31}^4\right)(RC_b\omega)^2 + 4\zeta k_{31}^2 (RC_b\omega) + 4\zeta^2} \quad (2)$$

$$R_{opt} = \frac{1}{\omega C_b} \frac{2\zeta}{\sqrt{(4\zeta^2 + k_{31}^4)}} \quad (3)$$

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Power Harvesting

Power harvesting or energy harvesting stands for recovering energy wasted in a process and to store and reuse that energy in another process. It is a means of prevention and utilization of the wasted energy drawn from various conventional and non conventional sources. During machine execution, a part of energy used, is lost due to friction and vibration and dissipated as unused heat. Systems have been developed to reduce these energy losses; however it cannot be completely prevented. The goal of power harvesting is to convert these byproducts of machine operations into usable power.

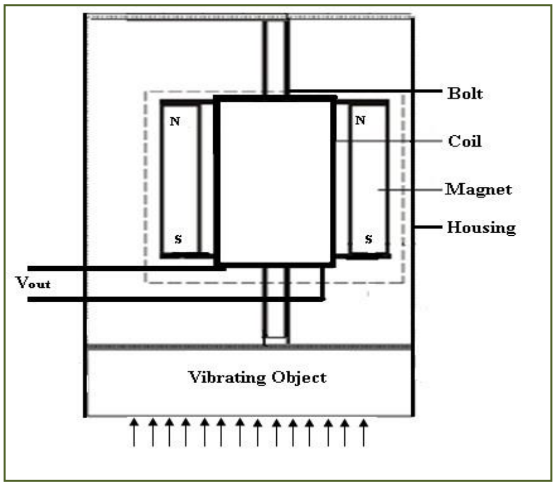

Figure 1
Schematic of induction based generator

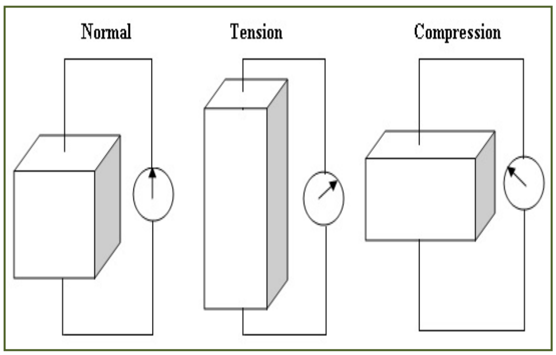

Figure 2
Schematic of piezoelectric generator

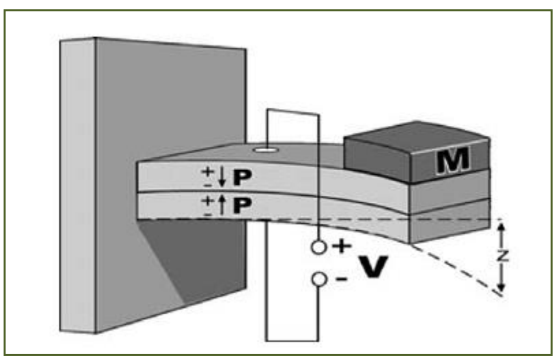

Figure 3
Piezoelectric generator cantilever model [Roundy et al. 2003]

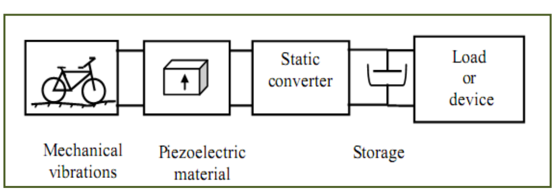

Figure 5
General diagram of generator based vibrations energy harvesting using piezoelectric material (Minazara et al. 2008)

Piezoelectricity:
Piezoelectricity is the ability of certain materials to generate a temporary voltage when pressure applied on it.

Piezoelectric Generator:
A piezoelectric generator is a type of generator that uses the principle of piezoelectricity to generate voltage.

This showed a voltage generation from the sensors due to normal vehicle movement. The vibration sensors they used were based on the inductive model.

In 1998, a self powered Signal Processing Unit based on vibration based power generation was designed (Amirtharajah & Chandrakasan 1998). In the system they used a moving coil electromagnetic transducer as a power source. The transducer was able to generate power in the order of 400uW. While the focus of the research here was to generate a good signal processing unit, the researcher developed a mathematical model for the power source and performed several test run on it, which gave a recorded database of a low amplitude power source.

While researchers performed indirect experiments on vibration to energy convertors, the idea to use it directly as a power source also came into view with the help of piezoelectric materials. In 1996 Umeda *et al* studied a piezoelectric generator which converted the mechanical energy into electrical, using a piezoelectric vibration (Umeda et al. 1996). In their study they analyzed the voltage output of piezoelectric material for differential pressure applied on it. Latter on the same year (Umeda et al. 1997) they conducted another experiment on the generator to find out the maximum capacity of voltage development of the generator. In this experiment they optimized their device and obtained higher power rating of 350-400uW.

