Review on Mechanisms of Vibration based Energy Harvesters

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Abstract:- In search of an alternative to the limitations of wire powered supply and energy storage there has been a rapid growth in ambient energy harvesting technologies. Vibration energy is abundantly available and has the potential to be harvested by different mechanism. Vibration energy harvesters (VEHs) mostly use Piezoelectric and electromagnetic means for energy harvesting. Each mechanism comes with certain advantages and disadvantages and improvement so ideas are elaborated and discussed upon in this current research review.

Key Words: (Size 10 & Bold) Key word1, Key word2, Key word3, etc (Minimum 5 to 8 key words)…

1. INTRODUCTION

Due to the implementation of modern advancement the various technique are step forward to upcoming growth of new creation like Wireless Sensor Network (wsn's), MEM's and the interconnection via the internet of computing devices.1,3 Every harvesting technique help us to eliminate the battery connected or wired connection and reduces the maintenance, labour cost, limited energy density, unavoidable periodic replacement, current leakage.4,5,6. Energy harvester is the best suitable as a substituted for battery and wired connection power supply7.

Energy harvester is helpful for converting the environmental energy into useful work it is cheapest and continuous source of energy with higher efficient of work. Energy harvester based on vibration in WSN find its application in mining and nuclear reactor plant, deep sea operation .Table 1 shows different properties of electromagnetic generators. In bio medical application it can monitor the condition of patients and provide emergency treatment such as muscles and nerve stimulation for light and medium, VEH's also help us to operate products in civil and infrastructure transport and human.

2. MECHANISM

The different type of vibrational energy harvesters includes Electrostatics, Electromagnetic, Piezoelectric and some niche mechanism such as Magnetostrictive, flexoelectric.

$$n=P/P$$

Where Pout is use to distribute power to the electrical load and Pin is originating from the vibrations. Another important term used to determine the mechanism is coupling coefficient.

$$Kc^2 = U/U$$

Where Kc is coupling coefficient which relates the total energy input with vibration energy harvester and Ust is transducer output and Uin is Energy Input per cycle. 16

2.1 ELECTROMAGNETIC ENERGY HARVESTER

It is a device which converts mechanical energy which is in the form of vibration to the electrical energy when a relative motion between the magnetise and conducting body according to faraday law:

$$V = N\, d/d$$

Where (N) is the number of turns, Φ, is the magnetic flux over a single loop.15 a simple EM configuration is presented in Figure 3. The motional electromotive force (emf) is

$$Emf = \int d\, .\, (v \times B)$$

Where dL is the change in the length vector along the inductive coil, B is the magnetic field vector, and v is the velocity vector of the magnet. 16

It has higher conversion efficiency for low frequency conversion of vibration16, 17. It does not require any external voltage source unlike electrostatic energy harvester. 16, 17 The power and current output are considerably high as compare to piezo electric and electrostatic energy harvester 18The fabrication of magnetic coil is challenging on Nano scale and micro scale.16,

17, 19Low general output voltage and due to friction there is parasitic damping, winding loss and magnetic detoriation. 16, 17, 19

ADVANCEMENT

In large scale architecture, electromagnetic vibration energy harvester performs well. For example, in an experiment conducted with car modelling regenerative electromagnetic based suspension stimulation it was found out that at 90km/hr. we can harness a maximum of 150watt of vibration power.20 For better performance and higher efficiency low cost design without contact with the vibrating structure are being explored. 17

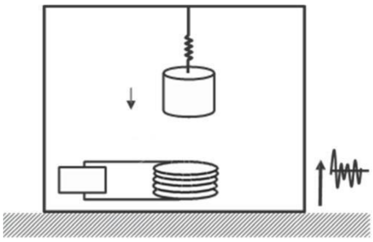

Fig. 2. A rudimentary electromagnetic energy harvester configuration. 16

2.2 PIEZOELECTRIC ENERGY HARVESTER

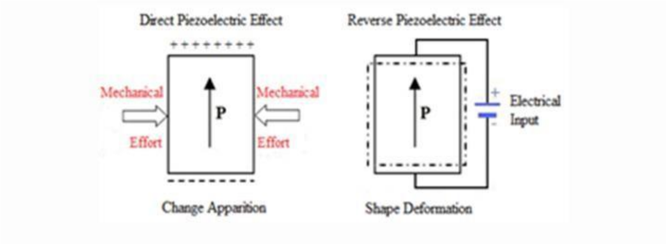

FIGURE 3: Electromechanical conversion of piezoelectric phenomena. 9

The Piezoelectric materials are those materials which convert Mechanical stresses or Strains into electricity or voltage.6, 15

