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A Review on Piezoelectric Energy Harvesting Systems Based on Different Mechanical Structures

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ABSTRACT

In the era of comfortable science and technology, there is a huge demand of self power source for portable devices and wireless sensor network systems. Due to decrement in size and power requirements of such daily use devices, researchers are focusing on developing such circuits which can generate electric energy from mechanical vibrations and hence can supply power to portable electronic devices. Energy harvesting technology using piezoelectric materials is a significant step in this direction because of their ability to directly convert the mechanical stress into an electric charge. This article discusses the effect of various shapes like cantilever beam, ring, shell, disc etc. on piezoelectric energy harvesting system.

Keywords: Piezoelectric, Cantilever beam, Ring, Shell

1. INTRODUCTION

Energy harvesting or energy scavenging or power harvesting can be defined as the process of collecting the minute amount of energy that would otherwise be lost and go waste as light, sound, heat, vibrations or movements, from one or more surrounding energy source, accumulating and using it at present time or storing it for future use. In the world, there is various untapped energy sources like: electromagnetic field, solar energy field, waste heat and thermal energy field, air field, sound, vibrational energy and even our body movements and motions. These all energy sources have the potential to be harvested in order to provide the power to wireless sensors and other portable electronic devices [1]. Now a day, two forms of battery have been used for low-power electronics, namely primary and secondary.

A primary battery is a single-use or "throw away" battery that is disposable in nature while the secondary battery can be recharged again. Some examples of primary batteries include Alkaline, Silver-Oxide and Mercury batteries. Lithium, Nickel-Cadmium and Lead-Acid storage batteries which are widely used in mobile phones, electric rickshaws, etc. fall into the category of secondary batteries. Although these batteries are non-toxic and environmentally friendly, their limited period cycle, unreliable utility and limited life span restrict their usage. Also, there are few applications that are affected due to chemicals which make current batteries undesirable. They are also unsafe to use for security and system monitoring because they can cause serious problems when they discharge without warning [2, 3]. So the researchers are entering into the field of energy harvesting in order to develop such technologies which can be used as self power source for portable devices and wireless sensor network system [4, 5].

Energy has been already harvested in the form of solar energy, watermill, windmill and the technologies based on long established principles such as the thermoelectric effects, photovoltaic and electro-dynamic [6, 7]. The renewable energy is that which came from the natural sources and is emerging as the future source of power due to the limited quantity of fossil fuel and instability of nuclear power [8]. Many researchers have been readily exploring various 'macro' renewable energy sources for instance geothermal energy, wind energy, solar energy and nuclear energy which generate energy at macro level within the range of kW or MW.

Energy harvesting at micro level is based on mechanical vibrations, mechanical stress and strain, human motion, magnetic force, chemical or biological sources, ocean/sea currents, thermal energy from various heat sources like furnace and frictional sources, which can generate power at mW or µW level for providing alternative of conventional battery [9]. Now a day's, 3D printing almost covers all sectors like healthcare, automobile, pharma, textile etc. 3D printing is also used for fabrication of piezo patches for piezo electric energy harvesting [10,11,12].

2 TYPES OF ENERGY HARVESTING SYSTEMS

There are many major and minor scale energy harvesting units that are currently being developed all around the world. Solar energy, wind energy, geothermal energy, nuclear energy, etc. are all major scale renewable energy harvesting systems. Their main purpose is generating large scale power so as to diminish the worldwide dependence on fossil fuel consumption [13]. The micro scale energy harvesting systems, including electromagnetic energy, vibrational energy, piezoelectric energy, water drop energy, etc. present us with an attractive and feasible solution to low-power generation that can power portable electronics applications effectively. Figure 1 depicts the various energy harvesting systems and the sources required for energy harvesting [14].

