

Performance Assessment in a Voice Coil Motor for Maximizing the Energy Harvesting with Gait Motions

Hector A. Tinoco, Cesar Garcia-Diaz, Olga L. Ocampo-Lopez

Abstract—In this study, an experimental approach is established to assess the performance of different beams coupled to a Voice Coil Motor (VCM) with the aim to maximize mechanically the energy harvesting in the inductive transducer that is included on it. The VCM is extracted from a recycled hard disk drive (HDD) and it is adapted for carrying out experimental tests of energy harvesting. Two individuals were selected for walking with the VCM-beam device as well as to evaluate the performance varying two parameters in the beam; length of the beams and a mass addition. Results show that the energy harvesting is maximized with specific beams; however, the harvesting efficiency is improved when a mass is added to the end of the beams.

Keywords—Hard disk drive, HDD, energy harvesting, voice coil motor, VCM, energy harvester, gait motions.

I. INTRODUCTION

OVER the last decade, energy harvesting technologies based on vibrations have been intensively studied to scavenge energy from ambient vibrations [1]. Recently, great efforts have been focused on technologies that permit to supply the energy for low power electronic devices either in-situ or in a remote way. Currently, different energy harvesters have been developed with different conversion technologies from which we can mention thermo-electric, electromagnetic, electrostatic, tribo-electric, and piezoelectric [2]. The main objective of an energy harvester is to transform the mechanical energy into electrical energy of low power.

A linear spring–mass–damper system is the most common type of energy scavenging device due to that it captures harmonic excitations easily. As demonstrated in different studies [1]-[4], a good performance can be achieved when the energy harvester device is tuned with the frequency of excitation. The majority of these devices uses low frequencies vibration sources that excite beams with piezoelectric transducers [3]-[7]. It means that cantilever beams with

inertial masses are used to capture the vibrations and convert it into electrical energy by the piezoelectric transducers [8]-[10].

The humans use different low power devices commonly every day, creating an energetic dependency to keep these in functioning. Batteries supply the dependency for these devices; however, it exists alternatives of energy sources that present higher power densities, but the majority of them are designed for large systems that require high power sources to operate.

The energy produced by the human body can be an alternative energy source since it produces power densities around 1 W/kg [11]. This available power density levels can be an interesting opportunity for low-power generation. Since electronic devices applied to biomedical and communications can take advantage of the harvesting energy produced by the human body [12]-[14].

Human motions can provide a dynamic of low frequency, in special gait motions, these can be used as an energy source. According to [14], the human gait has three probable energy sources for energy harvesting purposes, which are classified in three categories; two based on motions and one in force [13]. Those based on accelerations are pulse upon heel strike (i.e. the impact among the pressure of the shoe and the ground) and the acceleration due to the leg swing when an individual walks. For capturing gait motions, the most developed energy harvesting mechanisms are beams with proof mass [3], [7], [14], [15]. These mechanisms are based on the resonances of the system and should be optimally designed with the aim to maximize the energy production, as mentioned before.

In this paper, we study the performance of an electromagnetic energy harvester based on a VCM device found in the HDD. Different beams are coupled to the device to create a mechanical resonant system. The experimental approach is based on studying the influence of the beam lengths, and the inertial effects provided by a mass added to the electromechanical system.

II. MATERIALS AND METHODS

A. Beam Coupled to a VCM of an HDD

A HDD contains internally a servo system composed by a VCM that can read and write information in the rigid disk, and an illustration of the servo system is shown in Fig. 1 (a). In the system, a rigid arm is joined to a pivot that permits a restricted rotation of approximately 0.5 rad [16], [17]. The VCM is a direct current (DC) motor that transforms an input current to a

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force, velocity, or acceleration as output.

