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A REVIEW ON VIBRATION BASED ENERGY HARVESTING DEVICES

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ABSTRACT

There are a lot of micro systems which are very useful in our daily life and in other applications also. Some of these examples are watches, calculators, bluetooth headsets and wireless sensors etc. Some other applications are remote weather station, military monitoring devices and biomedical applications etc. Energy harvesting is a promising technique for solving the power issues in these devices and to make them self-powered by eliminating the external batteries. Modeling of energy harvesting devices is complicated by coupling between electrical and mechanical domains.

This paper reviewed the research work done in last few years. The improvements obtained in the vibrational-based MEMS piezoelectric energy harvesters show very good scope in the field of MEMS in near future.

This paper will be very useful for the comparative study and interested researchers of this field.

Keywords: Harvesting energy, MEMS, Micro systems, Piezoelectric.

I. INTRODUCTION

Traditional micro systems are worked on conventional batteries for their respective functions. Obviously these electrical storage devices have limited life span. Batteries of these devices may be damaged or discharged after a long time period of use. They have to be recharged after getting discharged or replaced when exhausted or used up. This issue is one of the major limits in these devices. Energy harvesting or power scavenging is a solution for this problem. The matter is only to make energy in usable form as energy is available in nature all around us in various forms. These forms or energy sources are described further.

Energy harvesting technique simply follows the law of conservation of energy as it says that the energy can neither be created nor be destroyed, it changes one form to another and harvesting technique also converts ambient energy surrounding the system (one form) into useful electrical energy (another form), accumulating it and storing for the use. So ‘energy harvesting’ is a technology that converts the excess energy available in the environment into usable energy for low power electronics.

Here we can identify several micro-energy harvesting sources:

Vibration, motion or mechanical energy: stairs, floors, movement of some object etc [1].

- Thermal.
- Pressure gradients.
- Momentum generated by radioactive reactions into electrical energy.
- Micro water flow.
- Solar and light.

• Biological.

To undergo growth a totally self-ruled apparatus however, old and wise electric units having limited living go across have to be gave another in place of with energy harvesters. quick motion or vibration based energy getting together is one of the best answers for powering self-ruled small-scale systems, needing payment to the fact that quick motion starting points are too ready (to be used) every-where in the all around general condition. The electrics energy is converted from vibrational energy via electrostatic, electro-mechanic or piezoelectric transduction method.

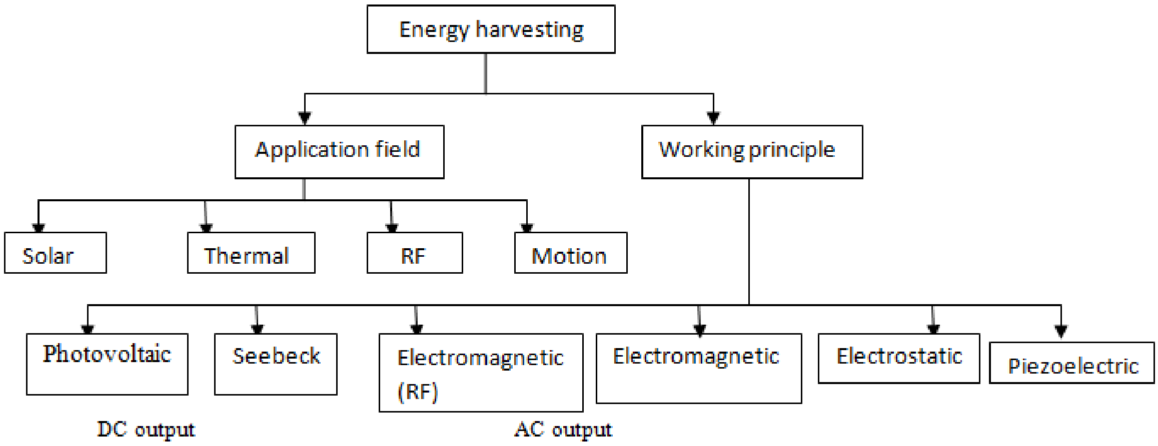

Fig. 1 Hierarchy of energy harvesting technologies

II. HISTORY

The first observation of harvesting energy in the form of current from natural source was in 1826. Thomas Johann See beck found that a current would flow in a closed circuit made up of two dissimilar metals when they are maintained at different temperatures.