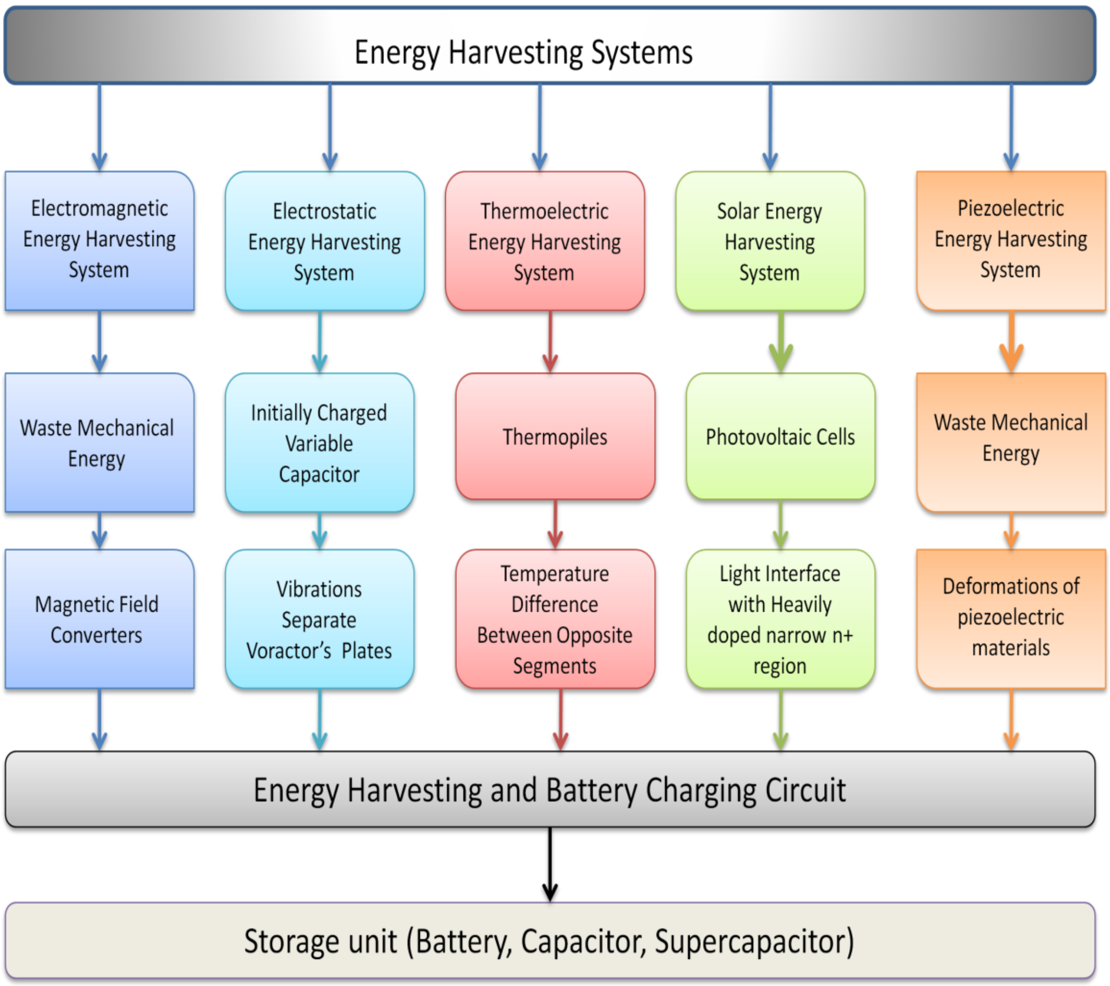

Figure 1: various energy harvesting systems

Piezoelectric Energy Harvesting System

Figure 2: Basic principle of energy conversion in piezoelectric energy harvester

The basic principle of energy conversion in piezoelectric energy harvester is shown in figure 2 in which stress/strain energy is converted into electrical energy. The piezoelectric energy harvesting system can change mechanical stress energy arising from various ambient sources like human body movement, sound vibrations, fluid vibrations etc. into electric energy [15]. When a piezoelectric material is compressed or elongated under any kind of stress, it tends to align the atoms of its crystal lattice and conduct electrical signals. If the piezoelectric material is not short circuited, the applied mechanical stress causes a potential difference across the fabric. Figure 3 shows a piezoelectric energy harvesting system.

