Human Motion Based Energy Harvester for Bio-Medical Devices

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***Abstract*—This paper presents a human motion based electromagnetic energy harvester for bio-medical devices. This harvester is composed of a Teflon tube, cylindrical magnets, rubber spring and wound coils. The developed energy harvester is tested on an experimental setup which has been developed to test power generation capability of the device with the vibration shaker at 3 g acceleration level. The combined open circuit maximum voltage of 4140 mV is generated by the harvester at 19 Hz and 3 g. Moreover, the harvester produced an optimum load power of 1.89 mW at a load resistance of 25 Ω and successfully recharges a 1.5 V battery in 60 min.**

***Index Terms*—Electromagnetic; Energy harvester; Human body motion; vibrations;**

I. Introduction

In daily life, the usage of a smart portable devices and gadgets are rapidly increasing. The computer world has changed the life of the human beings. Every person is surrounded by thousands of sensors because of the advancement in the technology day by day. There is a report that in 2020 every human being will be connected to billions of sensors and ever thing will be interconnected with each other so the technology has brought a lot of comfort to the society because of the automation. It means that due to the advancement of the technology, a lot of smart devices have been introduced to help the human being in the daily routine. In this technology era, every person is utilizing smart devices, such as, cell phone, wrist watch, tablets, smart glasses and smart radio etc. Individuals are so dependent on this smart technology that life without these sought of gadgets seems incomplete since these devices have brought a comfort and entertainment to human lives. In a daily routine with the advanced technology, a person can send an email within a few seconds with his smart phone, moreover, home appliances can be controlled and regulated with cell phones in todays world. Furthermore, one can get the information about the weather or a roadmap with a smart watch [1]. Advanced devices are playing a pivotal role in the defense sector as well. A modern military soldier is equipped with many sophisticated devices and gadgets, like, smart glasses, infra-red binoculars, wireless communication system, smart weapons and laser lights etc. [2]. Moreover, the advancement of the technology have make way for portable biomedical gadgets, such as, blood pressure monitor, heart rate meter, glucometer, insulin pump and pacemaker In the health sector technology has become very advanced with a lot of smart biomedical devices for the patients. A diabetic patient carries an insulin pump to check his sugar level with every passage of time, a person unable to hear easily has to wear some smart hearing aid or a heart patient has a pacemaker in his body to control the heartbeat [3]. These devices usually used by the human beings, normally require power to operate which is provided by batteries [4]. Without battery the gadgets are useless. The main drawback of the battery is that it has a very limited life span and replacement of the battery is needed after a certain period of time [5]. This limited life span of batteries make the advanced and sophisticated devices least versatile and restrict its applications [6]. However, the energy harvesting technology has the capability to power these portable devices and gadgets. In energy harvesting the available ambient energy is extracted and converted into electrical energy for device operation [7]. Advancements in energy harvesting from the human body motion can play a vital role to power the portable electronic devices. A number of energies are available inside, over and outside the human body from where energy can be extracted. The lists of energies available have been mentioned in the Table 1. In the Table 1 it is shown that there are different energy sources with a very good power density. So from these energies different gadgets can be charged and their batteries can be replaced. The human body motion has the ability to generate energy for these devices. Vibration plays a vital role in the field of energy harvesting. Research in Energy Harvesting from the human body motion plays an important role to power the portable electronic devices which are required for the human beings. The human body motion has the ability to generate energy for these devices [7].There is an opportunity to extract Energy from every movement of the human body and it can relate these movements with the vibration of the human body part.

Vibration is available in basic human activities, such as, walking, jogging, breathing, writing, knocking, tapping a foot, therefore, from all such human body motions energy can be harvested to power up the gadgets [8]. The human body motion can be converted into electrical energy through different mechanisms, such as, electromagnetism, piezoelectricity and thermoelectricity. These three are the most suitable mechanisms to extract energy from the human body motion [9]. Recently, energy harvesting from the human body motion has gain immense interest and a several research work has been reported in literature. An electromagnetic energy harvester has been fabricated for generating energy from human body motion [10]. The harvester is developed to be placed in a rucksack or backpack. The harvester is tested during walking and unhurried running. The maximum output power that is reported to be generated by the harvester is