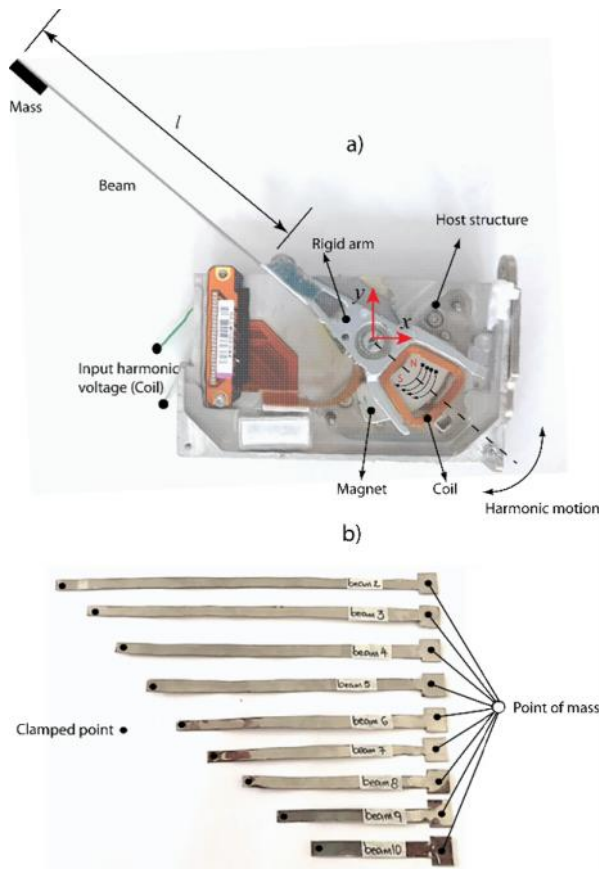


Fig. 1 Voice coil motor (VCM-beam device) of a HDD [18] (b) Stainless steel beams

A permanent neodymium magnet (as noted in Fig. 1 (a)) develops the motions in the rotatory arm when the device is used as actuator, it generates angular motions if a current is applied to the coil. When it is used as sensor, the electrical transduction is made from the motions when a movement is induced in the arm. In this way, the coil produces an electric potential in the output [17].

All modern HDDs have within these VCM motors; however, these are not used for the other purposes when HDDs are not working, as for example to recycle it. For this study, it is proposed that the VCM of a HDD can be used for energy harvesting applications. If a beam is coupled to an end of the rigid arm, mechanical energy can be transformed in electrical energy from motions produced by the excitation of the HDD device. For the experimental test of this study, different beams are considered varying the length. However, to achieve the maximum conversion of energy in the inductance, it is necessary to study how to produce the maximum energy harvesting. Therefore, it is necessary to study the influence of the dimensional (length and size) and mechanical (attached mass) parameters of the beam (see Fig. 1 (b) and Table I). The main idea is to get that the device resonates when a vibratory source is applied on it. For our application of energy harvesting, gait motions will be an

energy source of low frequency to excite the device.

The extraction of a VCM device from a recycled HDD is a simple procedure, which is based on isolating the actuation mechanism of the main structure of the HDD. Inside the device, there are two wires that belong to the coil and these emit the energy harvested. The main objective with the device is to produce small quantities of energy when gait motions act like vibration source in the rigid arm induced by the inertial effects.

TABLE I
 GEOMETRIC PROPERTIES OF THE BEAMS

Beam	Length [mm]
1	195
2	180
3	165
4	150
5	135
6	120
7	105
8	90
9	75
10	60

B. Experimental Setup Excited with Gait Motions

In order to demonstrate the procedure of energy harvesting, experimental tests are carried out with the adapted HDD device. As mentioned before, in the gait motions, there are three different energy sources that can be exploited [13]; in our study, we are going to use as vibratory source the acceleration generated by the leg swing motion. Therefore, a HDD device was adapted to mount it in a human leg as shown in Fig. 2 (a). The energy harvester device consists of a VCM with a beam coupled to the rigid arm, the beam can vary the length (see Table I), and a mass can be added in an end, which presents a fixed value of 0.82 g for this study.

