Sustainable Energy Development Using Piezoelectric Materials

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Abstract- *Smart solutions have shown a significant growth over the past few years for a sustainable future. To produce wireless and portable electronics with extended lifespan, the concept of harvesting renewable energy in human surrounding arouses a renewed interest. Producing electricity through transduction of stress generation by human activities can be used as mechanisms to transfer mechanical energy, using ambient vibration, into electrical energy that can be stored and used to power other devices. If piezoelectric-based systems have the possibility to match the performance and reliability characteristics of other smart solution systems, then it can ultimately be seen as a plausible candidate for energy generation. The economical status and foreseen potential of piezoelectric based systems compared to batteries are much more advantageous as power sources. In this paper we review and detail some of the fields of energy harvesting using piezoelectricity along with its fundamental working. A study of the implementation of piezoelectric materials in public transportation areas like airports, railway stations, bus terminals etc. as well as extracting energy from footfall stresses generated by human walking.*

Keywords- Smart solutions, piezoelectricity, footfall stresses, renewable energy.

I. INTRODUCTION

In the current generation of boosting energy costs and an exponential decrease in the supplies of fossil fuels, there arises a need to develop smart solutions for use and storage of energy which lay emphasis on protecting the environment as well. A baronial way to accomplish this is through energy harvesting.

Energy harvesting has been derived as method of collecting energy from various forms of mechanical stresses. The charge on the surface leads to mechanical tension or compression depending upon the polarity direction of the applied voltage. These mechanical stresses generate electricity, which is the basic phenomenon of piezoelectricity.

Piezoelectricity in simple words can be expressed as the accumulation of electric charge due to slight dimensional changes in certain non conductive materials which would suffice to variation in bond lengths between anions and cations. First discovered in 1880 by French physicists Jacques and Pierre Curie, these materials tend to generate electric potential in response to dimensional changes and even temperature changes, thus showing to pyroelectric effect too.

Due to mechanical compression or tension, the subjected mass shows a certain voltage drop in the voltmeter. Fig.1 explains the basic fundamental working of a piezoelectric material generating voltage.

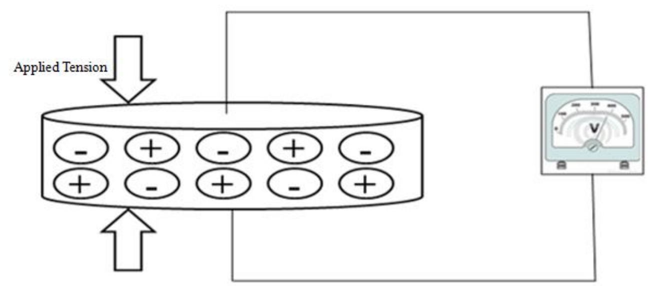

Fig.1 Piezoelectric crystal generating voltage due to applied tension

Piezoelectric materials being non conductive materials, can be sub divided into two major groups: ceramics and crystals. Piezoceramic materials provide a wide selection of piezoelectric ceramic materials based on modified lead zirconatetitanate (PZT) and barium titanate. The designation of 'soft' and 'hard' piezo ceramics refer to the mobility of the dipoles and hence also to the polarization and depolarization behavior. Whereas piezoelectric crystals like quartz (SiO_2), berlinite ($AlPO_4$), tourmaline provide an electrical polarization along the pressure direction. Apart from ceramics and crystals, other materials like zinc oxide (ZnO), aluminum nitride (AlN), polyvinylidene fluoride also demonstrate piezoelectric effect.

Materials proving to be piezoelectric usually implicate reversible process. Meaning, a piezoelectric material would have a change in dimension when it is exposed in an electric field . This phenomenon is called electrostriction. Devices applying this mechanism are used in sensing applications, such as tactile sensors, microphones, strain gauges etc. Fig.2 represents the block representation of piezoelectric materials and it's reversible process.

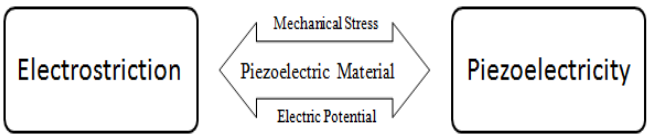

Fig.2 Representation of Electrostriction and Piezoelectricity

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.[6]

II. LITERATURE REVIEW

1. M. Hanif M. Ramli et al. (2014) :-

This study aims to assess the capacity of piezoelectric material for energy harvesting. A Piezoceramic P-876.A12 was used. A vibration energy harvester (VEnH) was constructed using a DC motor, a carbon fiber cantilever beam, a Piezoceramic strip and a microcontroller. Two case studies were organized to determine the energy generation. Fig.3 explains Vibration Energy Harvester in a smart chart.