Some Piezoelectric materials are Aluminium Nitride, Gallium Arsenide, and Lead Zirconate. There are also some recently discovered Piezoelectric Nano generators Zinc nanowires.6, 21Simple structure which have thin layer that are considerably lower in size compared to Electromagnetic Energy Harvester.17 Lower tendency effect by external or internal electromagnetic waves.17

ELECTRIC FATIGUE: - The polarity decreases after number of switching cycle.17, 22. Ceramic Piezoelectric Materials are brittle and has lower coupling coefficients.17, 23 Piezoelectric materials performance at high temperature condition is compromised.17, 22

ADVANCEMENT

Lead Zirconate titanate is a ceramic Piezoelectric material which is preferred by researchers due to its various characteristics like:-

Higher coupling coefficient as compared to other piezoelectric materials.23, 24

Has a resonator construction synchronous switch harvesting inductor circuit as it reduces internal capacitive impedance effect and can balance the fluctuation in vibration frequency and amplitude.25

Bismuth scandium lead titanate is again a piezoelectric ceramic which is suitable for high temperature (upto 450C).26

2.3 ELECTROSTATIC ENERGY HARVESTER

It is a triboelectric or capacitive technique in which the motion in between of two surfaces of charged capacitor results in change of potential difference between them and hence giving static electricity6, 15 .The two surface made of different materials are in contact the mechanical vibrations separations results in the decrease in capacitive potential difference which in form causes the flow of electrons between the two electrodes attached to the surface connected to the circuit.27

Electrostatic Energy harvester is able to operate without smart materials unlike Piezoelectric and Electromagnetic harvester thus making less concern for systems life span.17Due to its relatively small energy density generation an external voltage source is required for energy harvesting operation.17For wireless sensing network and micro electro-mechanical systems this approach is less compatible as the output voltage is extremely high.17

ADVANCEMENT

In an experiment a vibration energy harvester achieved top voltage of 34.06V and a peak output power density of

$0.77 W/m^2$.30 So to be used for harvesting energy from movement of a human stretchable and scalable electrostatic vibration energy harvesting system made of silicon and rubber coated stainless steel32 which has a combine teeth line hierarchical structure that minimise thin film air damping and further reduces the relative velocity between electrode surfaces. 8, 31

The combination of F-As2S3 and PEI VEH we can theoretically maximise the electrostatic effects as these two materials have high polarity difference. The peak power recorded for this combination was 1.23 and generation of current of 1.62mA at 2.5Hz with peak to peak voltage of 396V at 7.5Hz.33 figure 4 and 5 shows comparision of experimentally measured and theoretically derived voltage to base acceleration frequency.

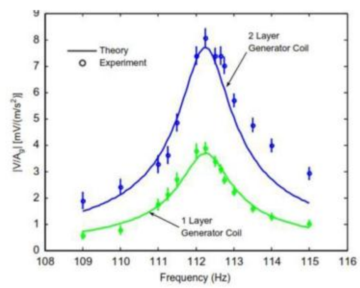

Fig. 4. Comparison of experimentally measured and theoretically derived voltage to base acceleration frequency response of an electromagnetic generator for a single and double layer generator coil (physical properties summarized in Table 1).

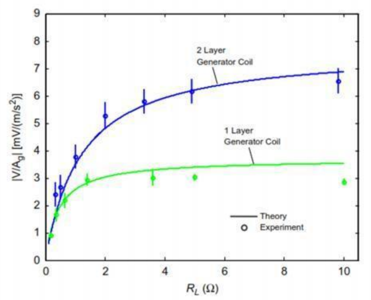

Fig. 5. Voltage generated by the electromagnetic generators in Table 1 at resonance for various load resistances.

