An Optimization of Energy Harvesting Techniques through Mechanical Vibration

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ABSTRACT

Energy harvesting through mechanical vibration have emerged as an important research area and continues to grow at rapid pace. A wide range of applications are targeted for the harvesters, including distributed wireless sensor nodes for structural health monitoring, embedded and implanted sensor nodes for medical applications, recharging the battery of large systems, monitoring the tyre pressure in automobiles and running security system in household conditions. Several transduction mechanisms exist for transformation of mechanical energy of mechanical vibrations into electric energy. Principle of vibration energy harvesters is in most cases mass-spring-damper system with one degree of freedom. Considering physical principles used to transform kinetic energy into electrical energy, there are four transduction mechanisms: electrostatic, piezoelectric, electromagnetic and magnetostrictive

One latest and good example of energy-harvester device is "Mechanical motion rectifier". It is based on electromagnetic principle and the key component is a unique motion mechanism, which is called "mechanical motion rectifier (MMR)", to convert the oscillatory vibration into unidirectional rotation of the generator. The prototype achieved over 60% efficiency at high frequency, much better than the conventional regenerative shock absorbers in oscillatory motion. Furthermore, road tests are done to demonstrate the feasibility of the MMR shock absorber, in which more than 15 Watts of electricity is harvested while driving at 15 mph on a smooth paved road. The motion rectifier based design can also be used for other applications of vibration energy harvesting such as from tall buildings or long bridges.

One another good example is harvesting vibration energy by a triple-cantilever based on triboelectric nanogenerator. Triboelectric nano-generators (TENG), a unique technology forharvesting ambient mechanical energy based on triboelectric effect, have been proven to be acost-effective, simple and robust approach for self-powered systems. TENG produces an open-circuit voltage up to 101 V and a short-circuit current of 55.7 μA with a peak power density of 252.3 mW/m^2.

***Keywords**: Ambient energy sources, energy scavenging, mechanical energy transducers, electromagnetic vibration energy harvester*

1. INTRODUCTION

Energy harvesting is an active field of research aimed at powering low power wireless systems, self-powered sensors and micro-systems and recharging existing batteries. Renewable energy can be harvested by generating electrical energy from solar, thermal or kinetic energy present within or around the system. Solar cells are excellent energy harvester under direct sunlight, but are limited in application under dim day light condition, in the night and where light has no access, such as in embedded systems. Thermal energy can be converted into electrical energy using seeback effect, but this approach produces energy in the range of a few μW only. Kinetic energy harvester converts kinetic energy present in the environment into electrical energy. It has already been demonstrated by several groups that the ambient kinetic energy can be easily converted into electrical energy in the μW range. Kinetic energy is typically present in the form of vibration, random displacement of forces and is typically converted into electrical energy using electromagnetic, electrostatic and piezoelectric energy transduction method. Kin et al, reviewed the piezoelectric energy harvesting based on vibration. Lefeuvre et al, described the energy harvesting techniques using piezoelectric materials with a case of random vibrations. Bowen et al, 2014 explained the peizoelctric and ferroelctric materials and structures for energy harvesting applications.

1.2SOURCE OF VIBRATIONAL ENERGY HARVESTER

Vibration energy available in a wide variety of sources can be conveniently used for potential powering of wireless sensors and low power devices. Such as escalators, bridges, rotor blades, windmill blades, pumps and one of great resources are automobiles.

According to "Indian Motor Vehicles knowIndia.net" following data are given:-

India was the sixth largest motor vehicle/car manufacturer in the world in 2013.Indian auto manufacturers produced a record 23.4 million motor vehicles in 2014-15.(Apr Mar).3.22 million passenger vehicles rolled out from Indian auto plants in 2014-15.

Table –I: Motor vehicle available in INDIA year wise.

Domestic Motor Vehicle Sales	2014-15(In Millions)
Passenger Vehicles	2.60
Commercial Vehicles	0.61
Two –wheelers	16.0
Three-wheelers	0.53
Total	19.00

Year	Total numbers of Vehicle sales (In Millions)
2013-14	3 + 14.36 = 17.36
2010-11	1.49+5.016 = 6.506
2009-10	1.211+4.123=5.334
2008-09	4.36+5.25 =9.61

"On the basis of above observation more than 19 million vehicles (Passenger Vehicle , Commercial Vehicle , Three wheeler) running on the road and suppose average 100 W electricity produce by each vehicle that means it is equivalent to 1900 MW electricity will be produce , which is great energy".