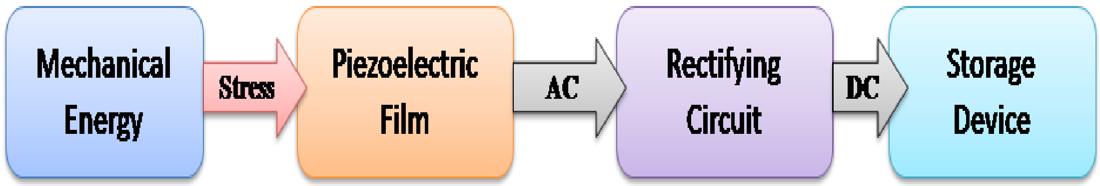

Figure 3: Piezoelectric energy harvesters

There are numerous methods of energy conversion which have been utilized to produce useful energy from waste vibrational energy as discussed above. Every method has its own pros and cons and their application is restricted to a specific type of extensive condition. Solar cells are efficient power generators in case of direct sunshine but are unsuitable for cloudy and hazy sunshine conditions [16]. They are also not very useful for indoor environments. Smart materials such as thermo-elastic materials are capable to achieve fairly low magnitude power of only 1µW/thermocouple. Another condition of these materials to work effortlessly is a high temperature difference. Among all of these, piezoelectric energy generation using hydro dynamism is much effective rather than other classifications further it can be applicable under a extensive variety of excitation [17] and the need for energy initiation is far less in contrast to others because even the water waste from households and industries can be a good source of vibrational energy for piezo materials that can be easily converted into useful electrical energy. PEHF system can be simply integrated with other energy harvesting systems to increase power output. Hence PEHF system is a source of clean and green energy.

3 TYPES OF PIEZOELECTRIC STRUCTURES

Piezoelectric materials used for the energy harvesting purpose are available in various shapes like cantilever beam, ring, shell, disc etc. which affects the output of harvester as discussed below:

Cantilever Beams:

A cantilever beam is a beam which has only one of its ends fixed and is also known as a “fixed-free” beam. Many energy harvesting techniques use piezoelectric cantilever beam structure. Energy harvesting system with piezoelectric cantilever beam can be of following types:

1. Unimorph structure with point mass
2. Unimorph structure without point mass
3. Bimorph structure with point mass
4. Bimorph structure without point mass

Unimorph: When a thin layer of piezoelectric is bonded with a non-piezoelectric material, it is called unimorph. This structure consists of only one active layer.

Bimorph: When we bond two thin layers of piezoelectric on both sides of a non-piezoelectric material, it is called bimorph. This structure consists of two active layers. Figure 4 shows the basic diagram of the cantilever type energy harvester. In this system, when the cantilever beam is subjected to vibrations or external force in the vertical direction, the base of the beam will also start to move up and down in synchronization with the external acceleration [18]. The inertia of the cantilever beam causes the vibration in beam; since the beam is not rigid, it tends to deflect from the mean position when the base support moves up and down. A small mass is fixed at the free end of cantilever beam due to which the amount of deflection increases. The resonant frequency of the beam becomes low and this larger deflection leads to more stress, strain and higher voltage. Point mass, beam shape and damping are the main factors affecting the power generation.

Stress and strain are maximum at the fastened end of the cantilever beam and decreases in magnitude at locations further away from the fixed end [19]. The portion of cantilever beam away from the clamped portion does not yield much to energy generation. For this reason and to lower the dimensions and weight of the cantilever, tapered or triangular cantilever is being used in energy harvesters.

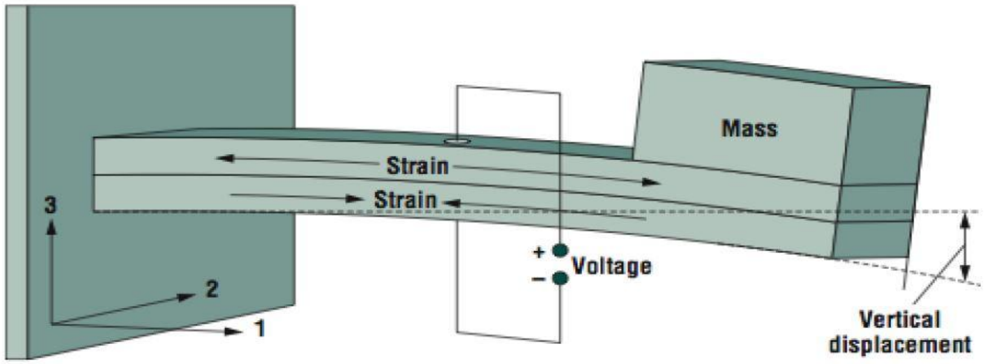

Figure 4: Basic diagram of cantilever type structure, (Caliò et al., 2014)