The first observation of harvesting energy in the form of charge was in 1880. Pierre and Jacques Curie successfully predict and proved experimentally that certain crystals would exhibit a surface charge when they are given a certain mechanical stress. This phenomenon was given the name piezoelectricity.

A. Electrostatic

A capacitor having two plates which are electrically isolated from each other by air, vacuum or an isolator. Opposite charge Q is created on the plates due to the connected battery of voltage V. When voltage is disconnected, charge is stored.

Capacitance of the capacitor:

$C = Q/V$

Where C = capacitance in farads, Q = charge on the plate in coulombs and V = the voltage on the plates in volts.

For a parallel plate capacitor, C is given by:

$C = \varepsilon (A/ d)$

Where ε = the permittivity of the material between the plates in F m−1, A= the area of the plates in m² and d is the separation between the plates in meters.

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Harvesting energy is provided by the work done against the electrostatic force between the plates. Electrostatic converters broadly divided into two parts: [2]

1) Electrets-free electrostatic converter

2) Electrets based electrostatic converter

1) Electrets free electrostatic converters

These converters do not use dielectric materials i.e. electrets. Converters simply use charging and discharging cycles of the capacitor.

2) Electrets based electrostatic converters

These converters use electrets which are basically dipoles (electrostatic) that store the charge for years so these type of converters have ability to convert the mechanical power into electrical one by using electrets.

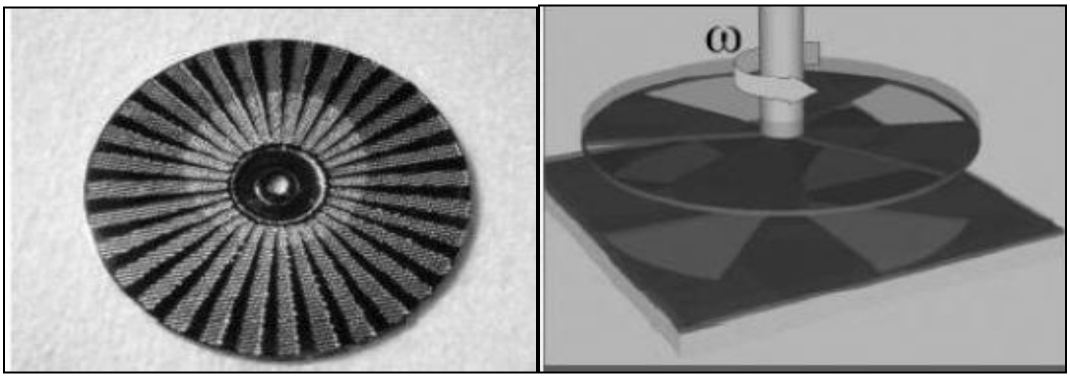

Fig. 2 Boland's electrets based generator prototype

Menninger et al at the MIT in 2001, developed MEMS electrostatic comb based vibration electrostatic harvester (VEH). This energy harvesting device used in plane overlap electrostatic converter. They proved that if power management electronics is limited in voltage, the voltage constrained cycle would make able to make greatest degree the output power. This prototype was used for simplification of power management circuits.

Tashiro et al, in 2002 designed a pacemaker which is capable of harvesting or collecting power from heartbeats. This prototype was put in on the heart of a goat & the power obtained was approx 58 μW.

In 2003, the best structure for the electrostatic devices was in plane gap closing proved by Roundy. He would be able to harvest up to 100 $\mu W/cm^2$ [2].