2.MECHANICAL MOTION RECTIFIER (MMR)

Mechanical motion rectifier is energy harvesting shock absorber which is able recover the energy otherwise dissipated in suspension vibration while simultaneously suppress the vibration induced by road roughness. It can work as a controllable damper as well as an energy generator. A mechanical motion rectifier (MMR) is a device which converts the oscillatory vibration into unidirectional rotation of the generator. Prototype MMR is to achieve more than 60% efficiency at high frequency, which is much better than conventional regenerative shock observer in oscillatory motion. The model is capable of analyzing electrical and mechanical components at the same time. Shock absorber is installed between chassis and wheels to suppress the vibration.

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Fig -2.1 MMR Setup in vehicle Chevrolet Suburban SUV

The road test is done to demonstrate the feasibility of the MMR shock observer and it is observed that more than 15 watts of electricity which harvested while driving at 15 mph on a smooth road. Zuo and Zhang et.al, observe that 100 to 400 watts of energy harvesting potential exist in the suspension of typical passenger vehicle travelling 60 mph on the good roads and more energy available for trucks or on the rough roads. The motion rectifier based design can also be used for other application of vibration energy harvesting such as from tall building, long bridge or ocean vehicles. It can significantly improve the reliability by reducing impact forces and increase efficiency by decreasing the influence of friction. he main contribution of this paper is an innovative concept of mechanical motion rectifier", which can convert bidirectional motion into unidirectional motion. It is not a substitute of electrical voltage rectifier. It can significantly improve the reliability by reducing impact forces and increase efficiency by decreasing the influences of friction. It also enables the electrical generator to rotate unidirectional at relative steady speed with higher energy efficiency. The second contribution is a circuit based modeling to analyze the system's dynamic properties both in electrical domain and mechanical domains. The third contribution of this paper is simulation, lab experiments, and road tests to verify the concept and advantages of mechanical motion rectifier based vibration energy harvester.

2.2 PRINCIPLE OF MMR

Shock absorbers are installed between chassis and wheels to suppress the vibration, mainly induced by road roughness, to ensure ride comfort and road handling. Conventional rotational regenerative shock absorbers translate the suspension oscillatory vibration into bidirectional rotation, using a mechanism like ball screw or rack pinion gears. Figure 3.2 shows one such an implementation, where the rotary motion is changed by 90 degree with a pair of bevel gears for retrofit.

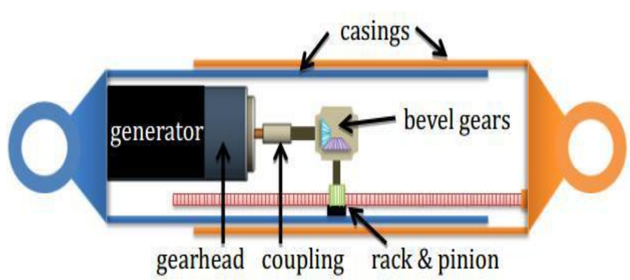

Fig 2.2 - Traditional design of a rack-pinion based regenerative shock absorber

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It is working on “motion rectifier” with two working mode: positive mode and negative mode. Key components of “motion rectifier” are two one way roller clutches that transmit rotation only in one direction and dive the motion in two different routes. As a result, shaft of the motor and planetary gear will always move in one direction. It converts the irregular reciprocating vibration into the unidirectional rotation.

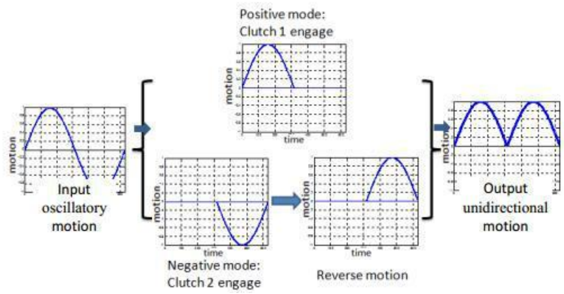

Fig 2.3 Principle of “motion rectifier” for oscillating motion

MMR with two roller clutch can be analogy to full-wave voltage rectifier using a centre tapped transformer and two diodes. The system inertia is equivalent to the electrical smoothing capacitor in series with electrical load. When the direction of the motion changes, the relative velocity between the driving part and driven part, which caused by backlash, would be much smaller so that the impact forces would be much smaller ,in this way reliability would be improved.

