Design and parametric studies of spring comprised piezoelectric energy harvester

K.Viswanath Allamraju   Srikanth Korla

Abstract- In this paper investigation on design of Spring-comprised Piezoelectric Energy Harvester (SPEH) for random vibrations, are modeled and analyzed. The work basically focuses on development of a novel spring comprised piezoelectric energy harvester with hitting masses, which is capable of harvesting energy from the ambient vibration. By properly designing the parameters, such as the length, diameter and mass of the shell and hitting masses, we can increase energy generated. Parametric analysis is carried out in SIMULINK for finding these parameters. The main aim of the research is to get maximum voltage & power output. Analysis is carried out by varying the stiffness of spring and support excitation. The design of SPEH has performed based on the analysis, and conducted experiments on the vibration shaker at a resonance frequency of 37 Hz., at support displacement of 40 mm and developed a voltage of 8 volts as a output.

Index terms-Piezo electricity, Energy Harvester, shell, simulink, spring comprised, simulink, random vibrations.

1. INTRODUCTION:

The process of acquiring the energy surrounding a system and converting it into usable electrical energy is termed power harvesting. At present, next-generation energy technology is a technology to harvest electrical energy using piezoelectric ceramics based on piezoelectric effect. Piezoelectric effect is the phenomenon where electrical energy is obtained when mechanical energy is applied to piezoelectric ceramic. Technologies are developed because of a shortage of energy in the world. One of the next-generation energy technologies is piezoelectric energy harvesting technology. Piezoelectric energy harvesting technology is very eco-friendly and useful because of the use of discarded physical energy around our living atmosphere. For example, electrical energy is harvested from a vibration of a road when people and cars pass the road. For this method, the piezoelectric energy harvesting technology needs proper piezoelectric Harvester. The world energy production sector is in transition and is nowadays called to face great challenges in a context in which the fossil fuel reserves are running out, while the energy demand steadily increases. On the other hand, the rising cost and the related environmental issues make the use of conventional energy resources more and more difficult. The increment of the world energy demand, mainly fulfilled by fossil fuels has brought to an increment in greenhouse gas emissions with serious consequences on our environment.

K.Viswanath Allamraju, Research Scholar in Mechanical Engineering, NIT Warangal, India PH:+919492060340,Email:akvn87@gmail.com

Srikanth Korla, Assistant Professor, NIT Warangal,India

Energy harvesting allows the recovery of the mechanical energy from environmental vibrations and is obtained through the piezoelectric materials according to the direct piezoelectric effect. More in detail, it implies the generation of an electric field across the material corresponding to a mechanical strain. Since past this technology found interesting applications in the framework of wireless sensor systems in order to make the transmission and acquisition units self-powered.

2. LITERATURE REVIEW:

Authors are focusing on Piezo electric generation by man powered and impact coupled devices. Power may be recovered passively from body heat, breathing, blood pressure, arm motion, typing, and walking or actively through user actions such as winding or pedalling. John Kymissis examined three different devices that can be built into a shoe, and used for generating electrical power "parasitically" while walking. One of these is piezoelectric in nature: a unimorph strip made from Piezo ceramic composite material. The second is a shoe-mounted rotary magnetic Harvester [1]. Later in 2002 Jose Luis Gonzalez shown how it is feasible to use the energy harvested from human body to power wearable units incorporating computing, communication and audio functions. Existing shoe mounted rotary electromechanical Harvesters can provide enough power from walking to supply these devices. The Harvesters based on piezoelectric effect are or will be also capable of powering wearable units. However more investigation and development is necessary to raise the electrical output power for the existing prototypes to the power level that can be obtained theoretically [2].