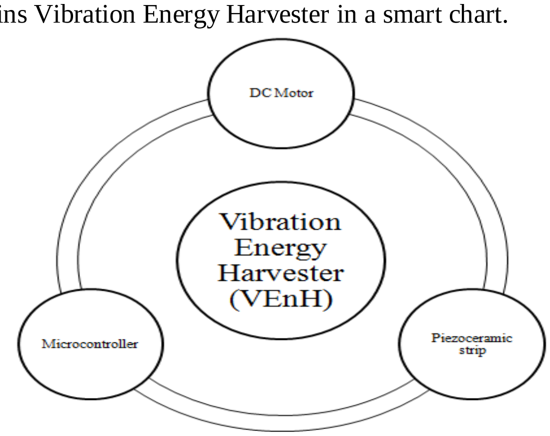

Fig.3 Vibration Energy Harvester assembly

- First experiment focused on characterization of input-output relationship by magnitude variation of the input displacement. The input displacement was produced by the vibration exciter and was slowly increased from 0mm to 18mm by amplifier gain of the function generator keeping the frequency constant at 1.82 Hz. Results showed that voltage increased gradually up to 15mm displacement, but also started reducing after that. This point being called the saturation point. At this point , the measured voltage was 1.63V. Optimal region of displacement was found to be between 8mm to 15mm.
- Second experiment used a laser DoplerVibrometer to determine the optimal operating frequency when the input displacement was held constant. The same setup was used to study charge storage process in 3 different mediums i.e. at 2.5V 10F super capacitor, a 3.6V NiMH rechargeable battery and a 9.6V NiMH rechargeable battery. The experiment was performed at a constant displacement of 15mm. Results showed that when frequency was operated from 0 to 10Hz, best excitation frequency was in the range of 1.8Hz to 3.5Hz. However, saturation point was reached at 4Hz and output voltage showed a decrease in voltage. It was concluded from the experiment that lower the frequency, much longer is the time taken to charge a single battery cell.[1]

2. E. Lemaire et al. (2015) :-

- This study reviewed the piezoelectric behaviour of Rochelle salt $(NaKC_4H_4O_6.4H_2O)$, also called as Seignette salt. In this, the Rochelle salts processing method, material and piezoelectric properties have been illustrated. To experimentally analyze the salt, pure millimetric crystals were treated as piezoelectric actuators of a paper-based cantilever beam. A laser Vibrometer was used to analyze the applied driving voltage. In this first resonant mode, a decrease in phase from 0 to -90^o was observed, indicating the out-of-plane displacement. Whereas in the second phase, an increase was observed but comparatively less than the out-of-phase decrease in the first resonant mode. Fig.4 demonstrates the voltage fluctuation on the oscilloscope.

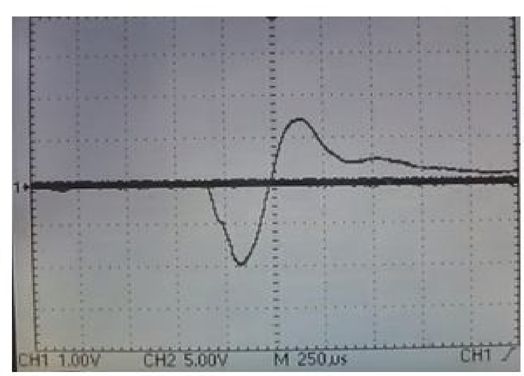

Fig.4 Rochelle Salt crystal voltage on an oscilloscope

- For the next step, the salt crystal and paper cantilever were combined together. In this, impregnation method was developed. The Rochelle salt impregnated paper were dried and the crystals were observed into the paper sheet, under ambient temperature and atmosphere.
- The characterization of electrical, mechanical and piezoelectric properties showed that Rochelle salt based paper had highlighted properties than the blank paper. The dielectric constant was observed to be double of the impregnated paper ($\in =$ 5.9-8.6) than the blank paper ($\in =$ 3.4). While a knocking experiment produced damped-free oscillations. In between each impact, the paper cantilever oscillated at 143Hz and electrical AC signal of maximum 100 mV. To determine the piezoelectric properties, the Berlincourt method was studied which confirmed piezoelectricity.[2]