TABLE 1. AVAILABLE ENERGIES OUTSIDE AND INSIDE HUMAN BODY

Sources	Power Density	ref.
Solar (direct sunlight)	100000 μW/cm²	[17]
Light (indoor)	100 μW/cm²	[17]
Ambient airflow	177 μW/cm³	[18]
Radio Frequency	180 μW/cm²	[19]
Infrared Radiation	22000 μW/cm²	[22]
Thermal (Ambient)	20000 μW/cm²	[17]
Thermal (Human)	600 μW/cm²	[17]
Blood Pressure (Human)	0.93 W at 100mmHg	[18]
Vibration (Human)	4 μW/cm³	[19]
bio-fuel (Human)	20.4 μw/cm²	[20]
Acoustic (Human)	0.003 μW/cm³ at 75 dB 0,11 μW/cm³ at 110 dB	[21]

300 W to 2.5 mW. An electromagnetic energy harvester is developed in [11] is capable to generate energy from shaking of hands. The tube length of the device is 66 mm and the width of coil winding is 10 mm. The harvester is tested under 1.6 g acceleration level and frequency of 6.7 Hz and a maximum output power that is reported of the harvester is 568.66 W.. An electromagnetic type energy harvester [12] is developed which is placed on the human limb. The reported harvester is characterized while walking on the treadmill. The energy harvester is producing a voltage is up to 0.68 V and an output power of 10.66 mW at walking speed of 8 km/h. The piezoelectric energy harvester has been developed in the paper which is wrapped around on human blood artery. The total size of the device is 0.30 cm3 and the device can generate peak power up to 60 nw. The device can be used for many biomedical equipment such as pacemakers [13]. The Piezoelectric HMI glove has been reported in the paper which harvests energy from the human fingers. The glove is fabricated from human washing woven. The piezoelectric plates and the glove play a good role in extracting the energy from the human fingers. The total power generated from all the fingers is 31.9 w [14]. In the paper [15] in which Electromagnetic energy harvesters were developed which are placed on a foot and are checked under different motion speeds. The energy harvester gives an average output power from 0.84 mW to 4.13 mW. Another interesting working has been reported from the paper [16] in which researchers have developed a thermoelectric generator which generates electric energy from the human body heat. The device can generate maximum output power ranging from 40 W to 520 W with the load resistance of 16 kΩ.

In this work a human motion based, non-resonant, electromagnetic type energy harvester is reported. The harvester has a freely moving magnet, a series of wound coils and end rubber springs. The developed device is capable of producing power from motions of the human body, such as, upper arm motion, hand shaking, , lower arm motion, thigh motion or foot motion.

II. DESIGN AND ARCHITECTURE

The cross-sectional view of the fabricated electromagnetic type energy harvester is shown in Fig. 1. The device has been produced from a Teflon material and it consists of a Teflon tube, a moving magnet, four wound coils which are produced inside the grooves provided in the Teflon tube and head caps. Hemispherical rubber springs are provided in the head caps to cousion the motion of the magnet when it will hit the head cap during motion. Moreover, air slots or holes have been made in the tube which can minimize air damping. On the top and bottom of the tube there are threads used to screw the head caps on the tube.

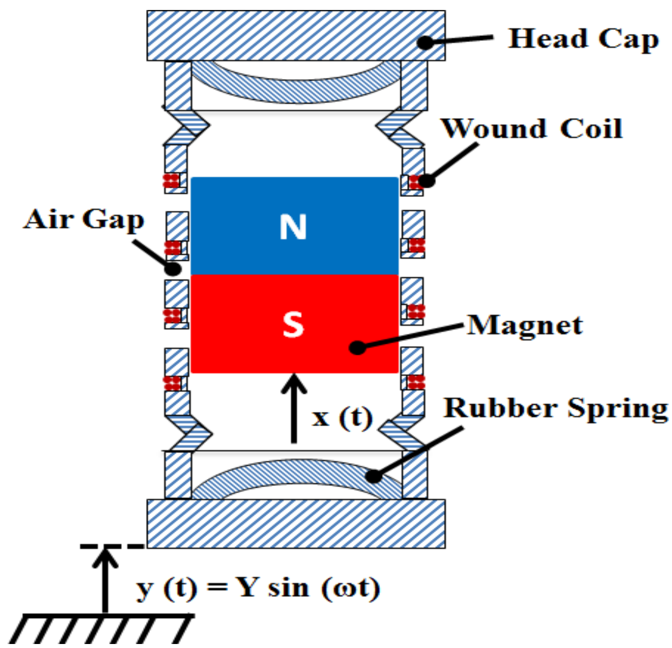

Fig. 1: Cross-sectional view of developed electromagnetic energy harvester

When the developed energy harvester is subjected to oscillation, y (t), the magnet and the coil moves relative to each other due to which, the coils experience the changing magnetic flux density and an emf is produced in the coil according to the Faradays Law of electromagnetic induction.