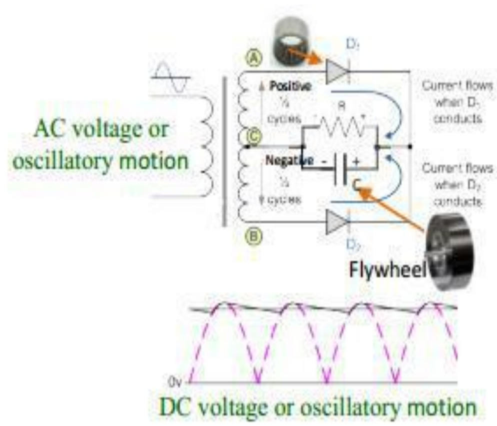

Fig 2.4 Electrical analogy for “motion rectifier”

3. DESIGN OF HIGHLY-COMPACT MOTION RECTIFIER BASED HARVESTER

Design of MMR is very compact in comparison of existing other design. In this design they using pair of rack and pinion, one shaft and three bevel gears .Two roller clutches are mounted between the shaft and the two larger bevel gears, which are always engaged with the small bevel gear .When rack moves up and down, the pinion and shaft rotate clock wise and counterclockwise directions. Due to the engagement of one-way roller clutches at instant time only one large bevel gear will be engaged and be driven by the shaft; another large bevel gear disengaged with from the shaft by the roller clutch. The assembly of the pinion, shaft, and bevel gears will be mounted to one cylinder, and another cylinder covers outside and to guide the linear motion. Similar as roller bearings, the roller clutches can’t hold large thrust in the axial direction, so two thrust bearings are designed to support the thrust forces on the two larger bevel gears. In order to reduce the friction between the inner and outer cylinders, we insert Teflon rings between the two cylinders. The rack is preloaded and guided by a roller in the place opposite to the pinion. The enclosed construction of the shock absorber prevents dirt from hurting gears inside.

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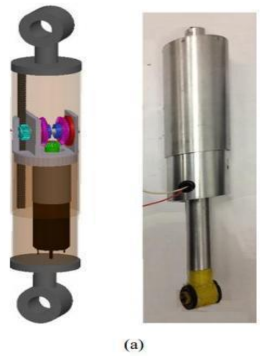

Fig 3.1 sample and 3D view of MMR

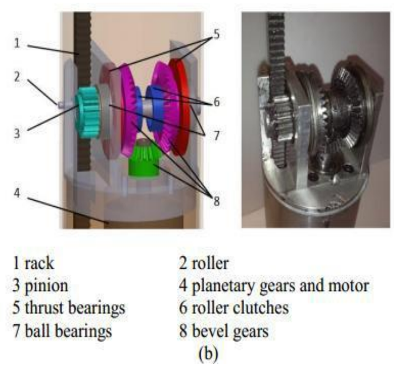

Fig 3.2 components of MMR

3.2 EXPERIMENT AND RESULTS

Experiment Setup –

Experiment Setup The prototype was tested with the MTS 858 Mini Bionix II testing system and a dynamic signal analyzer (Hewlett Packard Model 35670A).

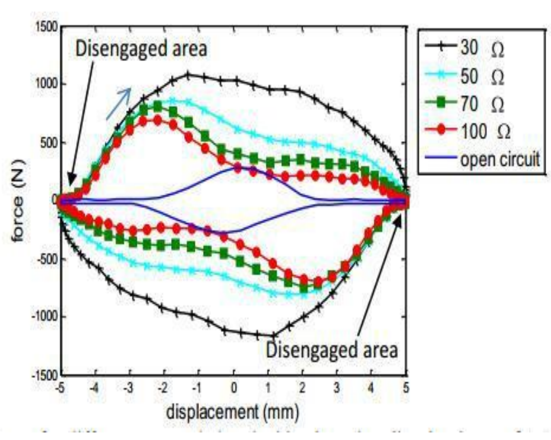

Fig 3.3 Damping loops for different external electrical loads under vibration input of 1.5 Hz and5mm amplitude.