Spring-comprised Piezoelectric Energy Harvester (SPEH) for random vibration is modeled and analyzed in this work. The work basically focuses a novel spring comprised piezoelectric energy harvester with hitting masses, which is capable of harvesting energy from the ambient vibration. By properly designing the parameters, such as the length, diameter and mass of the shell and hitting masses, we can increase energy generated. For finding these parameters we carried out parametric analysis in SIMULINK. The main aim of the project is to get maximum voltage & power. Analysis is carried out by varying the geometry, mass of a shell & stiffness of spring. Based on the analysis design of SPEH would be done.

Ki Hwan described a method for efficient piezoelectric energy harvesting from impacts using an array of piezoelectric modules. He showed that rectifying the output of each module separately affords higher output voltage and faster charging than the use of a single rectifier. In addition, an increase in the rate of impacts produces an increase in output voltage and charging rate. However, under real conditions, it may not be practical to increase the rate of impacts. Instead, it is more practical to include a phase difference. The inclusion of a phase difference between impacts on individual modules in the array has the same effect as an increase in the rate of impacts increase in the charging rate. Another advantage of including a phase difference is that the forces are distributed temporally. These methods can be used to realize more efficient piezoelectric energy harvesting [3].

Later Kumar discussed the simulation studies on a vibration based energy harvesting system to convert the undesirable mechanical vibration to useful green power. The design consists of a resonating proof mass and a spring system enclosed in housing and fixed on the source of vibration. He proposed that by using an array of such devices tuned to slightly different frequencies, a wide bandwidth response can be obtained [4]. Shashank presented a patent as “energy harvesting with plurality of piezoelectric elements”. The invention pertain generally to a mechanism for capturing mechanical energy and converting it to electrical, and is particularly useful for continually charging or providing emergency power to mobile, battery powered devices that are handheld or carried by persons. The mechanism comprises a plurality of elongated piezoelectric elements for generating electric energy from mechanical energy. [5]. A spring comprised piezoelectric energy harvester is proposed in this paper. We developed a complete model of such a vibration harvester. Our innovation here is to take advantage of impact made by hitting masses on unimorph PZT5H elements. The impact made by hitting masses produces voltage. Voltage generated can be used for charging the low power electronic application.

3. DESIGN OF SPEH

A typical energy harvester is composed of a cantilever beam with tip mass at the end and PZT film on the beam surface, which produces limited strain in PZT film. Our innovation here is to take advantage of impact made by hitting masses on PZT elements. The impact made by hitting masses produces voltage. Voltage generated can be used for portable electronic application. To our knowledge, no publication proposing a detailed model of the device including the description of the impact mechanism and the resulting behavior of the piezoelectric bender exists. The authors have developed a model of spring comprised impact based energy Harvester (SPEH). The advantages of this device are Impact based harvester provides higher voltage than conventional cantilever type of devices, device is compact, its construction is simple, it is easy to handle and it can be fitted with vehicles or used to harvest energy from vehicular traffic as well as from the train and pedestrian one, it is robust in use and no maintenance is required and also environmental pollution can be minimized.

The research is basically focuses a novel piezoelectric energy Harvester with hitting masses, which is capable of harvesting energy from the ambient vibration. The design comprises of a cylindrical shell with piezoelectric elements fixed inside of it. Hitting masses are placed inside freely. When mass hits piezoelectric film it generates voltage across piezoelectric element. By properly designing the parameters, such as the length, diameter, thickness and mass of the battery and hitting masses, we can magnify the motion particularly at its natural frequency. The main aim of the research is to get maximum output power. Analysis would be done by varying the parameters such as stiffness of spring, damping coefficient, and mass of a battery in SIMULINK. Finally optimum parameters for a system will be figured out. Based on these parameters design of SPEH would be done.

