Study of PEH Configurations & Circuitary and Techniques for Improving PEH Efficiency

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Abstract— The term "energy harvesting" refers to the generation of energy from sources such as ambient temperature, vibration or air flow. Converting the available energy from the environment allows a self-sufficient energy supply for small electric loads such as sensors or radio transmitters. Kinetic energy can be converted into electrical energy by means of the piezoelectric effect: Piezo elements convert the kinetic energy from vibrations or shocks into electrical energy. Using suitable electronics, this effect can be used for creating a self-sufficient energy supply system. This is of particular interest whenever a power supply via cable is not possible and the use of batteries and the associated maintenance expenditure are not desired. On that point are numerous agents on which amount of energy that can be gleaned from a vibrating system depends. The condition of the piezo - patch, position of the piezo - patch, magnitude of applied load, type of material used, model configuration, circuitry used etc. are some important elements that must be considered during energy harvesting. In this paper, we have reviewed the vibrational energy harvesting from different model configurations and also we have brushed up some papers in order to examine the various techniques through which efficiency of a piezoelectric energy harvester can be bettered.

Key words: Energy Harvesting, Cantilever, Shell, Stack, Cymbal, MEMS, Piezoelectric Materials, PEH (Piezoelectric energy harvesting)

I. ENERGY HARVESTING FROM VARIOUS CONFIGURATIONS

There are numerous factors on which amount of energy that can be harvested from a vibrating system depends. Shape of piezo-patch, position of piezo-patch, magnitude of applied load, type of material used, model configuration, circuitry used etc. are some important factors that must be considered during energy harvesting. In this section we have reviewed the vibrational energy harvesting from different model configurations.

A. Cantilever Configuration

In a cantilever type arrangement one end of the structure (plate, beam etc.) remains fixed while other end is free to get displaced, such type of structure can produce large amount of deformation under vibrations and hence can be used to produce pressure-electricity.

Flynn and Sander (2002) worked on PZT-5H to find out the maximum limit of a stress cycle, that was 330W/cm and concluded that limiting stress is an important constraint for a vibrating cantilever configuration. Elvin et al.(2001) performed the energy harvesting experiment using PZT material on a simple beam , proposed a theoretical model and concluded that a simple bending beam can be used as a power source for strain energy sensors. Wright et al.(2003) investigated piezoelectric convertors and capacitive MEMS and found that low level vibrations occurring in office environment and local household can be used as an effective power source. Roundy et al.(2004) optimized a two layer cantilever piezoelectric generator and validate it by theoretical analysis. Figure (1) shows a two layer bender cantilever configuration used for energy harvesting.

Fig. 1: A two layer bender mounted as a cantilever. Where S is strain, M is mass, V is voltage and Z is vertical displacement. Roundy et al.(2004)

Lealand et al.(2005) worked on enhancing power harvesting capacity from low level ambient vibration sources and modeled a piezoelectric based small cantilever device. Wright et al.(2006) reduced the resonance frequency up to 24% by using axially compressed piezoelectric bimorph and found that 19-24% below the unloaded natural frequency ,power output becomes 65-90% of nominal value. Inman et al.(2005) compared the efficiency of monolithic piezoelectric(PZT) and micro fiber composite(MFC) and also determined experimentally the capacities of three different piezoelectric devices(a monolithic PZT, a bimorph Quick Pack QP and MFC) to recharge a discharged battery. Park et al.(2009) proposed a piezoelectric cantilever with a proof of micro-machined Si mass for low frequency vibrations energy harvesting applications and concluded that average power and power density were 0.32W , 416 W/cm² respectively.