III. FABRICATION OF ENERGY HARVESTER

A cylindrical rod of Teflon material has been used to fabricate the Teflon tube. In the cylindrical rod a hole of 2.4 cm diameter and height of 6 cm has been made through CNC lathe machine. Then internal diameter of 2.3 cm has been made to pass the cylindrical moving magnet.. The four small grooves of 0.4 cm are made with the help of milling machine for each coil to wound inside the groove and with these grooves the coil is not disturbed. Then air gaps or holes of 0.6 cm are made between these coils with the help of a milling machine to reduce the air damping inside the tube. This helps the magnet to reduce air friction. The thickness of the tube is 0.3 cm.. The caps or heads are made for the energy harvester after completing the fabrication of the Teflon tube with the height of 3.2cm, external diameter of 4.2 cm and internal diameter of 2.5). The Rubber balls are placed inside the heads for the moving magnet to bounce back fast and easily. Inside the tube there is a powerful cylindrical moving magnet with 1.8 cm diameter and 2.4 cm height. After completing all the process, an assembled prototype of energy harvester is shown in the Fig. 2. The Total Length of the Electromagnetic Energy Harvester is 11cm. Detailed dimensions and parameters have been shown in the Table 2.

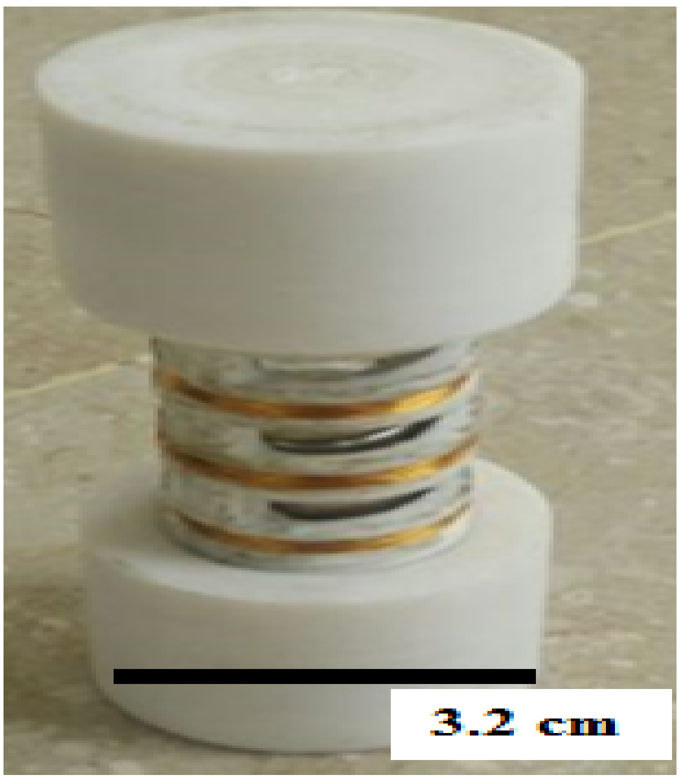

Fig. 2: Photograph of an assembled prototype

IV. EXPERIMENTATION

The energy harvester has been tested with an energy harvesters test bench which has been developed for the characterization of such devices is shown in the Fig. 3. In the test bench there is a power supply, vibration shaker, function generator, oscilloscope and a power amplifier. The device is tested in the lab with sinusoidal excitation at different acceleration levels. The four coils are connected with each other in series to obtain the the combined voltage signal from the coils. In the experimentation the combined coils has been characterized without load and with load under different acceleration levels and the generated voltage has

TABLE 2. DIMENSIONS AND PARAMETERS OF PROTOTYPE

Description	Values	Unit
Prototype Dimension	11 X 3.6	cm
Internal Diameter of the tube	2.3	cm
Heads/Caps	4.2 X 3.2	cm
Magnet Dimension	2.4 X 1.8	cm
Thickness of tube	0.3	cm
External Diameter of tube	2.4	cm
Groove thickness	0.4	cm
Air Gaps/ holes thickness	0.6	cm
NO. of turns of each coil	50	
Coil resistance	12	Ω

been measured. Then the device is characterized under 3 g acceleration level and output voltage versus frequency is plotted in Fig. 4. The maximum generated voltage is 4140 mV with a resonance frequency at 19 Hz.