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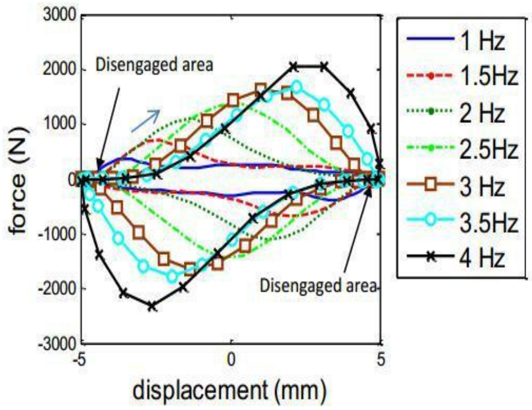

Fig 3.4 Damping loops for different input frequencies with electrical load Ri +Re= 106.6 Ω

3.3CONCLUSION OF MMR

"Motion rectifier" based design of electromagnetic energy harvester for enhanced efficiency and reliability for potential application of vibration energy harvesting from vehicle suspensions. "Motion rectifier" can transfer the oscillatory motion of vehicle suspension into unidirectional motion of the electrical generator, thus enabling the generator operating in a relatively steady speed with higher efficiency. In such a design, the motion inertia will act as a filtering capacitor to temporarily storage the energy and smooth the rotation, which can decrease the influences of backlash impact and static friction.

4.Harvesting Vibration Energy By A Triple-Cantilever Based Triboelectric Nanogenerator (Teng)

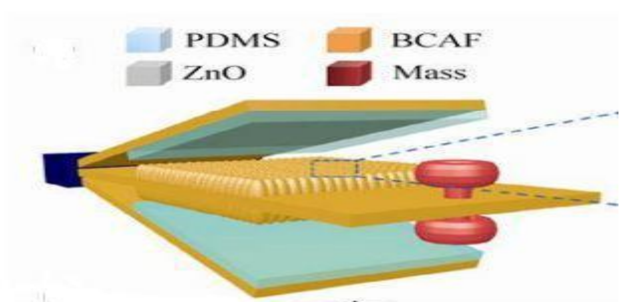

Fig 4.1 triboelectric Nanogenerator (TANG)

Triboelectric effect – "The triboelectric effect is phenomenon that material becomes electric charged after it contacts a different material through friction." It is based on triple-cantilever TENG harvesting vibration energy with the assistance of nanowire arrays fabricated onto the surface of beryllium-copper alloy foils. TENG produces an open-circuit voltage up to 101 V and short circuit current reached up to 55.7 µA with peak power density of 252.3 mW/m^2 . Output power of single device with a size of 3.2 cm by 2.8 cm is high enough to simultaneously light up more than 40 commercial LED. Unambiguously demonstrating its feasibility of power portable electronics. Using as sensor for environmental and infrastructure monitoring security.

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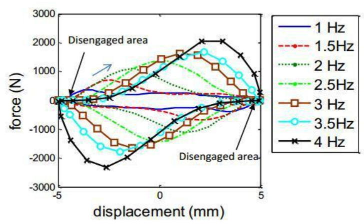
4.2 DESIGN & CHARACTERIZATION OF TENG



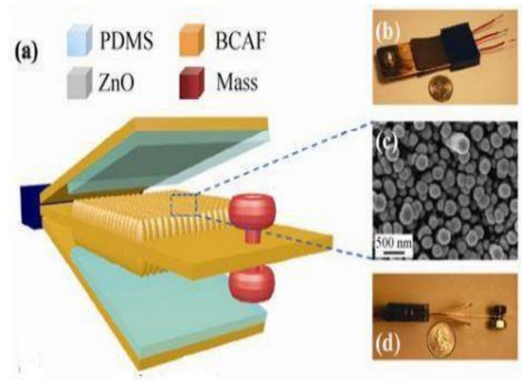
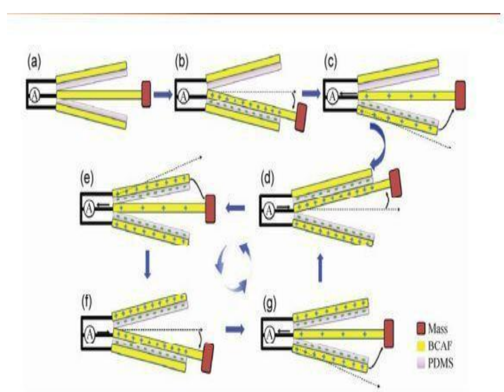