On 2002 Shad Roundy, Paul K.Wright and J Rubay (Roundy et al. 2003) designed a Vibration to Electricity convertor using the principle of piezoelectric sensors. They prepared a *Cantilever* model for the generator (Figure 3). A strip of piezoelectric material was fixed at one side with the housing, while the other end was kept free with a weight on it. The strip was kept parallel to ground and the base was fixed with the vibrating surface. As the vibration occurs, the strip experiences a horizontal movement causing it to undergo repeated stress and strain. This generates a voltage in the strip. The model was tested using laboratory setups and an average of 200-250uW power was obtained from a vibration source with acceleration amplitude of 2.5 m/s^2 at 120 Hz.

Latter on 2004 Shad Roundy and Paul Wright (Roundy & Wright, 2004) optimized and tested the cantilever model. They formulated a mathematical model describing the output voltage (eqn. 1) and r. m. s. power transferred to the load (eqn. 2). They tested the device on both capacitive and resistive load and obtained a power of 375-400uW and also able to store the energy using a capacitive load. They also formulated the optimized resistance load (eqn. 3).It can be stated that, keeping all other parameters constant, the output voltage and power in a piezoelectric generator were directly proportional to the amplitude of the acceleration experienced by the material and its square respectively rather than the amplitude of the pressure applied on the material.

On 2007, a laboratory based study on Piezoelectric Generator was performed (Singh & Middleton, 2007). During their experiment they developed a model of the input vibration using the vibration profile obtained from a water jet driller. They also prepared a model of the voltage generating circuit (Figure 4) and match those two in a single model obtaining a comprehensive model of entire vibration to electricity conversion for a controlled and specific vibration system. While the previous experiments on controlled and specified vibration profiles were going on; in the year of 2007 Elie Lefeuvre and her team (Lefeuvre et al, 2007) tested a piezoelectric generator on a completely random vibration spectrum and obtained the voltage output vs vibration input for a random vibration system.

Minazara et al (2008) designed and performed a field experiment on the piezoelectric generator using a bike on 2008 (Minazara et al. 2008), (Figure 5). They designed a mechanical set up and attach accelerometer into separate parts of the bike (in the frame, in the fork, under the handlebar, under the saddle), (Figure 6). Thus they selected the fork as the position which sustains maximum force due to a

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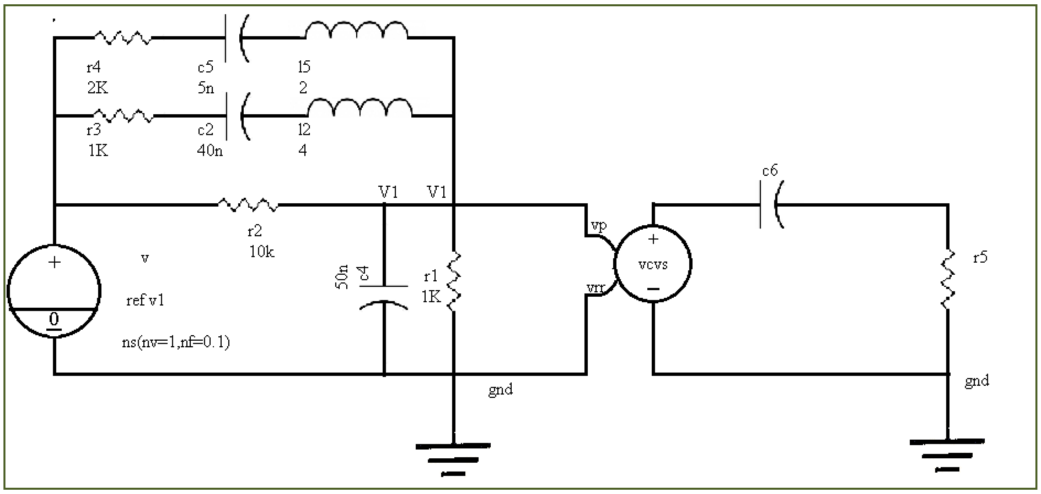

Figure 4
Vibration and Voltage generator simulation circuit model (Singh & Middleton. 2007)

journey. Then they replaced the accelerometer with a piezoelectric generator and drove the bike on several types of tracks (clay track, worn trail, paved road etc) and thus obtained a recorded profile of the voltage generated. They also used a capacitive circuit to trim the voltage produced and a resistive load. Using this model they obtained power in order of 30mW with a speed of 21km/h in clay track.