The combined coils characterization with load resistance has been taken after completing the characterization without load. The harvester is subjected to a vibration at 19 Hz and 3 g acceleration amplitude and different load resistors are attached to the harvester, the result of this experiment is plotted in fig. 5. As the load resistance is enhanced the through current decreases as a result of which the voltage across the resistor increases. Beyond 50 Ω load resistance the output voltage almost becomes constant (310 mV).

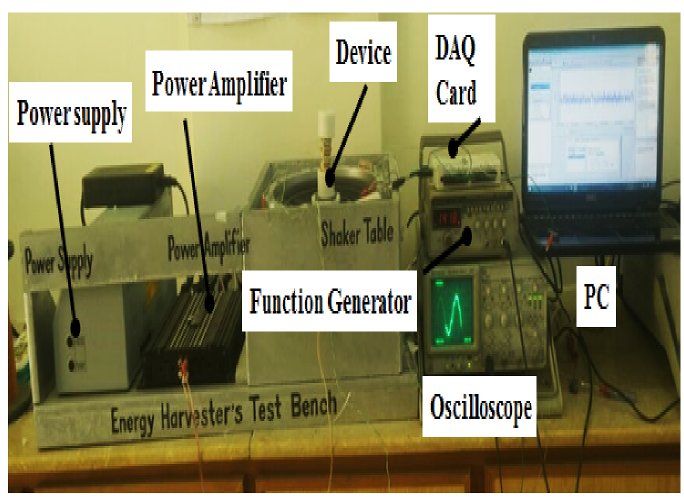

Fig. 3: Test bench for In-lab characterization

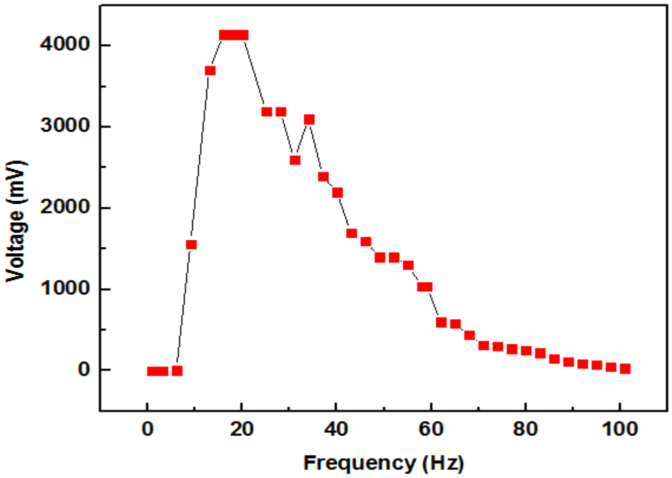

Fig. 4: Open circuit voltage at acceleration level of 3 g.

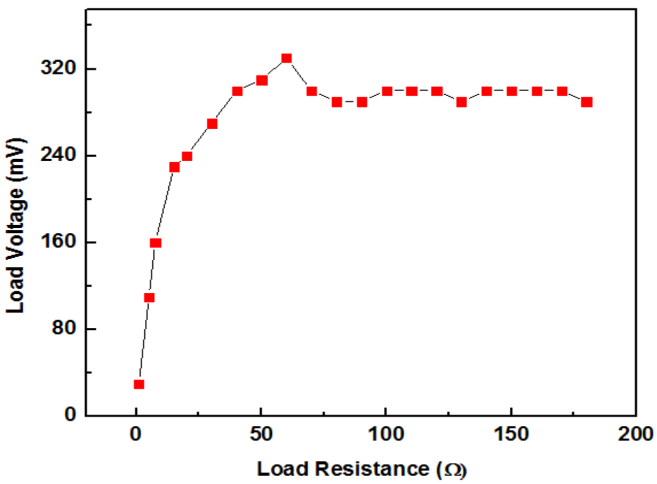

Fig. 5: Load voltage versus load resistance at 19 Hz and acceleration level of 3g.

