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ORIGINAL ARTICLE

Energy Harvesting Through Piezoelectric Material at Micro Scale Level

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ABSTRACT

Energy harvesting has been a topic of discussion and research since three decades. With the ever increasing and demanding energy needs, unearthing and exploiting more and more energy sources has become a need of the day. In the current era, wireless data transmission techniques are commonly used in electronic devices. For powering them connection needs to be made to the power supply through wires else power may be supplied from batteries. Batteries require charging, replacement and other maintenance efforts. For example, in the applications such as villages, border areas, forests, hilly areas, where generally remote controlled devices are used, continuous charging of the microcells is not possible by conventional charging methods .So, some alternative methods needs to be developed to keep the batteries full time charged and to avoid the need of any consumable external energy source to charge the batteries. To resolve such problems, Energy harvesting technique presented in the current work is the best alternative. There exists variety of energy harvesting techniques but mechanical energy harvesting happens to be the most prominent. This technique utilizes piezoelectric components where deformations produced by different means are directly converted to electrical charge via piezoelectric effect. Subsequently the electrical energy can be regulated or stored for further use. The work presented in this paper recommends Piezoelectricity as an alternate energy source. The motive of the work is to obtain a pollution-free energy source and to utilize and optimize the energy being wasted. Current work also illustrates the working principle of piezoelectric crystal and various sources of vibration for the crystal.

Key words: *Piezoelectric material, mechanical energy, electrical energy, piezoelectricity, energy harvesting*

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INTRODUCTION

Energy harvesting is the process by which energy is derived from external sources and utilized to drive the machines directly, or the energy is captured and stored for future use. In the current era, which is witnessing a skyrocketing of energy costs and an exponential decrease in the supplies of fossil fuels, there arises a need to develop methods for judicious use of energy which lay emphasis on protecting the environment as well. One of the novel ways to accomplish this is through energy harvesting. Energy harvesting, or energy scavenging, is a process that captures small amounts of energy that would otherwise be lost as heat, light, sound, vibration or movement. It uses this captured energy to improve efficiency and to enable new technology, like wireless sensor networks. Energy harvesting also has the potential to replace batteries for small, low power electronic devices. Piezoelectric materials can be used as a means of transforming ambient vibrations into electrical energy that can then be stored and used to power other devices. With the recent surge of microscale devices, piezoelectric power generation can provide a convenient alternative to traditional power sources used to operate certain types of sensors/actuators, telemetry, and MEMS devices. The advances have allowed numerous doors to open for power harvesting systems in practical real-world applications. Much of the research into power harvesting has focused on methods of accumulating the energy until a sufficient amount is present, allowing the intended electronics to be powered. Some traditional energy harvesting schemes are solar farms, wind farms, tidal energy utilizing farms, geothermal energy farms and many more. With the advent of technology, utilization of these sources has increased by leaps and bounds [1]. When viewed on a large scale, energy harvesting schemes can be categorized as shown in table 1.

Table 1: Types of energy harvesting schemes

Type of Energy Harvesting	Sources of Energy	Solution	Ultimate Goal
Macro Energy Harvesting	Renewable sources of energy like solar energy, wind energy, tidal energy etc.	Energy Management solutions	Reduce oil dependency
Micro Energy Harvesting	Small scale sources of energy like vibration, motion, heat, etc.	Ultra-low power solutions	Driving low energy consuming devices

Piezoelectric Energy Harvesting is a new and innovative step in the direction of energy harvesting. Piezoelectric crystals can be utilized to obtain voltages of very small values and hence can drive low voltage devices. Hence, Piezoelectric Energy Harvesting comes under the category of Micro scale energy harvesting scheme.

WORKING OF PIEZOELECTRIC CRYSTAL

Piezoelectric effect is the ability of certain materials (crystals) to generate an electric charge in response to applied mechanical stress. There are many materials, both man-made and natural, that exhibit a range of piezoelectric effects. Some naturally piezoelectric occurring materials include Quartz, Rochelle salt, Topaz, Tourmaline, Cane sugar, Berlinite (structurally identical to quartz), Bone (dry bone exhibits some piezoelectric properties due to due to apatite crystal, and the piezoelectric effect is generally thought to act as a biological sensor), Tendon, Silk, Enamel, Dentin, Lead Titanate ($PbTiO3$), Potassium Niobate ($KNbO3$), Lithium Niobate ($LiNbO3$), Rochelle, etc. [2]. An example of man-made piezoelectric materials includes Barium Titanate ($BaTiO3$) and Lead Zirconate Titanate. There initial demonstration showed that the quartz and Rochelle salt exhibited the most piezoelectricity ability at the time. There are two types of piezoelectric effect:

1. Direct piezoelectric effect and
2. 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. The energy harvesting via Piezoelectricity uses direct piezoelectric effect. The Phenomenon of direct piezoelectric effect will be clear from the diagram shown in fig. 1.