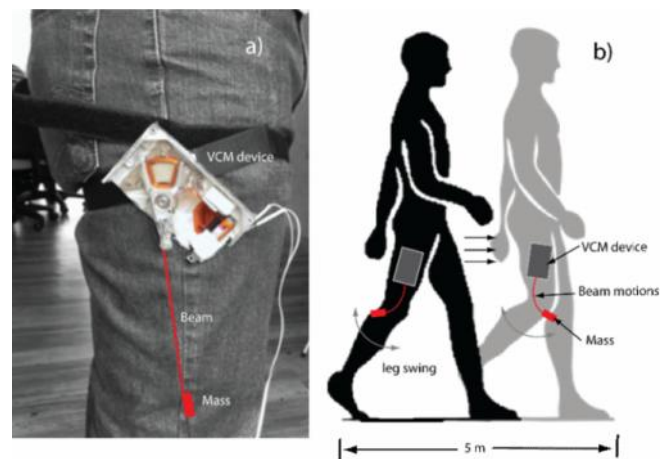


Fig. 2 (a) VCM attached in a leg. (b) Gait motions with the VCM-beam device

The experimental test was designed for walking 5 m in a straight line (scheme of test shown in Fig. 2 (b)); two individuals (labeled as A and B) were selected for carrying out the gait motions considering that the individuals did not have

any pathological antecedent.