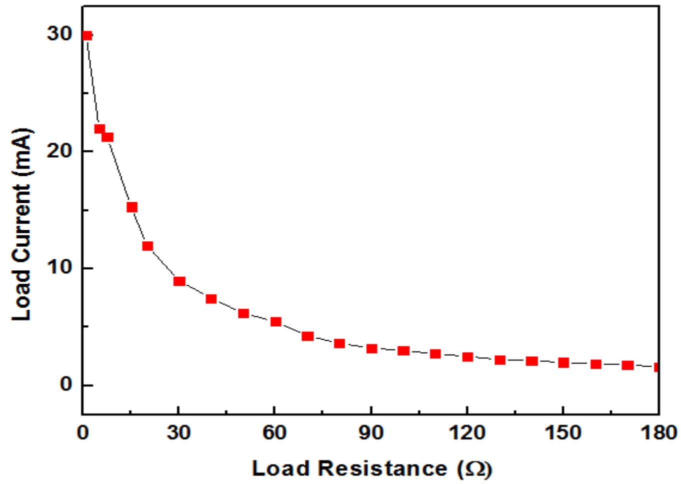

Fig. 6: Load current versus load resistance at acceleration level of 3g

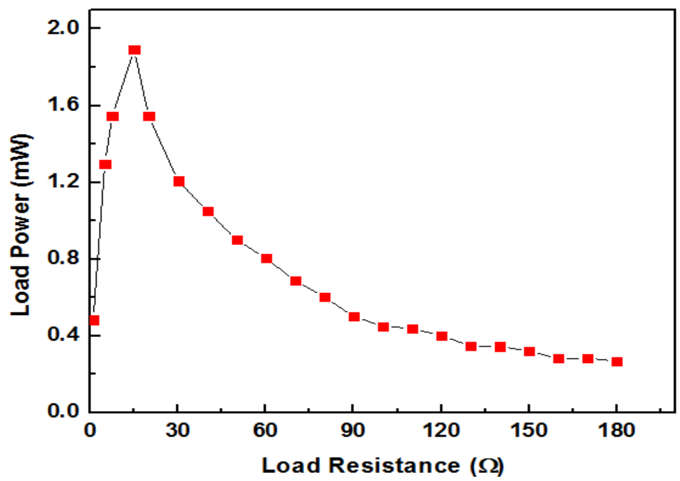

Fig. 7: Power vs load resistance at 19 Hz and acceleration level of 3g.

For the electromagnetic energy harvester, the load current verses load resistance is plotted in Fig. 6. The plot is obtained from the measurement performed in fig. 5. The maximum output current of 30 mA is generated at a load resistance of 1 Ω.

For the electromagnetic energy harvester and the load power verses load resistance is plotted in Fig. 7. The plot is obtained from the measurement performed in fig. 5. The maximum output power of 1.89 mW is generated at a load resistance of 23 Ω.

Moreover, with the energy harvester, a battery of 1.5 V has been charged when the harvester is exposed to the sinusoidal vibration in the lab. The device has been placed on the experimental setup and the rectifier is connected to convert the output AC of the harvester to DC for charging the battery. The battery has been fully discharged before the experimentation. After an hour of recharging the battery becomes completely charged as shown in the Fig. 8.

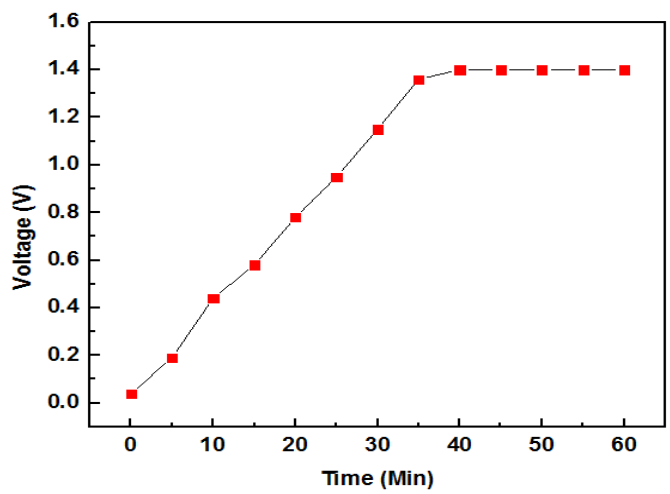

Fig. 8: Voltage versus time while charging the battery.

A. CONCLUSION

In this work an electromagnetic energy harvester has been developed for human body motion. The device has been fabricated and successfully characterized in the lab under sinusoidal excitations. At 19 Hz and 3 g acceleration level the prototype produced an open circuit maximum voltage of 4140 mV. However, under same vibration conditions a maximum load voltage of 310 mV is delivered to the load resistance 50 . Moreover, at 19 Hz and 3 g acceleration a maximum power of 1.89 mW is generated when a load resistance of 25 Ω is attached to the harvester. Furthermore, a battery of 1.5 V is successfully charged (in 60 min)with the developed energy harvester inside the lab. The reported energy harvester is capable of powering the biomedical devices

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