Discs:

Instead of using a piezoelectric cantilever beam to harvest energy, energy harvesters of circular shapes can be preferred because of their higher force loading capability. These are of two types:
(a) Cymbal Transducers
(b) Circular Diaphragms

(a) Cymbal Transducers

These are the applications of high impact forces. This system consists of two metal caps enclosing piezoelectric ceramic. The metal provides better yield strength than aluminium and brass, thus provides higher force loading capability to the transducer. When an axial force is applied to cymbal transducer, metal caps amplify and convert the axial force into radial force in piezoelectric material. Both d_{33} and d_{31} yields to the charge generation [20]. Equation of effective piezoelectric charge constant d^{eff} can be written as:

$$d^{eff} = d_{33} + A|d_{31}| \quad (1)$$

Cymbal transducers provide better energy output than piezoelectric cantilever beam because of its capability to withstand higher impact force. These are not useful for harvesting energy from natural sources of vibrations because of low magnitude of vibrations. Figure 5 shows the basic diagram of cymbal transducers type energy harvester.

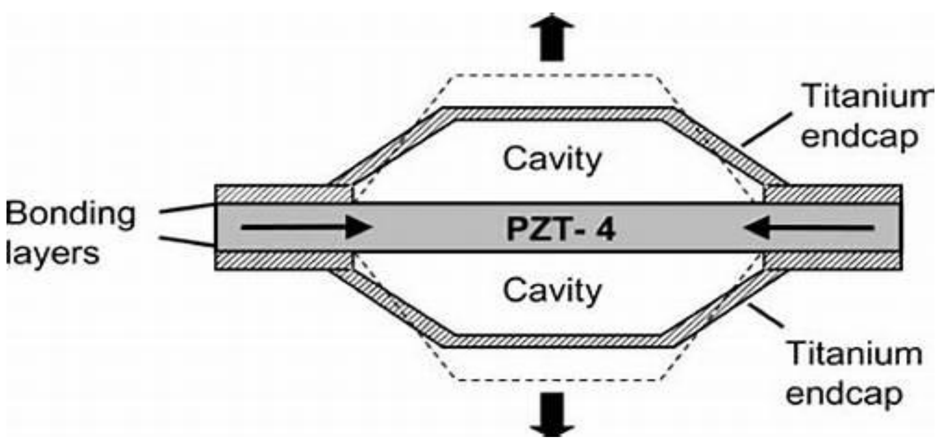

Figure 5: Basic diagram of cymbal transducers

Diaphragms:

A circular diaphragm is very much like a cantilever beam. To make a piezoelectric circular diaphragm, a thin circular disc of piezoelectric ceramic is bonded to a metal plate and after then the complete structure is clamped from the edge while in piezoelectric cantilever beam, the beam is clamped from one end only. A small mass element can be added at the centre to provide pre-stress to the piezoelectric ceramic. Pre-stress causes lower resonance frequency and hence the more energy output in piezoelectric energy harvesters [21]. Prestress can be introduced in piezoelectric ceramics during the fabrication process of piezoelectric-metal structure. In this a piezo ceramic layer is placed between two dissimilar metal layers and then the structure is heated and cooled to normal room temp. As both metals have different thermal expansion coefficient, the whole structure will warp and this will introduce pre-stress in the piezoelectric ceramic. Figure 6 shows the basic diagram of circular diaphragms type energy harvester.