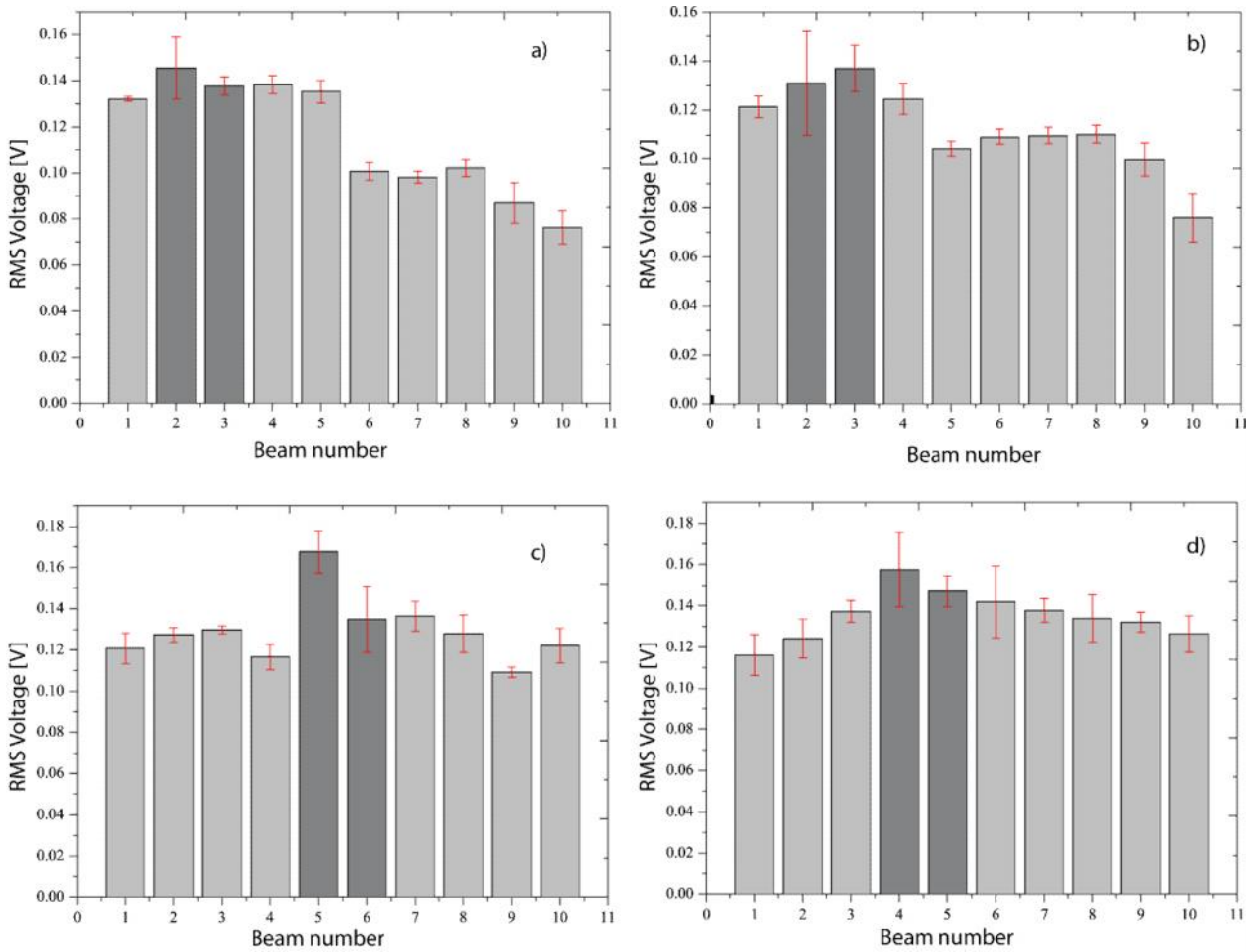


Fig. 3 RMS voltage for VCM-beams without mass: a) Individual A. b) Individual B. VCM-beams with mass: c) Individual A. b) Individual B

The tests are performed in two stages; beam without a concentrated mass and beams with an added mass in the end. For taking voltage measurements in the VCM-beam device, a data acquisition system is used. In our case, these were acquired via a data acquisition board (NI USB-6211, National Instruments) that controls a sampling rate of 80 samples per second during 8 seconds which are necessary to read in a frequency interval of 0-20 Hz to avoid the aliasing in the acquired signals.

III. RESULTS AND DISCUSSIONS

Two energy harvesting tests were performed for each individual (A and B); device with beams (without mass) and beams with an added mass as mentioned above. For each beam, 10 repetitions were carried out, it means that 200 tests were done by each individual. The results are illustrated in Figs. 3 (a) and (c) for the individual A; and Figs. 3 (b) and (d) for the individual B in which the root mean square (RMS) voltages are shown. We can observe in Figs. 3 (a) and (b) that the trend in very similar (individual A and B) for all the

beams; however, for the beams 2 and 3, the voltage is maximized in both cases and it begins to decay until the beam number 10, the shortest one. The performance of the beams 2 and 3 present an increment of 40% in the voltage with respect to the beams numbered higher than 6, respectively. Standard deviations of the measurements are underlined with color red in the bars of Fig. 3.

In Figs. 3 (c) and (d), there is observed that when the mass is added in the end of the beams (0.82 g), RMS voltages reach maximum values in beams 5 and 6 (individual A); and 4 and 5 (individual B) of 0.17 V approximately; incrementing a 25% with respect to the maximum values obtained with the beams without mass. But, it is important to highlight that for the shortest beams the voltages were incremented (from the number 6) considerably. In terms of optimization, the mass parameter shows that the energy harvesting can be maximized searching an adequate value for the device. Therefore, it is noted the beam length presents a lower sensitivity for the energy harvesting, as evidenced in Figs. 3 (c) and (d).

