# An improved non-harmonic motion powered piezoelectric energy harvester for wireless body sensor networks

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**Abstract -** Many human diseases exist which need constant monitoring. Wireless body sensor networks (WSNs) are widely used for health monitoring and medical interventions. Traditional non- regenerative energy supplier *i.e.* batteries for WSNs is becoming a big barrier to wireless body sensor networks due to small dimension, low power circuit and sensor. In this paper, we present an improved piezoelectric energy harvester for wireless body sensor networks which is well suitable for low frequency non harmonic motion. The operational frequency range and electrochemical coupling has been amplified using proof mass which actuates an array of piezoelectric bimorph beam through magnetic attraction. Integrated circuit was used for testing the voltage regulation. It was observed that at the frequency of 2 Hz and acceleration of 24 $m/s^2$ a maximum power output of 45mW can be achieved.

**Key Words:** Wireless sensor network, piezoelectric Energy harvesting, wireless body sensor networks, non-harmonic motion.



## 1. Introduction

Day by day advances in the area of sensor design, information technologies and wireless networks made wireless sensor networks as a one of the most important technologies that can change the future. WSNs may be considered as small wireless computers that sense, process, and communicate environmental stimuli, including temperature, light, and vibration. In present scenario, WSNs become essential in many areas like health care (home monitoring, biomedical, food safety), industrial operations (factory, production, supply chains), environmental (agriculture, habitat preservation), infrastructure (energy, traffic and transportation, flood gauges, bridge stress, power grids, water distribution), and military, as well as for research and development. Among above mention areas, wireless body sensor networks (WBSNs) are widely used for health monitoring and medical interventions [1-2]. Globally, human are living with chronic diseases such as heart disease, cancer, Alzheimer's and other forms of dementia, placing larger burdens on healthcare. WSNs are used for monitoring of patients in clinical settings, home and elderly care center monitoring for chronic and elderly patients and Collection of long-term databases of clinical data [3-5].

With advances in WSNs, dimension of components of WSNs are reduced drastically and hence becoming a big barrier to use traditional battery–powered sensor nodes. There are need to develop a new energy sources. Since dimension of WSNs decrease, the energy consumption is also reduced. It creates a scope to discover a new source which can generate energy. In case of body sensor networks, replacement of batteries as power supplier becomes an essential activity. Piezoelectric energy harvester powered by non harmonic motion may be one of the solutions to tackle above problem. Major advantage of piezoelectric energy harvester powered by non harmonic motion is the transformation of surrounding renewable sources energy in to electric energy and hence it will provide sustainable and maintenance free energy delivery [6-7]. This paper aims to develop a improved non-harmonic motion powered piezoelectric energy harvester for wireless body sensor networks which may be used for various healthcare monitoring devices or other operation works which require less energy.

## 2. Operating Mechanism

Recent studies revealed that rotational structures are more advantageous for non-harmonic motion powered piezoelectric energy harvester compare to linear system because they are set in motion by either linear or rotational excitation [8-9]. It is also observed that proof mass like metal rolling rod can be used to improve efficiency of a non-harmonic motion powered piezoelectric energy harvester [6]. But this system is only effectively worked when devices orientation is known like bridge monitoring. In case of human body, if device is twisted too far, then the rolling rod will remain at the lowest point and as a result there is no energy harvesting. We introduced a new device in which an eccentric proof mass is free to rotate around its axis. Two magnets and a piezoelectric beam are fixed in such a way that magnets are facing each other. When a external excitation is generated the rotator is move and swing its magnet. Due to pasting of tip magnet on the beam, it results initial deflection of the beam tip. Main advantage of this set up is that the proof mass is free from motion limit. The absolute maximum power of rotational and gyroscopic proof mass device can be obtained by using following formula [10]

$$P_{\max} = \frac{\omega^3 \Omega_0^2}{4} * \frac{mR^2}{4}$$

where $\omega$ denotes angular excitation frequency, $\Omega_0$ is the excitation amplitude, m is the mass and R is the radius.

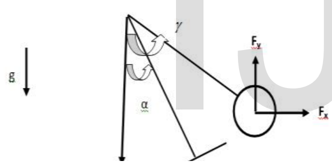



Figure 1. Eccentric proof mass under external excitation

Dynamic behavior of rotational set-up can be understood by the configuration presented in figure 1. In the figure, we can see that a point mass at a distance R from its axis of rotation is received an external excitation under gravity. Forces $F_x$ and $F_y$ are reaction forces generated due to linear external excitation, gravitational force acts in the downward direction. The angle between vertical axis and base line represents rotational base excitation, the angle between vertical axis and proof mass line is angular deflection and the angle between base line and proof mass line represents resultant angle. R is distance from m to the axis of rotation, moment of inertia around axis can be obtained as I=mR2. From above set it is clear that under an external excitation, rotor may be behaves like a pendulum. When proof mass attached to upper arm of human rotates from the left to right a proof mass deflect magnetic coupling between magnet and tip magnet. The lower excitation in downward direction due to orientation of the axis perpendicular to the running direction results strong excitation coming from swing and running motion.

## 4. Prototype and Measurement Set-up

Figure shows the main components of the rotational energy harvester.