B. Shell Configuration

The efficiency of piezoelectric energy harvesting can be improved by shell type structure because it can generate more strain as comparison to flat plate. Yoon et al.(2008) used a pneumatic shock machine to investigate the effect of gunfire shock on a ring shaped PZT-5A element and show the dependency of piezoelectric constant on load rate , energy transfer efficiency on the change in normalized impulse and shock bearing ability of piezo material. Yang et al.(2007) harvested piezoelectric energy torsional vibrations from a circular piezoelectric cell using polarized ceramics. Figure (2) shows a circular piezoelectric shell under mechanical loads as a generator.
Danak et al. (2005) used the shell theory to optimize the analytical model of curved piezoceramic and develop an expression for charge generation and concluded that charge generation can be improved due to higher strain by using curved shape piezoceramic.

Fig. 2: Circular piezoelectric shell generator under mechanical loads. Yang et al. (2007)

C. Stack Configuration

In stack type structure energy harvesting capacity is high due to multi-stacking of piezoelectric materials of $d_{33}$ mode, which provides a large capacitance and hence higher power output. Friswell et al. (2009) used stack configuration to analyze two different electrical circuits with and without inductor by stochastic approach. Lefeuvre et al. (2006) proved that energy conversion rate can be improved in a mechanical loading cycle by using synchronized switch damping (SSD) however this type of stack may be weak under cyclic shocks. Figure (3) shows the mechanical part of the experimental set up that is a structure composed of a 180 mm long cantilever steel beam clamped at one end on a rigid base.

Fig. 3: Experimental set up. Lefeuvre et al. (2006)

D. Cymbal Configuration

In micro level energy harvesting cymbal structures can be used very significantly because if they are subjected to transverse external forces they can provide more power output due to higher in plane strain. Li et al. (2011) proved that a piezoelectric transducer in flex-compressive mode can produce more electric power output than in conventional flex-tensoidal mode, by using double ring type stack containing one pair of pre-compressed bow shaped elastic plates. Kim et al. (2005) performed finite element analysis to show that under pre-stress cyclic conditions, piezoelectric energy harvesting can be more promising. Figure (4) shows the dimensional details of fabricated cymbal transducer.

Fig. 4: Fabricated cymbal transducer. Kim et al. (2005)

II. TECHNIQUES FOR IMPROVING ENERGY HARVESTING EFFICIENCY

In this section we have reviewed some papers in order to analyze the various techniques through which efficiency of a piezoelectric energy harvester can be improved. There are various ways of enhancing the efficiency like: using different piezoelectric materials in various combinations, using better circuitry for storage etc. and we have listed some of the important factors among them.

A. Using Specific Piezoelectric Configurations

Efficiency of piezoelectric power harvesting devices can be improved through modified piezoelectric material configurations and this can be done by applying pre-stress to maximize the strain, changing the stress direction, changing poling direction, providing the additional layers of materials, using different material compositions, maximizing the coupling coefficients, altering the electrode patterns and through the proper tuning of resonance frequency of the device.

Lee et al. (2005) worked on developing the more flexible piezoelectric materials that can be a better option of piezoceramics which are too brittle and less deformable, in cyclic loading conditions. Lee et al. (2004,2005) compared the durability of three different types of electrode layers (PVDF films coated with: poly 3,4-ethylenedioxythiophene/poly 4-styrenesulfonate{PEDOT/PSS}, indium tin oxide{ITO}, platinum{Pt} ) and found that PEDOT/PSS film was best among three. Mohammadi et al. (2003) produced flexible piezoelectric composites using PZT fibers of various diameters which were aligned, laminated and modeled in a epoxy(40% of the volume containing fibers and rest 60% of epoxy ) and concluded that sample containing the smaller diameter fibers were producing higher power outputs. Sodano et al. (2005a) compared the efficiencies of three different materials(PZT, a quick pack QP and macro-fiber composite MFC ) and found the efficiency of PZT higher than other two.
Baker et al. (2005) compared the capacities of different piezoelectric materials under $-31$ & $-33$ modes and concluded that in vibration environment, $-31$ configuration cantilever was most efficient and in high vibration environment, stack configuration was more durable. Yang et al. (2005) showed that a piezoelectric transducer operating in $-33$ mode can be more efficient if the coupling coefficients are high and operating frequency of device is near to its resonance frequency. Wu et al. (2006) improved the efficiency by altering the resonant frequency of a bimorph actuator through a microcontroller. Kenji and Takakgi (2010) worked on cymbal transducer to improve energy harvesting efficiency from high power mechanical vibrations using k modes ($k_{33}$, $k_{15}$ and $k_{t}$) rather than flex-tensional modes and explained three different modes of energy transfer in a piezoelectric energy harvesting system.