Fig 4.2 Photograph of typical cantilever beam

The bottom surface of top cantilever and top surface of bottom cantilever are coated with poly dimethyl siloxane (PDMS) films and middle cantilever are covered by ZnO nanowire array which layer copper will deposited. A mass is attached at end of its effectiveness of vibration. Middle cantilever has two chances the contact the top and bottom cantilever in each cycle of vibration. PDMS film can easily deformed to increase the effectiveness contact area and nanowire array can deeply inserted into PDMS to increase the effective contact area and thus leading to substantially higher electric output. A cycle of electricity generation process illustrating mechanism of the TENG can be explained by coupling between triboelectric effect and electrostatic effect.

Fig 4.3 : A cycle of electricity generation process for illustrating the mechanism of the triple-cantilever based TENG



4.3 EXPERIMENT & RESULT

Electric output measurements were performed on a triple-cantilever based TENG device with effective contact area of 3.2 cm × 2.8 cm, at triggering frequencies of 3.5 Hz, Hz, and 4.0 Hz. The open-circuit voltages (VOC) at 3.5 Hz, 3.7 Hz , and 4.0 Hz are about 89 V, 101 V, and 81 V, respectively, indicating that the 3.7 Hz is the resonance frequency of the TENG. As shown in the inset of, a positive voltage is generated due to the immediate charge separation on the departure of the middle cantilever from the PDMS film on the bottom cantilever. Since the electrons cannot flow back to screen the induced electric potential difference between the two electrodes under the open-circuit condition, the voltage remains at a plateau until the next contact [10–14]. Moreover, the peak values of the rectified short-circuit current (ISC) at 3.5 Hz, 3.7 Hz and 4.0 Hz also reach up to 45.9 µA, 55.7 µA, and 44.5 µA, respectively.

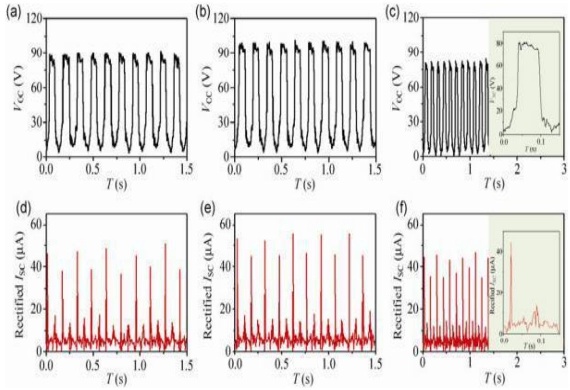


Fig 4.4 Open-circuit voltage (VOC) at vibration frequencies of 3.5 Hz (a), 3.7 Hz (b), and 4.0 Hz (c) andrectified short-circuit current (ISC) at vibration frequencies of 3.5 Hz (d), 3.7 Hz (e), and 4.0 Hz (f). The insets of (c) and (f) are enlarged views of half cycles of the VOC and ISC at 4.0 Hz, respectively.

5.CONCLUSION

An overview of sources of ambient energy available for harvesting was presented. Description of four vibration energy harvesting mechanisms was proposed with respect to pros and cons of each technique. The aim of this technique is to make the energy harvester produce maximum power output in the most effective way. “Motion rectifier” based design of electromagnetic energy harvester for enhanced efficiency and reliability for potential application of vibration energy harvesting from vehicle suspensions. The “motion rectifier” based design achieved a mechanical efficiency of over 60% and no obvious backlash effect. It also harvested average powers 40.4 Watts and 25.6 Watts on 30 and 93.4 external resistive loads under vibration of RMS velocity 0.047m/s and we have also seen triple-cantilever based TENG for harvesting vibration energy in ambient environments. This innovative structure provides the middle cantileverwith two chances to contact the top and bottom cantilevers in each cycle of the vibration, doubling the vibration energy conversion efficiency.

Future Work

Mechanical vibration is great source of energy harvesting, we have seen at present time more than 19 million automobiles are available in INDIA and it will be very large data in future. Improvement is possible in efficiency as well as reliability. We can save 10-14% fuel by recharging car battery and small electronics device. We can make more robust and regular unidirectional rotational design.

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