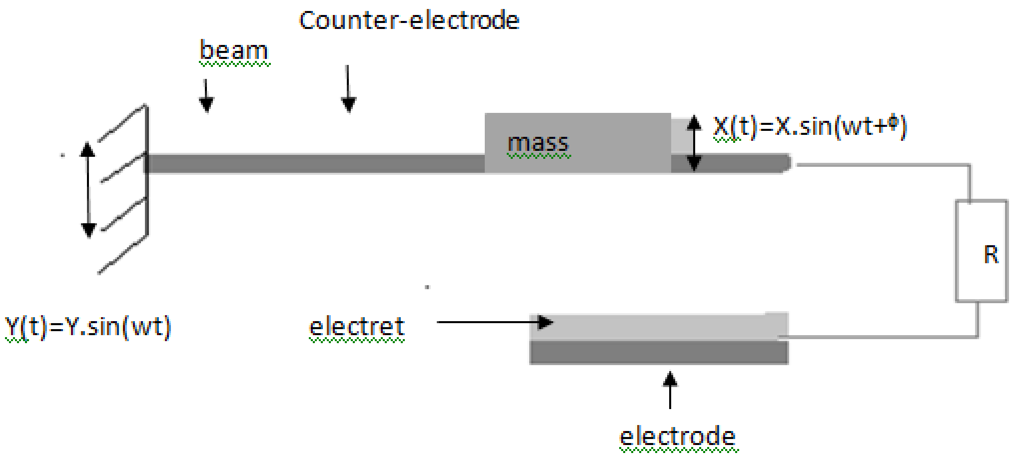

Fig. 3 Cantilever based electrets energy harvester

In 2005, a Despesse developed the highest power density of a VEH ever reached, they are able to work on a lower vibration frequencies and able to harvest 1mW power for a vibration of 0.2 G@ 50 Hz.

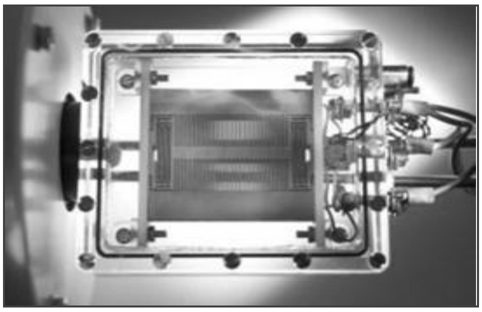

Fig. 4 Electrostatic VEH

In 2006, the first structure using patterned electrets was developed by the University of Tokyo [4]. Miki et al improved the first architecture devices by using non-linear effects and developing multiphase system.

Now we can compare the various useful parameters of the experiments and theories given by different scientists. Here we are comparing by tabulate these

By these tables we can easily show the optimization of parameters like output power etc. Here maximum output power is 1050 µW.

TABLE I An Overview of Electrostatic VEH for Electret Free

Author	**Tashiro**	**Roundy**	**Despesse**
O/P power	36µW	11µW	1050µW
Surface	-	100mm²	1800mm²
Volume	15000mm³	100mm³	1800mm³
Vibration	1.2G@6Hz	0.23G@100Hz	0.3G@50Hz

Polarization voltage	45V	-	3V

It was for the electrostatic VEH for electret free. Now we move towards the electrostatic VEH for electret based and take its overview.

Here in case of electrets based electrostatic VEH, we can see that the maximum power is 50µW at 1400V electric potential [2].

TABLE II An Overview of Electrostatic VEH for Electret Based

Author	**Vibration/ Rotation**	**Active surface**	**O/P power**	**Elec-tric poten -tial**
Boland	4170rpm	$0.8cm^2$	25µW	150V
Sterken	1G@500Hz	$0.09cm^2$	2nW	10V
Boisseau	0.1G@50Hz	$4.16cm^2$	50µW	1400 V
Miki	1.57G@63Hz	$3cm^2$	1µW	180V
Naurse	0.4G@2Hz	$9cm^2$	40µW	-
Suzuki	5.4G@37Hz	$2.33cm^2$	0.28µW	450V

B. Renewable Energy and Smart Grids

All the energy sources are not that much available like wind and solar power. So unlike conventional sources of electric power, these renewable sources cannot be controlled at the request of power grid operators or of the plant owner. Daily and seasonal effects and limited predictability result in intermittent generation [3].