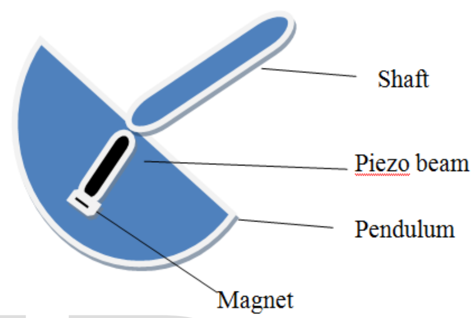


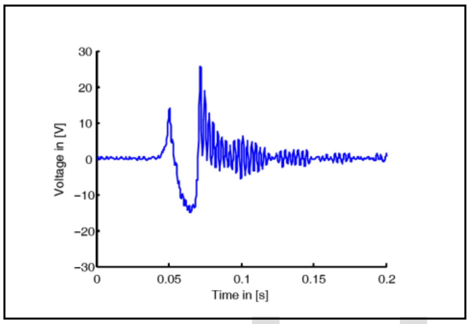

Figure 2. Piezoelectric rotational harvester



Electromechanical coupling has been increased by pizeo beam leave to vibrate due to excitation received. An arrangement was done such that the beam is fixed in the lid on one side and a magnet is mounted inside the rotor. Main principle behind this concept is, when the rotor swing under excitation attraction between two magnets act at each pass. 120 µm thick piezolyer are connected in series. The total volume of device is 4.5 $cm^3$ weighing 10 g. The effective rotor mass was 6 g. To observe the large displacement amplitude and low frequency of human motion a linear shaking system was design and build. For this purpose, Kollomorgen AKM33-ANCNR-01 brushless servo drive motor with rotary encoder was used. The machine drive controller can be received a maximum drive current of 4 A and 240 V main power supply. We were designed the experiment in such a way the acceleration, deceleration, travel time matched to each other. First magnet mounted at the tip having dimension 1mm × 1 mm × 1 mm and second inside the rotator with dimension 1.5 mm × 1.5 mm × 1.5 mm have been used. Both are NdFeb magnet of N50 type and they are fitted such that faced and attracted each other. Reproducible excitations obtained with a frequency range between 0.30 Hz to 2 Hz.

## 5. RESULTS

If external excitation is not sufficient then due to attraction force between the magnets rotor may be get stuck during equilibrium position. To overcome this problem, the way of adjust its limit is by changing the coupling between the magnets. There are two approaches, to optimize the gap or choosing weaker and small magnets. Figure 3 shows the voltage measured across the piezo beam set a 2 Hz. The gap between the permanent magnets on the beam tip and the rotor was at its optimum value.



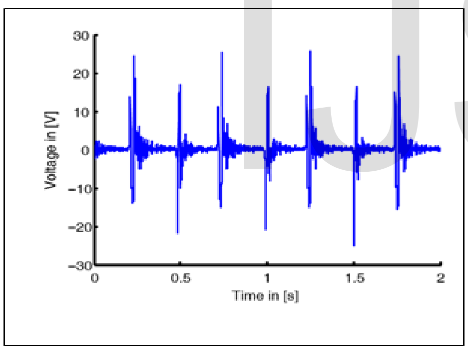




Fig: 3 Actuation of beam at 2 Hz and optimum gap

From rotor to the beam, air gap plays an influential role on magnetic coupling. Power can be increased linearly with the number of actuations. Variation of power output with relative gap size indicates that at initial gap power of 2.8 µW can be achieved at an rms voltage of 2V. Power generated and gap is found inversely related to each other. It is observed that alternative positive and negative peak voltage causes due to plucking of beam twice during a cycle. It is also observed that at low acceleration and frequencies the excitation is not sufficient to make the rotor overcome the magnetic coupling force. Figure 4 represents the horizontal and vertical orientation. It is observed that best result of 25 µm was achieved at an acceleration of 30ms$^{-2}$ for horizontal orientation while 45 µm was achieved at an acceleration of 30ms$^{-2}$ for vertical orientation.

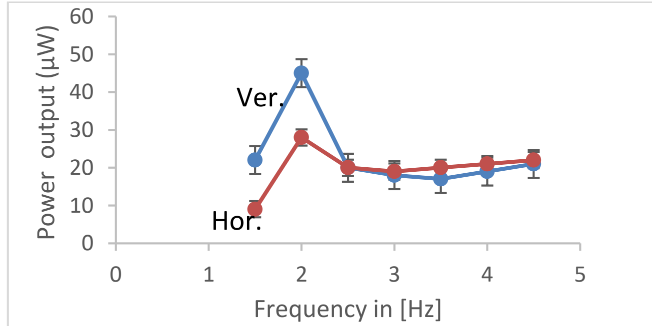



Figure 4. Measurement for horizontal and vertical orientation including error bars for sample error deviation

### 6. Conclusion and Future Work

This paper presents an improved non-harmonic motion powered piezoelectric energy harvester for wireless body sensor networks encountered in human motion. Magnetic actuation of piezoelectric beam based frequency up conversion technique has been used for designing of harvester. The developed energy harvester is a rotational piezoelectric device in which proof mass is a mild steel rotor. The device is developed keeping in mind that device should be dependent on the device orientation and suitable for linear and rotational excitation imposed by the human body. A portable measurement system is described in which the magnetic coupling between the rotor and beam are allows for a completely contactless actuation. To overcome the degradation, gap between the permanent magnets are optimized with respect to coupling between rotor and beam tip which results lowering of interaction force and the initial deflection of the beam. The results show that the rotor dynamics play a important role in the characteristics of the harvester. It is observed that device has a tendency to go in to continuous rotation at certain frequencies mainly around 2 Hz. When device was attended continuous rotation maximum power output of 45 µw was obtained. Finally, this paper presents a practicable option for energy harvesting for wireless body sensor networks. Future work will investigate the number of magnets mounted inside the rotor and their arrangement, testing of reluctance coupling over inductive methods with respect to achievable transmission depth into body.

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