The output voltage obtained from a single piezoelectric crystal is in mill-volts range, which is different for different crystals and the wattage is in microwatt range. So in order to achieve higher voltages, the piezoelectric crystals can be arranged in cascading manner, that is, in series. The energy thus obtained is stored in lithium batteries or capacitors. This is the working principle behind piezoelectric energy harvesting system. Now the extreme engineering lies in optimization of piezoelectric energy, which is done in various ways. A lot of studies are being carried out in order to know which crystal will be the best to obtain maximum output voltage, what should be the structure of piezoelectric component, which type of circuit should be used at the output terminals of piezoelectric crystal in order to have maximum wattage. In the next section, we have mentioned a number of sources of vibration which are already being used for piezoelectric energy harvesting and a new idea in this direction has been proposed by the researchers.

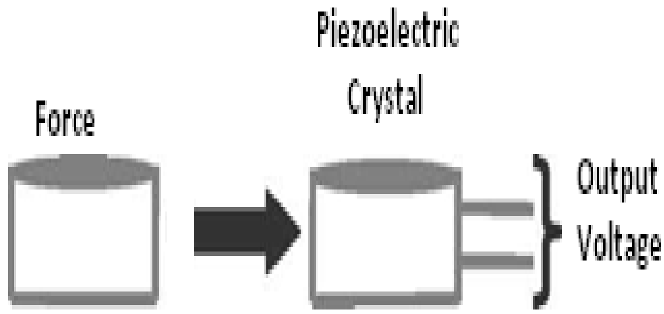

Fig. 1: Principle of direct Piezoelectric Effect

SOURCE OF VIBRATION FOR CRYSTAL

(A): POWER GENERATING SIDEWALK:

The piezoelectric crystal arrays are laid underneath pavements, side walks and other high traffic areas like highways, speed breakers for maximum voltage generation. The voltage thus generated from the array can be used to charge the chargeable Lithium batteries, capacitors etc. These batteries can be used as per the requirement [3].

(B): POWER GENERATING BOOTS OR 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 [3]. 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 were abandoned due to the discomfort from the additional energy expended by a person wearing the shoes.

(C). GYMS AND WORKPLACES:

Researchers are also working on the idea of utilizing the vibrations caused from the machines in the gym. At workplaces, while sitting on the chair, energy can be stored in the batteries by laying piezoelectric crystals in the chair. Also, the studies are being carried out to utilize the vibrations in a vehicle, like at clutches, gears, seats, shock-ups, foot rests.

(D). MOBILE KEYPAD AND KEYBOARDS:

The piezoelectric crystals can be laid down under the keys of a mobile unit and keyboards. With the press of every key, the vibrations created can be used for piezoelectric crystal and1hence can be used for charging purpose [4].

(E). FLOOR MATS, TILES AND CARPETS:

A series of crystals can be laid below the floor mats, tiles and carpets which are frequently used at public places.

(F). PEOPLE POWERED DANCE CLUBS:

In Europe, certain nightclubs have already begun to power their night clubs, strobes and stereos by use of piezoelectric crystals. The crystals are laid underneath the dance floor. When a bulk of people use this dance floor, enormous amount of voltage is generated which can be used to power the equipments of the night club [5].

OUTPUT STAGE OF PIEZOELECTRIC ENERGY HARVESTING SYSTEM

The output of a piezoelectric crystal is alternating signal. In order to use this voltage for low power consuming electronic devices, it has to be first converted into digital signal [2]. This is done with the help of AC to DC converter as shown in Fig. 2. Figure 2 shows a simple diode rectifier to convert AC to DC. This is followed by a capacitor, which gets charged by the rectifier up to a pre-decided voltage, at which the switch closes and the capacitor discharges through the device. In this way, the energy can be stored in the capacitor, and can be discharged when required. But the energy harvesting capacity of this circuit is not appreciable. Hence, a DC to DC converter is used after bridge rectifier stage, which is shown in the fig. 3. The addition of DC-DC converter has shown an improvement in energy harvesting by a factor of 7. A non-linear processing technique "Synchronized Switch Harvesting on Inductor" (SSHI) was also proposed by the researcher for harvesting energy [7-9]. It consists of a switching device in parallel with the piezoelectric element. The device is composed of a switch and an inductor connected in series. The switch is in open state except when the maximum displacement occurs in the transducer. At that instant, the switch is closed and the capacitance of the piezoelectric element and inductor together constitute an oscillator [10-11]. The switch is kept closed until the voltage on the piezoelectric element has been reversed. This circuit arrangement of the output circuit is said to have a very high energy harvesting capacity.