So smart grids promise to facilitate the integration of renewable energy and will provide other benefits as well.

Smart grids play important role as a solution to the problems like reliability and efficiency associated with the renewable energy sources.

The smart grid, an evolution of electricity networks toward greater reliance on computation, communications, and control, promises a solution. The uncertainty of wind and solar generation are major complications that must be addressed before the full potential of these renewables can be reached.

The term gained prominence through the U.S. Energy Independence and Security Act (EISA) of 2007, the European Technology Platform for the Electricity Networks of the Future, and similar initiatives across numerous other countries. The U.S. Department of Energy has provided a concise description of the smart grid.

The smart grids technology platform summarizes the benefits of smart grids as follows. They:

- better facilitate the connection and operation of generators of all sizes and technologies.
- Allow consumers to play a part in optimizing the operation of the system.
- Provide consumers with greater information and options for choice of supply.
- significantly reduce the environmental impact of the whole electricity supply system.
- Maintain or even improve the existing high levels of system reliability, quality and security of supply.
- Maintain and improve the existing services efficiently.
- Foster market integration.

C. Piezoelectric Energy Harvesting

Transduction principle

The piezoelectric effect converts mechanical strain into electric current or voltage. It is based on the fundamental structure of a crystal lattice. Certain crystalline structures have a charge balance with negative and positive polarization, which neutralize along the imaginary polar axis. When this charge balance is perturbed with external stress onto the crystal mesh, the energy is transferred by electric charge carriers creating a current in the crystal. Conversely, with the piezoelectric effect an external charge input will create an unbalance in the neutral charge state causing mechanical stress.

In a monocrystal, the polar axes of all of the charge carriers exhibit one-way directional characteristics. These crystals demonstrate symmetry, where the polar axes throughout the crystal would lie unidirectional even if it was split into pieces.

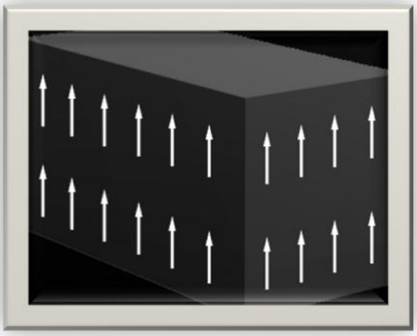

Fig. 5 Monocrystal

Instead, a polycrystal is characterized by different regions within the material with different polar axes. For symmetricity, there should be such a point at which the crystal could be cut that would leave the two pieces with the same resultant polar axes. It is asymmetrical because there is no such point.

In order to reach the piezoelectric effect, the polycrystal is heated to the Curie point along with strong electric field. The heat allows the molecules to move more freely and the electric field forces the dipoles to rearrange in accordance with the external field.

Fig. 6 Polycrystal

In 2010, piezoelectric thick films have increasing interest due to the actuation force and potential high sensitivity and for MEMS actuators and sensors.

In 2012, Xu, Ruichao, Lei, Anders described the fabrication and characterization of a significantly improved version of a microelectromechanical system-based PZT/PZT thick film bimorph vibration energy harvester with an integrated silicon proof mass.