2.4 MAGNETOSTRICTIVE ENERGY HARVESTER

The iron gallium alloy are magnetostrictive materials which experiences strain when a magnetic flux is induced, and further applying stress to a Piezoelectric materials generates electricity.15, 34 When the electron spins on its own axis orbital magnetic moment is super positioned into atomic magnetic moment due to this internal electronic motion of the atoms all ferromagnetic magnetic materials possess magneto structure potential. 13, 35figure 6 shows the atomic orientation with and without external magnetic field

The basic advantage of magnetostrictive energy harvester as compared to piezoelectric energy harvester is as magnetostrictive has lower susceptibilities to ageing and depolarisation change leaks and brittleness.34 figure 8 shows different composite of magnetostructive-piezoelectric materials. They are able to sustain harsher environment and are also more flexible as compared to piezoelectric energy harvester but the only disadvantage is they need biased magnet to function in most cases.40figure 7 shows a basic model of magnetostrictive energy harvester

ADVANCEMENT

In an experiment conducted by Jafari et al on coiled beam which have layer of met glass 2605sC under power optimisation produce an output of 9.4mW under the influence of vibrational excitation . 38When magnetostrictive materials induce magnetic flux on coil when it is in stress. The current start flowing in the coil due to magnetic flux according to Faraday's Law. He claimed that this model offers better energy density at lower frequency input as compared to piezoelectric type. 38

With the help of finite elements analysis on Galfenol rod, a change of 1.1Tesla of magnetic flux density was found to be sufficient to power Vibration Energy Harvester for Wireless Sensors. 38

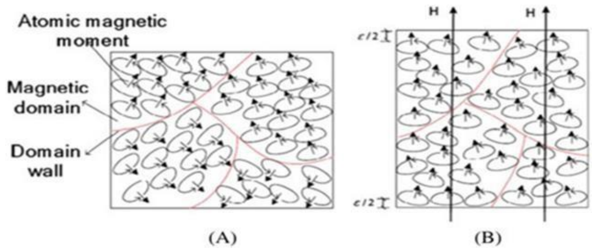

FIGURE 6 (A) Spontaneous magnetism and random orientation of magnetic moments without an external field

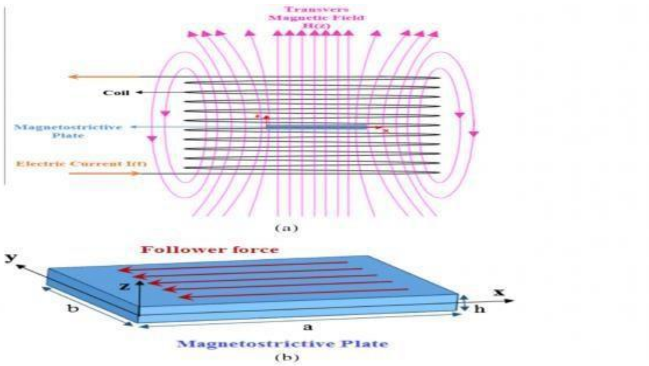

FIGURE 7 Basic models (reproduced drawing) of the magnetostrictive energy harvester: A, compression and B. 36, 37

2.5 FE/POLYMERIC ENERGY HARVESTER

Flexoelectric materials are also known as electrostrictive polymers. These polymers characteristics exists in all dielectric material, where development of polarisation is due to the strain gradient even when the material is non-piezoelectric.42, 43

As shown in figure 9 the flexoelectric materials experiences polarisation when deformed. 22

These type of energy harvesters possess certain advantages like it can withstand large strain making them ideal for energy harvester in smart textile. In Nano and micro scale flexoelectric material outperforms the piezoelectric materials in some situation.22. Due to its large strain gradient it can be used in human clothes as human movement requires higher strain over stroke.42

Due to limited research in flexoelectric energy harvester the current designs exhibit low coefficient and unfamiliar degradation properties on Nano scale. Barium strontium titanate is a ferroelectric with high dielectric permittivity which causes a narrow and sharp dielectric peak near the ferroelectric-Para electric phase transition temperature making it unsuitable for wide temperature range application.44Fabrication of flexoelectric energy harvester system is comparatively complicated.44

ADVANCEMENT

It have been tested by mahanty et al, a flexible sponge-like Nano generator with zinc oxide as an piezoelectric material and polyvinylidene fluoride hexafluoropropylene as an flexoelectric variant.it have achieved a power density of 1.21mW/cm^{2}and

energy conversion efficiency around 0.3% with 9V of open circuit potential difference and 1.3µA/cm^2 of short circuit current when a mechanical impact of 0.36 MPa stress amplitude is applied above the surface.45