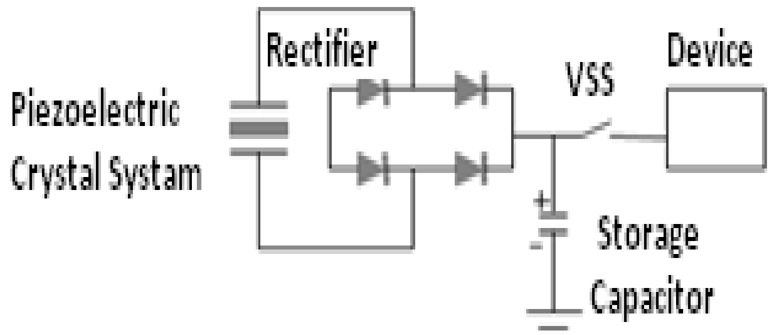

Fig. 2: Bridge rectifier type AC to DC converter

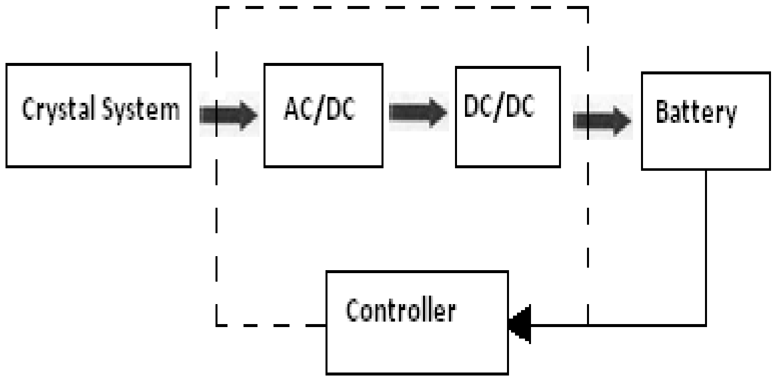

Fig. 3: Energy Harvesting Circuit

IMPLEMENTATION

Experimentation has been done on a Piezo-crystal and it is tested with a Light Emitting Diode (LED). The two terminals of the LED are connected with the two terminals of the crystal. Choice of Blue LED is being made for experimentation. Single stroke on the crystal blows blue LED with full intensity. Measured values of output voltage and current from the crystal come out to be 3.5 Volt and 100 milliamps. The only shortcoming of this using a single crystal and a LED was that both the voltage and current obtained exists instantaneously. To increase the range of voltage and current output, an assembly of six crystals in series and six such series has been put in parallel. When number of voltage sources are put in series, then the net voltage increases, while when a number of voltage sources are put in parallel, then the strength of signal, that is, current increases. This is the concept used behind the assembly. The output of parallel connection is fed to the current amplifier for signal strengthening and the output of series connection is fed to the amplifier for biasing purpose and also to the voltage amplifier. The assembly has been put under a doormat and the output obtained from amplifier has been very encouraging, which was around 6 V voltage and 1 ampere current. This magnitude of voltage and current can be certainly used to charge a battery.

CONCLUSION

The work presented in this paper is a theoretical model for energy harvesting system using piezoelectric materials. It is evident that harnessing energy through piezoelectric materials provider a cleaner way of powering lighting systems and other equipment. It is a new approach to lead the world into implementing greener technologies that are aimed at protecting the environment. The method used to perform power harvesting is to use PZT materials that can convert the ambient vibration energy surrounding them into electrical energy. This electrical energy can then be used to power other devices or stored for later use. This technology has gained an increasing attention due to the recent advances in wireless and MEMS technology, allowing sensors to be placed in remote locations and operate at very low power [7]. The need for power harvesting devices is caused by the use of batteries as power supplies for these wireless electronics. As the battery has a finite lifespan, recharging needs to be done once discharged. Charging of batteries in order to provide energy to the electronic devices in the applications such as borders or hilly regions is a tedious job to do. Piezoelectric energy harvesting systems are a onetime installment and they require very less maintenance, making them cost efficient. One of the limitations of this technology is that its implementation is not feasible in sparsely populated areas as the foot traffic is very low in such areas. Further experimentation has to be carried out for its implementation on a larger scale, with an efficient interface circuit at a low cost in universities.

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