In 2010 an induction based generator was designed and laboratory tested by Bogdan Sapinski. He designed an MR damper based vibration to electricity convertor (Figure 7), (Bogdan 2010) where he put a set of magnet within a copper wire coil such that the magnets can have free horizontal motion within the coil. He tested this design using a laboratory set up and tabulated the relation between several parameters in the system. The present author group conducted a similar type of experiment in 2012. An induction based generator was developed where a coil was made to undergo vertical movement with respect to the vibration force, within a magnetic field (Figure 8). The instrument was fixed on a bicycle which was then driven into several types of tracks (Eg. Bitumen Track, Clay Track, Country Track, Worn Trail, Forest Trail etc) with an average speed of 10-15km/hr. The resultant voltages generated in the order of 0.4 to 1.5 mv in different type of track as described, with appropriate amount of currents (Sengupta & Solanki 2012). The results correlated well with the theoretical prediction. However, detail studies are needed with the changing variables like strength, quality and specification of the magnet used, springs and suspensions, controlled condition etc.

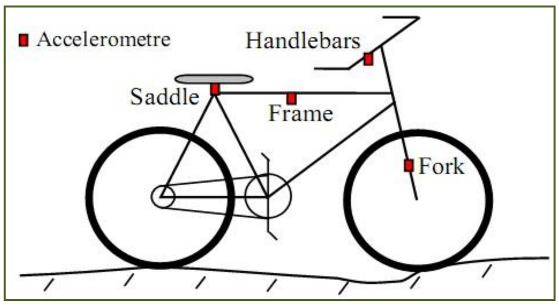

Figure 6
Accelerometer positions in bike (Minazara et al. 2008)

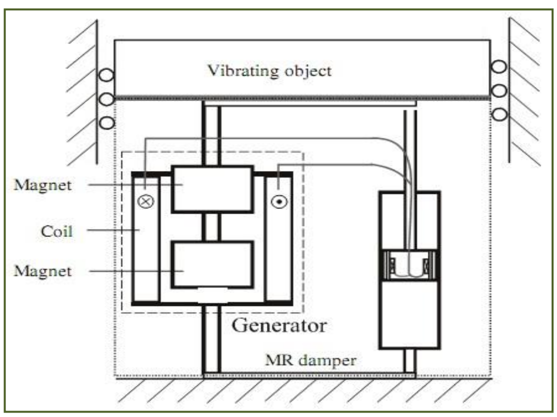

Figure 7
Schematic of self-powered MR damper based vibration control system (Bogdan 2010)

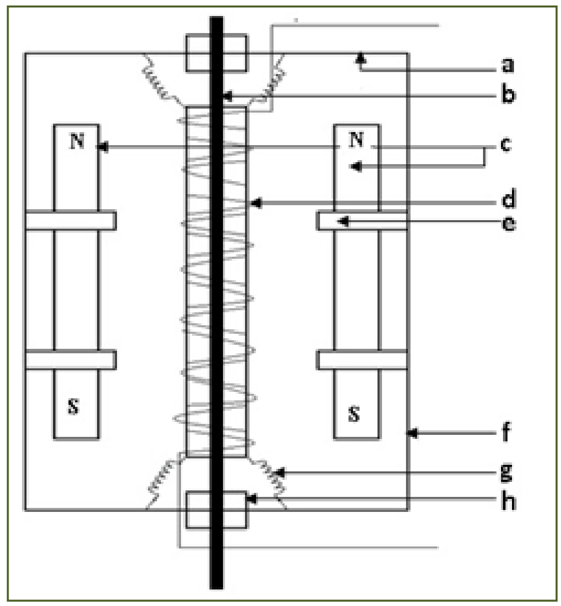

Figure 8
Schematic Design of the induction based vibration to energy convertor (Sengupta & Solanki 2012);
a) Plastic plate stabilizing the induction coil within the magnetic field
b) Axial rod
c) Magnets
d) Induction Coil
e) Magnet Holders
f) Metallic cylinder
g) Spring & strings holding the coil
h) Obturators

Induction Generator:
An induction generator or asynchronous generator is a type of AC electrical generator that uses the principles of induction motors to produce power.

3. CONCLUSION

With the growing need of energy, harvesting of mechanical energy from vibration can be a good and useful source. This mode can also be used to develop self powered rechargeable devices. However there are still many problems. One of the major problems is the output. While the induction generators are large in size and absorb a good amount of energy themselves, the piezoelectric devices are very small and has very low yield. Minimizing the induction generator size without compromising the output and maximizing the yield from piezoelectric generator without increasing the setup cost is a

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challenge in the current context. Also, the appropriate standardization for a steady and stable output pattern of energy is also very crucial. The multidimensional potential of the practical applications of the vibration based energy convertors needs serious attention. With the increasing need of energy and increasing use of wireless technologies the vibration based energy convertors may give us a new edge in technology.

SUMMARY OF RESEARCH

1. This review provides a summary on researches performed on power harvesting from vibration.

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