3. B. Lafarge et al. (2015):-

- An innovative bond graph model of the piezoelectric harvester is studied in this paper for a quarter vehicle system, when a car travels a road with a speed bump at 30km/h. The main objective was to generate electrical power from ambient vibrations of the car to extract power of optimal characteristics and configuration. The power of a quarter vehicle system was evaluated to harvest energy when parameters like the location and characteristics were varied.
- A power balance sheet was made to understand power distribution. A bond graph model was well adapted to simulate power exchanges inside the system. A sprung mass m_2 and an un-sprung mass m_1 were connected in series combination with a suspension spring of stiffness K_2 and a damper of C_2 damping coefficient. [3] The solicitation on random rough road with a motion function $y(t)$ is demonstrated in the below Fig.5

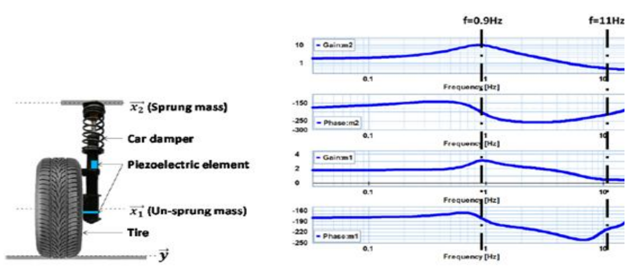

Fig.5 Frequency response of a quarter car system [3]

- The dual mass system was expressed by Newton's second law as below,

$$m_2 x''_2(t) + K_2\big(x_2(t) - x_1(t)\big) + C_2\big(x'_2(t) - x'_1(t)\big) = 0$$

$$m_1 x''_1(t) + K_1(x_1(t) - x_0(t)) + K_2(x_1(t) - x_2(t)) + C_2(x'_1(t) - x''_2(t)) = 0$$

- Furthermore, a power evolution was simulated by the bond graph model of the car. Elasticity was represented by storage elements C and I, dissipative element R and the modulated flow source (MSf). Results showed that sufficient power in the car damper could be harvested. A bond graph model and simulation of the power harvesting system was embedded in the car damper.
- It was observed that piezoelectric was located between two surfaces, onto the left or onto the right. Finite difference method was used in several parts of the car damper to simulate the influence of the location on the power conversion across the elemental behaviour. A representation of the two possibilities of the car damper location is demonstrated in Fig.6 [3]

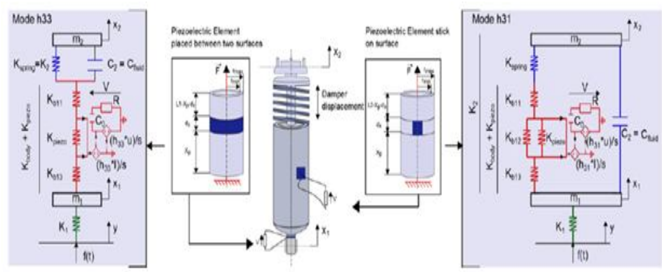

Fig.6 Damper representation with two possibilities: piezoelectric element located (on the left) between two surfaces and bounded (on the right) on the car damper surface [3]

- Results showed that the bond graph model gave an estimated power of around 0.5mW, sufficient enough to use miniaturized microcontroller of 100µW. The simulated results in this case study suggested only for two locations, whereas it could be easily extended for all locations.

4. Hasan GökseninÇetin et al. (2015) :-

- Hasan GökseninÇetina et al. studied the behaviour of elastomeric pillars which act as a set of oscillators on the vibrating structure, which stored elastic energy being a piezoelectric layer.
- The piezoelectric polymer layer being of PVDF material, consisted of electrodes which were patterned in half-electrode configuration. Reason being for half-electrode configuration, the pillars had lateral vibrations, due to which the bending stresses acted on the interface between pillar and piezoelectric layer. Hence, resulting in compression on one side while tension on the other side.