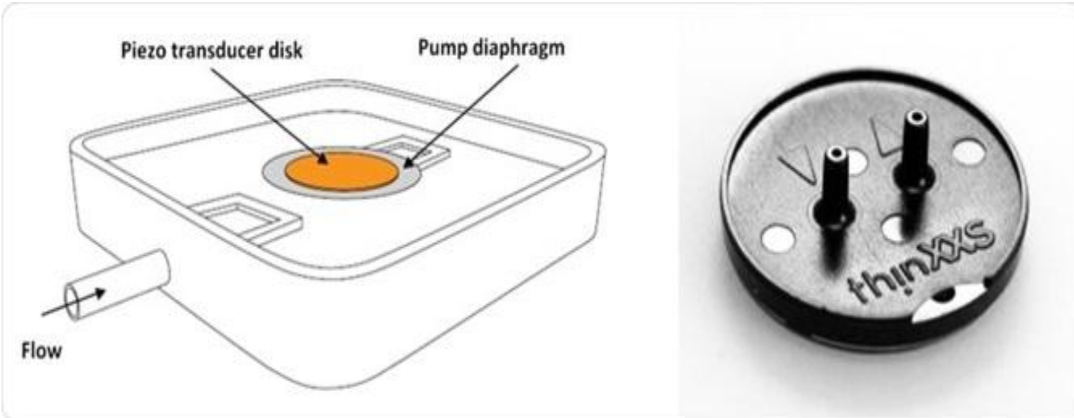

Figure 6: (Left) Piezo-ceramic disks attached to the circular pump diaphragm (right) Piezo-transducer driven micro-diaphragm pump

Shell:

For sources of vibrations other than forces in linear directions, i.e. angular or rotational vibration sources, a piezoelectric shell generator is useful. In this configuration, a cylindrical shaped piezoelectric ceramic shell is fixed to a base [22, 23]. Motion of base can be angular or rotational. In this structure also, a small mass is attached to the upper end of the shell. This small mass lowers down the resonance frequency of shell and hence structure provides higher power output [24]. Figure 7 shows the basic diagram of shell generator type energy harvester.

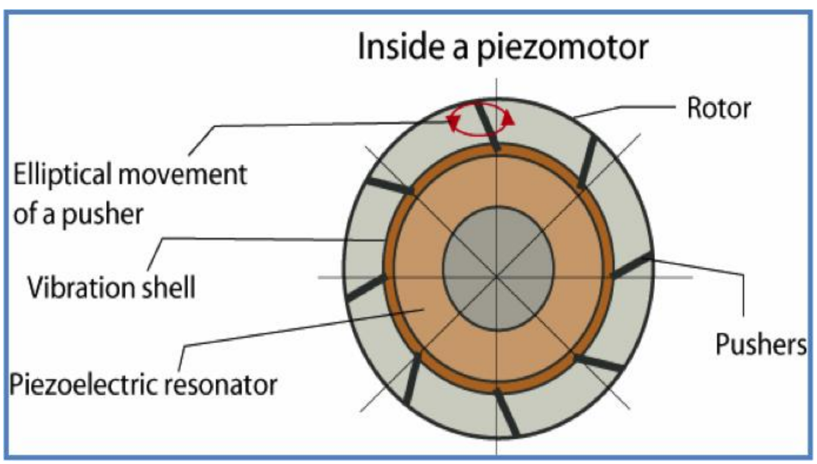

Figure 7: Basic diagram of shell generator

Ring-MEMS:

This type of piezoelectric configuration is used for Micro-Electro-Mechanical systems (MEMS). As these systems are of small dimensions so it is a challenge to achieve low resonance frequency because of large values of elastic moduli of piezoelectric ceramics and crystals [25]. The ring piezoelectric harvesting structure was made by placing a substrate layer underneath a strip of thin film of aluminium nitride (AlN) [26]. Further the stress produced within the layer caused the AlN thin film to roll up and hence we get Ring-MEMS structure. Figure 1.20 shows the basic diagram of ring MEMS type energy harvesters.

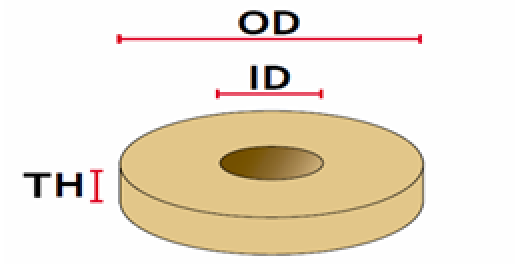

Figure 1.20 Schematic diagram of ring MEMS

CONCLUSION

This review article discusses different aspects of energy harvesting from mechanical vibrational energy using different piezoelectric materials structures. An overview has been given about different aspects of energy harvesting using vibrations generated from different sources. Also, some research projects have been discussed regarding significant energy harvesting using interaction of different types of piezoelectric materials and ambient vibrations from various sources. Using different piezoelectric materials, many models have been developed by researchers to analyze the efficiency of the device has been discussed and concluded that as the system vibration capacity increases, the piezoelectric energy harvesting is also increase till resonance frequency of system.

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