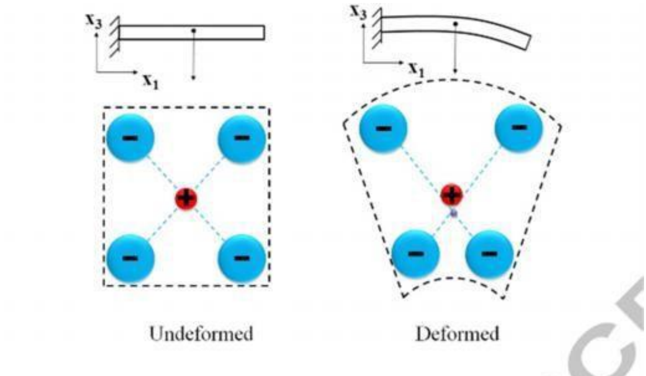

Figure 2: Polarization due to bending of a centrosymmetric beam

2.6 HYBRID ENERGY HARVESTER

The hybrid energy harvester is desirable in many cases because of the stochastic nature of vibrations from the atmosphere. inconsistence in other energy harvester.in this hybrid concept Huang et al presented that using electromagnetic transducer which uses magnetostrictive effect from magnetostrictive and piezoelectric laminate composite. The reason being high energy density and magneto mechanical-coupling effect of MS materials.46.figure 10 shows an arrangement of a magnetostrictive-piezoelectric energy harvester. In a research on a Piezoelectric-Electromagnetic hybrid Energy Harvester has revealed that there is a promising improvements on collected power energy extraction efficiency, operational frequency bandwidth, and circuit load range.47, 48 In comparison with different energy harvesting system it was found that a normal energy harvester gives an efficiency of 41%with 2.26mW47 of power while an alternative hybrid using lead zirconate titanate as an piezoelectric material along with a magnet in an electromagnetic mode gives an efficiency of 30.1%which is operating in a frequency range of 34-40 Hz with a peak power of 710µW having a normalised power density of 2.272 mW/cm^3/g .49 A hybrid of piezoelectric and electromagnetic vibration energy harvester generates an output which is 2.93% more than the piezoelectric alone and having a108% wider bandwidth than a piezoelectric energy harvester.53

ADVANCEMENT

In an experiment conducted byToreyn,6 et al on a group of thermoelectric and electromagnetic energy harvester which used chromel-alumel as an thermoelectric material while neodymiumironboron magnet was used as an electromagnetic component of an cantilever hybrid design6.i this the ambient temperature acts as an source of heat for thermoelectric material, as it was found in the experiment that taking the dimension size at 9.5 × 8 × 6 mm of an prototype generates a peak voltage of 16.7 mV and a power of 1.91 nW (TE = 0.79 nW; EM = 1.12 nW), with a vibration frequency of 3.45

kHz.6 In other experiment Wang et al50 have hybridised an ElectroMagnetic-ElectroStructive Vibration Energy Harvester with a power management circuit which charged the capacitor fast up to 112%; the EM apparatus generated a 2.5 mW maximum, while the ES output was 1.7 mW.50 Seol et al have explored the possibility of using Ferro fluid-based ElectroStrictive-ElectroMagnetic hybrid. Ferrofluid (EMG 707), NdFeB magnet, and aluminium (Al) electrodes were used. The ElectroStrictive effect occurs when the ferrofluid acts as contact medium between the top and bottom electrodes during shaking. As for the ElectroMagnetic mechanism, the magnet polarises the ferrofluid at the bottom; thus, the fluid itself contains a magnetic field and causes a changing flux when shaken, which occurs through the copper coil around the Vibration Energy Harvester housing and produces emf.51,52.An Energy Harvester design that uses the ThermoElectric approach, radio frequency, and vibration for wireless communication purposes generates 200 µW.54

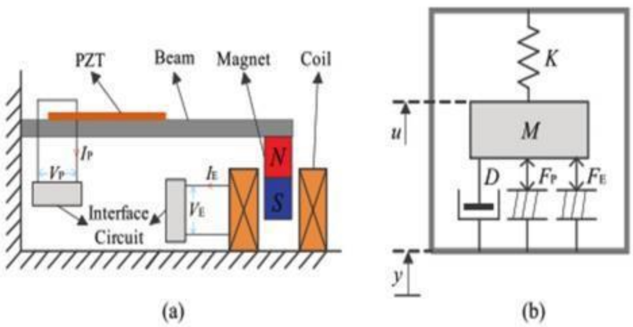

Fig. 1. (a) Schematic of a typical PE&EM-VEH and (b) equivalent SDOF system.