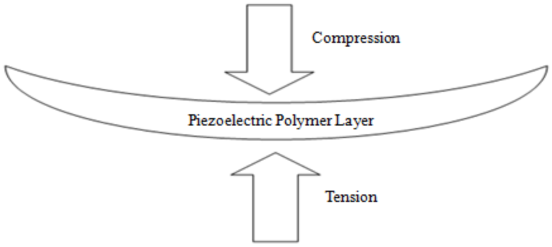

Fig.7 Demonstration of compression and tension on a piezoelectric polymer layer

- EHS is made by soft moulding and additive manufacturing techniques. The structure could be manufactured with same or different aspect ratio using the single pillar or multiple pillar arrays. An experimental setup consisting of signal generator, a vibration shaker, an accelerometer and a data acquisition system was used to study the performance of EHS.
- Various base excitations were applied to get the lateral vibrations. The output voltage was measured for half electrode configuration. It was observed that resonance frequency occurred at 62Hz , being consistent with analyzed results.[4]
- An output of 58.4µW for a single pillar system was observed when an acceleration of 3g at resonance condition was provided. Output voltages of four pillars with different heights were also measured under a constant harmonic base excitation at 15 Hz and a magnitude of 1 g. The discrete frequency components were proved that multiple array pillars with different dimensions successfully harvest energy from the multi-frequency vibrations.[4]

III. APPLICATION BASED SCENARIO

1. SUSTAINABLE DANCE FLOOR-

A Vibration Energy Harvester (VEnH) can generate voltage across a given displacement range while keeping the frequency range constant. Or can generate a specific frequency range while keeping the displacement constant. Hence, such energy harvesters can be used for generating footfall stress energy on a large scale. Footfall stress energy can be implemented on a number of large scale applications. One such application was implemented by a Sustainable Dance Club (SDC) which began as a creative concept, originated by Rotterdam based organizations Enviu-innovators in sustainability. Together they developed an idea into a project and organized a launch event on 2006 in club Off_Corso in Rotterdam. The party, which showcased many original sustainable ideas and products, was a huge success and attracted 1200 clubbers. The SDC provides an Energy Meter which encourages the dancers to obtain maximum possible energy level. A fusion of electronics, embedded software and smart durable materials, every tile made a movement of up to 1 cm when danced on. An advanced electric motor transformed the movements into electric power. It was observed that every person's movement generated about 2-20 Watts of power, depending on the dancers weight and the activity on the dance floor.[5] This generated energy was then used to power the interactive elements of the floor. An illustration has been shown in Fig.8[7]

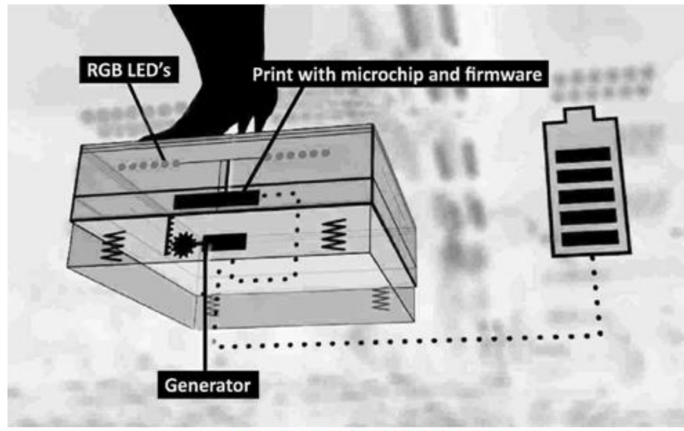

Fig.8 Sustainable Energy Dance Floor [7]

2. AIRPORT & RAILWAY TERMINALS-

Airport stands and railway stations can be used as a vital platform for energy generation. Using floor space in public areas allow for a large source of wasted energy to be utilized as a form of alternative energy. A demonstration was conducted by East Japan Railway Company (JR East) from January 19 to March 7, 2008 at Yaesu North Gate, Tokyo Station, on a new power-generating floor.Installed at the ticket gate area, it generates electricity from the vibrations created by passengers walking through the ticket gates. The power-generating floor is embedded with piezoelectric elements, which are 35 millimetres in diameter, and disc-shaped components used for loudspeakers. It uses 600 of these elements per square meter. While the loudspeaker creates sound by converting electric signals to vibrations, the floor adopts the reverse mechanism that produces electricity by harnessing the vibration power generated from passengers' steps. It is being developed by JR East with the aim of making stations more environmentally friendly and energy efficient (Japan for Sustainability, 2008). [6]

IV. CONCLUSION

In this paper, different case studies for energy harvesting using piezoelectric materials have been presented. It is prominent to use harvested energy to provide a cleaner way of life. With the beginning of the era of nano-technology more compact and efficient material could be introduced to produce large amount of electricity. Cheap and highly piezoelectric material would increase the power output. Future experimentations could be carried for large scale implementation in the modern world, which could be cost efficient too.

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