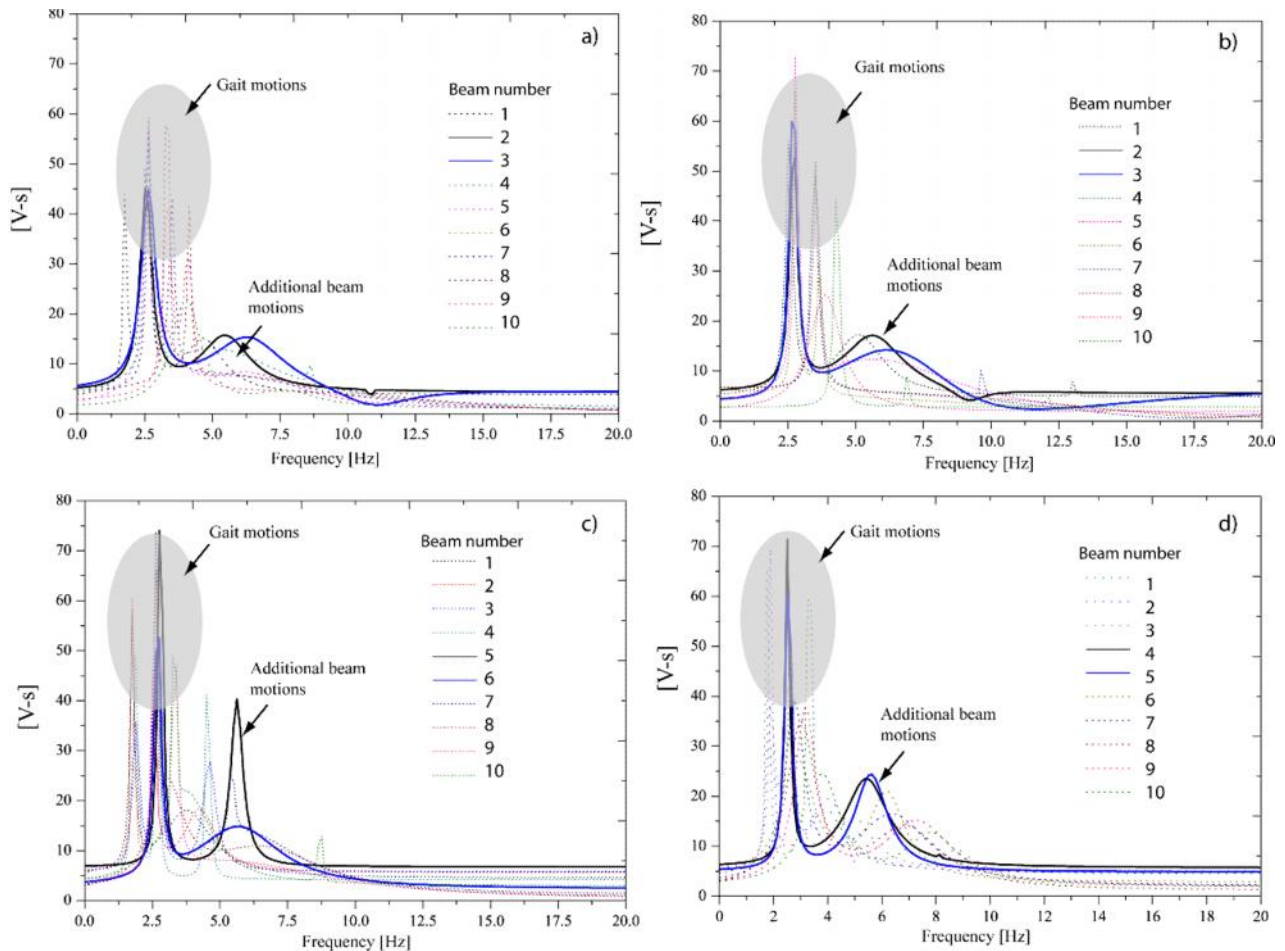


Fig. 4 Frequency Analysis for VCM-beams without mass: a) Individual A. b) Individual B. VCM-beams with mass: c) Individual A. d) Individual B

To observe the behavior of the beams in the frequency spectrum, the Fourier transform is applied over the voltage signals obtained in the time. Therefore, in Fig. 4, the voltage signals are shown in frequency. In all figures, we see that the gait frequency excitation is just about 1-4 Hz. These motions are demarked in each figure by means of a gray color since these represent the higher peaks in the graphs. To understand the effects of the length and the added mass, we highlight the cases that were discussed in Fig. 3. For example, it is analyzed that in both cases (beams 2 and 3, Figs. 4 (a) and (b)) additional peaks in frequency appear in 5.6 and 6.25 Hz. It indicates that the other higher frequencies to those of the gait are stimulated mechanically. In the case of beams with mass, the peaks are exposed in 5.6 Hz showing a higher amplitude. All new peaks can be attributed to the impacts generated by the constraints of the rotatory system. However, this effect helps to increment the energy harvesting mechanically.

IV. CONCLUSIONS

The primary purposes of this paper have been to investigate the performance of an electromagnetic energy harvester with the aim to maximize the energy harvesting from gait motions. Results showed that for some parameters of length and mass,

the energy harvesting was increased. Specifically, the mass was the parameter that had more importance in the maximization. Therefore, the shortest beams obtain more energy than the longest ones, with addition of a concentrated mass.

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