3.1 Preliminary design

The innovation introduced arises from the use of hitting masses instead of piezoelectric cantilever transducers. The concept of SPEH is similar to cantilever type of harvester where in the former case masses hits to the piezoelectric element which is inserted in a shell (Fig. 3.2), and in the later case strain is produced in piezoelectric element attached to the beam. The prototype of the energy harvesting device is made up of a frame with shell containing two piezoelectric elements & three hitting masses. The masses are placed free inside the shell. The piezoelectric elements used are of bimorph type. Whenever vibrations are imparted to the frame the springs transfers the vibration to shell, due that masses start hitting the piezoelectric elements. It develops voltage across piezoelectric elements. The generated voltage can be rectified with the help of a rectifier circuit. This energy can be stored in suitable storage device. The spring stores the energy coming from the external vibrations & transfers that energy to hitting masses. Hitting masses hits piezoelectric elements & converts that energy in to electricity.

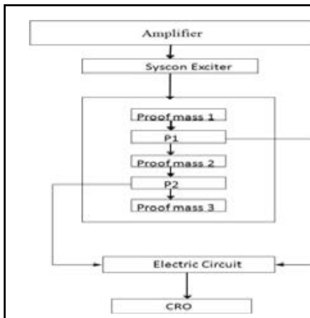

Fig.3.1: Layout of SPEH operation

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Fig 3.1 shows the layout of SPEH operation, p_1 & p_2 represents piezoelectric elements. The source vibration provides the vibration energy. This energy is getting transferred to the SPEH. From SPEH it gets transferred to hitting masses. Impact made by hitting masses on piezoelectric materials generates electric voltage. This electrical energy gets transferred to the electric circuit. Electric circuit converts it in to a rectified dc voltage. This voltage can be used by electronic equipments or can be stored in storage device.

3.2 Response of SPEH

In our proposed model, the excitation of the system is through the support instead of being applied on the mass. In such case, the support is considered to be excited by a sinusoidal motion y=Y sin ωt .The vibration of a device is due to excitation of base frame.

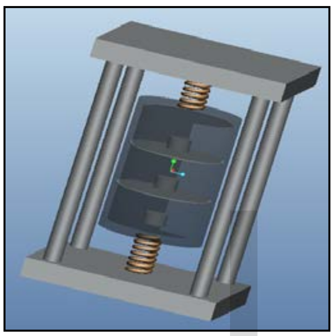

Fig. 3.2(a): Proposed design of SPEH by using CREO

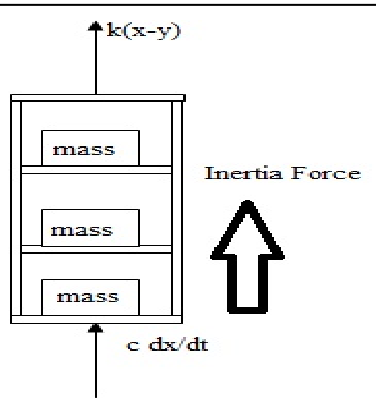

Fig. 3.2(b): Schematic diagram of SPEH

The analysis of forced vibrations due to excitation of support can be done considering absolute amplitude & relative amplitude of mass with respect to the support or base. In our case the nomenclature of various parameters is as follows:

M= Lumped mass
k= Effective stiffness of spring
c= Effective damping coefficient
ω= Excitation frequency
ω_n = Natural frequency
ξ= Damping factor
t= time

By applying the D-Alembert's method and the principle of superposition, calculated the response of SPEH. Equation 3.1 defines the characteristic of motion of the SPEH.

$$M\ddot{x}(t)+c[\dot{x}(t)-\dot{y}(t)]+k[x(t)-y(t)]=0 \qquad (3.1)$$

3.3 Parametric analysis of a SPEH with constant input support displacement

Parametric analysis of SPEH using SIMULINK is carried out for finding the parameters of a system such as stiffness of a spring, mass of a shell. SPEH is designed based on this parametric analysis. Equation (3.1) is simulated in SIMULINK. The model consists of various blocks such as gain, integrator, scope etc. In this case the input given to the model shown in fig. 3.3 is constant support displacement and the data used is mass of shell M=100gm stiffness of a spring k=10000N/m, damping coefficient c=0.1 Ns/m.