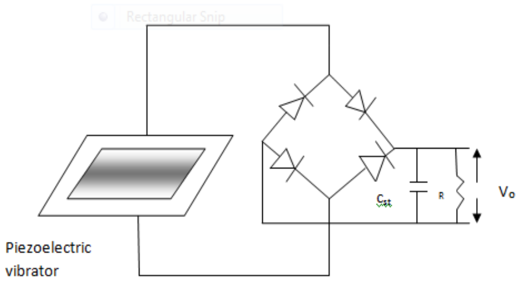

Fig. 7 Vibration energy harvester through piezo material

A.Vasquez Quintero studied a low complexity and low temperature fabrication process for vibration energy harvesters. He presented a process flow used to transfer thinned PZT thick sheets onto flexible polymeric substrates using lamination techniques. The transfer was achieved using a dry film photoresist laminated at relatively low temperatures (85°C). The geometrical influence on resonance frequencies were investigated by FEM simulations. Optimization of the output power was performed by modifying the neutral plane within the device and by using a localized seismic mass at tip; which has resulted in an output power of 30 µW at 52 Hz and an acceleration of 1g.[2]

D. RF Energy Harvesting

In 2014, recent advancement in semiconductor technology and fabrication process enables realization of the concept of radio frequency energy harvesting. RF energy harvesting, a process in which energy contained in electromagnetic waves is converted into useful electrical energy, will help realize perennially operating sensors.

RF energy harvesting sensors can attain the desirable characteristics of sensor design, lifetime and network performance.

Wireless sensor network is usually designed to have the longest possible lifetime. Energy harvesting is the process of scavenging ambient energy from sources in the surrounding environment. It is an attractive method for overcoming the energy limitations of conventional battery powered wireless devices. It can fulfill the major requirement of these sensors that is energy or power.

RF energy harvesting is allowing sensors to recharge energy storage capacitors from the incident RF radiation. [5]

The main challenge of harvesting RF energy is the free-space path loss of the transmitted signal with distance.

The Friis transmission equation relates the received(Pr) and transmitted(Pt) power with distance R as

$$Pr = Pt\ Gt\ Gr(\lambda/4\Pi R)^2 \qquad \text{.... (1)}$$

Where Gt=transmitting antenna gain

Gr=receiving antenna gain

λ= wavelength of the transmitted signal

We can see that received signal strength diminishes with the square of the distance.

RF energy harvesting circuits

It was primarily based on the voltage multiplier circuit.The incident RF power is converted into DC power by the voltage multiplier while matching network, composed of inductive and capacitive elements, ensures the maximum power delivery from antenna to voltage multiplier.

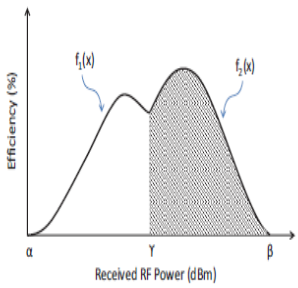

Fig 8 Efficiency curves of two energy harvesting sister circuits, for LPD and HPD

In this, individual parameters of harvesting circuits are investigated and then this study is used in the optimization framework of the energy harvesting circuit.

As shown in figure 8, at each particular crossover point γ, the total area under efficiency curve is the cumulative sum of the area under the two distinct efficiency curves corresponding to the LPD and HPD designs, one on either side of the crossover point γ. The total area under efficiency curve is hence,

$$Area(total) = \int_{\alpha}^{\gamma} f1(x)dx + \int_{\gamma}^{\beta} f2(x)dx \quad .....(2)$$

The dual-stage design yields almost double the efficiency than that of a major commercially available energy harvesting circuit.

III. CONCLUSION

As the ambient energy sources are so diversified (vibrations, RF, thermal etc.), Here in this paper many techniques to harvest and to convert to DC power supply energy from the available sources, have been presented.

It is hard to make a decision that which technology is the optimized or best one among all that are discussed because a number of parameters make the comparison difficult. These parameters are efficiency, output voltage, harvested power, the size of harvester, availability etc.

Energy harvesting techniques and their applications are expanding and becoming more attractive especially with advance in microelectronics and MEMS. Power management allows for harvesting from multiple sources, which depends on the application. It can lead to directly power the application circuit without using battery.

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