3. CONCLUSIONS

In this paper we review the VEH mechanism and the furthur development in architectural in the recent time in general, there are some changes done to made the relevant of this paper: innovative design (eg, compact, flexible, and wearable), increases the strain concentration with greater proof mass, timed circuit for broader RF, adaptation of nonlinear dynamic systems, and more optimal EH material properties. 6,119,135 The main difficulty is, however, are the stochastics and wide bandwidth of ambient vibrations, where the VEH required complex system in order to achieve.17 In terms of VEH fabrication, more true and cost-effective methods are needed, since WSNs and MEMS microscaling are expected to continue, thus implementing of micromachining technique are key to the commercialisation of VEH.136 Apart from WSN and MEMS, large-scale VEHs (1 Wto 100 kW) from transportation and civil activities to be a espouse solution for the energy exigency; a tuned damper produce 85KW of energy of a 76-storey building if a wind load of 13.5 m/s is applied.12 beside use of concentrating on EHs, secondary functions of the VEH as passive, active, immasive hybrid, semiactive isolation, or regenerative type damper help us to give strength for structurefor thre optimised lifestime and maintenance cost.137,138 For instance, an EM VEH was developed for vehicle suspension systems for road comfort, and regenerative power offer and increased the genetic algorithm multiobjective optimisation (NSGA-II) for special conditions.139 Current VEHs is only use for supply of energy forsuch as WSNs and MEMS and act as addition sources for heavy machinery or civil structure such as vehicle peripheral systems and backup lighting. Through hybridisation, help to enhanced VEHs can potentially become a chiefly energy source in the future.136 there are some combinations of mechanism and civil infrastructure to specify the operating condition of in RF, acceleration, environment, and scale. To become a mainstream energy solution, however, VEH R&D need to focus on niche applications, but they also need to be dexterous to competete different devices. By commercialising VEH and achieving relizable economics of scale, the VEH will be able to overhaul the battery storage devices and wired devices.

REFERENCES

1. Arroyo E, Badel A, Formosa F, Wu Y, Qiu J. Comparison of electromagnetic and piezoelectric vibration energy harvesters: model and experiments. Sensors Actuators, A Phys. 2012; 183:148-156. https://doi.org/10.1016/j.sna.2012.04.033

2. Balpande SS, Pande RS, Patrikar RM. Design and low cost fabrication of green vibration energy harvester. Sensors Actuators, A Phys.

2016;251:134-141.https://doi.org/10.1016/j. sna.2016.10.012

3. Hui KH, Lim MH, Leong MS, Al-Obaidi SM. Dempster-Shafer evidence theory for multi-bearing faults diagnosis. Eng Appl Artif Intel.

2017;57:160-170. https://doi.org/10.1016/j. engappai.2016.10.017

4. Shaikh FK, Zeadally S. Energy harvesting in wireless sensor networks: a comprehensive review. Renew Sustain Energy Rev. 2016;55:1041 -1054. https://doi.org/10.1016/j.rser.2015.11.010 5. Ferdous RM, Reza AW, Siddiqui MF. Renewable energy harvesting for wireless sensors using passive RFID tag technology: a review. Renew Sustain Energy Rev. 2016;58:1114-1128. https://doi.org/10.1016/j.rser.2015.12.332

6. Siddique ARM, Mahmud S, Heyst BV. A comprehensive review on vibration based micro power generators using electromagnetic and piezoelectric transducer mechanisms. Energ Conver Manage. 2015;106:728-747. https://doi.org/10.1016/j.encon man.2015.09.071

7. Ali SF, Friswell MI, Adhikari S. Analysis of energy harvesters for highway bridges. J Intell Mater Syst Struct. 2011;22(16):1929-1938. https://doi.org/10.1177/1045389x11417650

8. Pellegrini SP, Tolou N, Schenk M, Herder JL. Bistable vibration energy harvesters: a review. J Intell Mater Syst Struct.2012;24(11):1303-1312. https://doi.org/10.1177/1045389X 12444940

9. Kokkinopoulos A, Vokas G, Papageorgas P. Energy harvesting implementing embedded piezoelectric generators-the potential for the Attiki

Odos traffic grid. Energy Procedia. 2014;50:1070-1085. https://doi.org/10.1016/j.egypro.2014.06.126

10. M'Boungui G, Adendorff K, Naidoo R, Jimoh AA, Okojie DE. A hybrid piezoelectric micro-power generator for use in low power applications. Renew Sustain Energy Rev. 2015;49:1136-1144. https://doi.org/10.1016/j.rser.2015.04.143

11. Zheng Q, Shi B, Li Z, Wang ZL. Recent progress on piezoelectric and triboelectric energy harvesters in biomedical systems. Adv Sci. 2017;4(7):1-23. https://doi.org/10.1002/advs.201700029