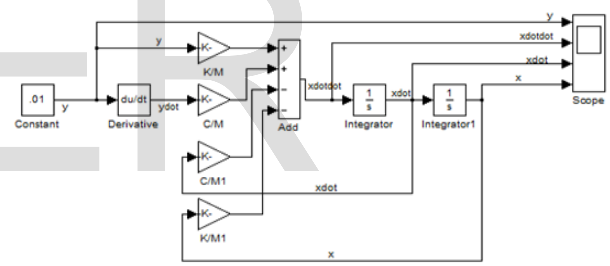

Fig.3.3 Model of SPEH with constant input (model developed in SIMULINK)

It is observed that the amplitude of vibration reduces gradually with time. Natural frequency of system is 37 Hz. If we give input constant displacement as Y=10mm the mass starts vibrating with maximum amplitude as X= 8mm. The amplitude reduces to zero after time equal to .5 sec for a given input values. Weight of hitting mass is assumed as 5gm force acting on hitting masses can be calculated by, $F = m(g \pm \ddot{x})$ (3.3)

Where, g is acceleration due to gravity & $\ddot{x}$ is acceleration due to motion of the body. From the acceleration graph we can observe maximum acceleration is $\ddot{x}$=400 m/s² and maximum force acting on mass is 2.049 N.

3.4 Analysis to study the effect of variation in spring stiffness on the system

It is demonstrated in Fig. 3.4 the plots of response of shell with various values of spring stiffness k. Other

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parameters are kept const in the analysis. The values for various parameters are, mass of SPEH is 150 gm, damping coefficient 0.1 Ns/m and support amplitude is 40 mm.

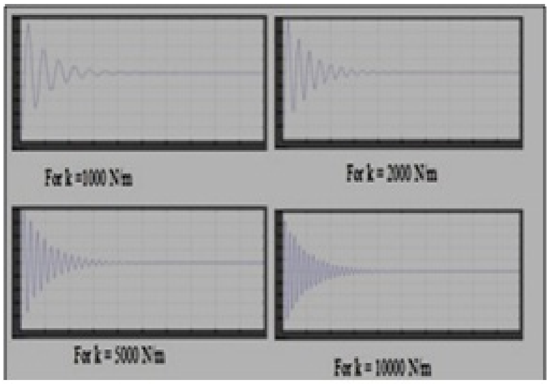

Fig.3.4: Response of shell at different values of stiffness

If the stiffness of the spring increases the amplitude of oscillation of the lumped mass is also increasing linearly as shown in fig. 3.5 . At the stiffness of 1000 N/m the value of maximum amplitude is 7 mm, at k = 2000 N/m, maximum amplitude is 8 mm and the difference is 1 mm for the increase in stiffness of 1000 N/m. At k = 3700 N/m, the value of maximum amplitude is 8.5 mm and at 10,000 N/m the value of maximum amplitude is 9 mm. By observing the response of shell at different values of spring stiffness, the maximum variation of amplitude is between 1000 N/m to 2000 N/m and minimum variation is between 3700 N/m to 10000 N/m i.e. 0.5 mm.

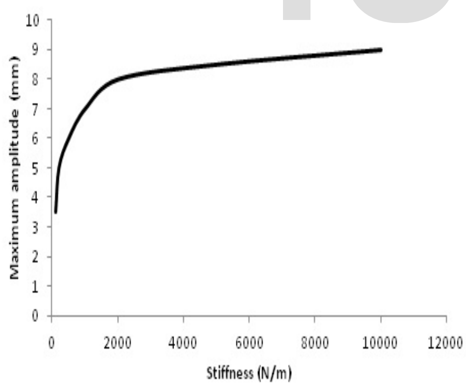

Fig. 3.5 Maximum amplitude of a shell Vs Spring stiffness (effect of variation in spring stiffness)

3.5 Experimental setup

Experiments are conducted for studying the response of the shell by changing the support excitation displacement for getting the maximum output voltage which is measured through BK precision Oscilloscope. The principle working is when the proof mass hits the Piezo actuators; stress generated by hitting masses is converted into strain and generates the electricity. The applicable constitutive equations are given by the same author in his previous research paper titled as "Investigation of design parameters and actuator constraints in piezoelectric energy harvesters" in detail. Fig. 3.6 (a) shows the experimental setup of SPEH test rig with oscilloscope . The values for various parameters are, the lumped mass of a scavenging device is 100 gm, Stiffness of a spring k=10000 N/m.