B. Through Better Circuitry

Efficiency of energy harvesting can also be improved by using such circuits which can extract more power from piezoelectric devices. In this section we have reviewed some researches which were focused on improving the efficiency of piezoelectric energy harvesters through modifying the electric circuitry. Figure (5) shows the utilization of a DC to DC converter after AC to DC converter, to improve the energy harvesting capacity of the circuit.

Shenck and Paradiso (2001) improved the efficiency of shoe mounted piezoelectric generator through introducing the switching converter into its initial circuit which was utilizing linear regulating scheme. Ottman et al. (2002) and Lesieutre et al. (2004) optimized the duty cycle of a switching DC-DC step down converter and found that at an optimal duty cycle of 2.8% for their system, efficiency obtained a maximum value of 70%. Figure (6) shows the working of a bridge rectifier type AC to DC converter which converts the alternating signal produced by the piezoelectric crystal into digital signal. Ammar et al. (2005) improved the efficiency of charge accumulation on the battery for a prototype energy harvesting circuit by creating an adaptive algorithm in order to optimize the duty cycle of a DC-DC buck converter.

Lefeuvre et al. (2005b) developed a power harvesting circuit containing a rectifying diode bridge and a flyback switching mode DC-DC converter. They used “synchronous electric charge extraction” technology and achieved an improvement in charge transfer by an amount of 400% over a linear impedance based converter. Sodano et al. (2005b) compared the charge storage and discharging capabilities of a capacitor and a nickel metal hydride battery. They concluded that using the capacitor as charge storage is advantageous because the energy can be used instantaneously while the battery will take few hours to get charged but need not to be used immediately, and can be used later.

Guan and Liao (2006) compared charge storage capabilities, charge-discharge efficiency, self-discharge rates, energy densities and life time of all three storage mediums (an electric double layer type super-capacitor EDLC, a nickel metal hydride battery, a lithium ion battery) and found that super-capacitor was better than two specially when self-discharge rate is not significant factor.

Figure (7) shows a circuit for “Synchronized Switch Harvesting on Inductor” technique that was proposed in 2005 and can be used to boost up the energy harvesting capacity of a piezoelectric harvester.

III. CONCLUSION

Various techniques of piezoelectric energy harvesting were reviewed in this paper.

- Principle of piezoelectricity, three general methods of vibrational energy harvesting, various type of piezoelectric materials, different types of piezoelectric...
energy harvester device configurations, energy harvesting efficiency improvement techniques, vibrational damping from energy harvesting, recent developments and the future scope of the technology were investigated.

- Piezoelectric vibrational energy harvesting technology is remarked as a permanent, environment friendly and durable power supply source for both portable electronic devices as well as for recharging the batteries for charge reservation.

- We have studied piezoelectric harvester can directly convert the strain into electrical energy without any need of external voltage source and also suitable for any size device configuration. Inspite of these attributes, output voltage produced by these harvesters is quite less and even during cyclic loading conditions chances of breakdown are more.

- We can make the technology of piezoelectric energy harvesting more reliable and trustful by using more flexible piezoelectric materials with high coupling coefficients and integrating them into efficient rectifiers and storage circuits.

- Piezoelectric energy harvesting systems are a onetime installment and they require very less maintenance, making them cost efficient hence the adaptation of this technology for producing pressure electricity.

REFERENCES