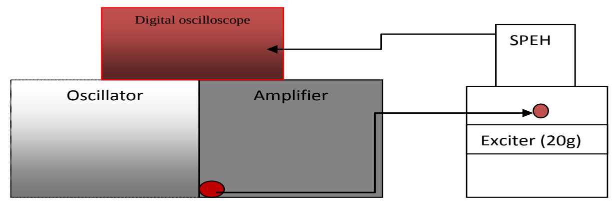

Fig.3.6 (a): Line diagram of experimental setup

At a excitation frequency of 37 Hz the shaker is operated by amplifying the current to give different amplitudes to the shaker. Oscilloscope is used for measuring the output voltage of SPEH; it indicates the voltage on vertical axis and time in seconds on horizontal axis. Authors considered the time of hitting mass and measured the frequency. At the time of hitting, the voltage is measured as 8 volts and after that the output is between 2 to 5 Volts as shown in Figure 3.6(b).

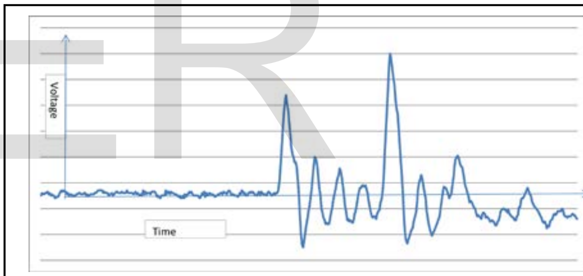

Fig. 3.6(b) Reading of Oscilloscope (at 3.5 Sec)

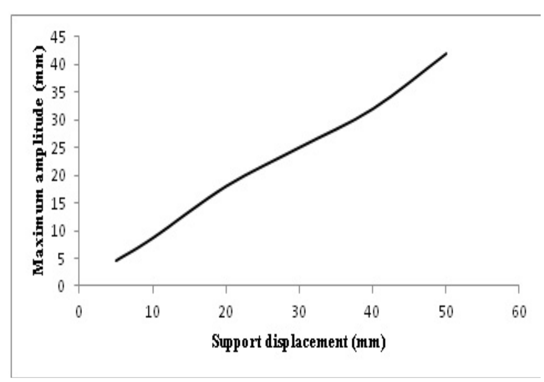

Fig. 3.7 Maximum amplitude of a shell Vs Support displacement (effect of variation in support displacement)

It is observed in fig. 3.14 that as the support displacement increases the amplitude of vibration increases. For support displacement of 5 mm the amplitude is 4.5mm while for value of support displacement 37 mm the amplitude is 42 mm and got the reading of 8 volts in the oscilloscope by our experiments. The stable time remains same for all values of support displacement.

4. Conclusions

In this paper the authors proposed a SPEH. The theoretical analysis is done to generate mathematical model of a device. Parametric analysis on mathematical model is done in SIMULINK. The effect of various parameters such as stiffness, support displacement on the system is studied. It is observed from the analysis that in order to increase time of vibration, value of k/m ratio is to be maximized within working frequency range and there should be less damping other than piezoelectric energy generation. The modeling of parts of SPEH is performed based on values of parameters design. It is observed that to increase time of vibration, value of K/m ratio is to be maximized within working frequency range (37 Hz) and also that value of support displacement should be large to get better results. In this area the authors are doing research for getting the more output power for the application of low power devices such as mobile phones, portable electronic scales, electronic laser lamps,watches and wireless sensor networks.

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