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# Experimental validation and modelling of electromagnetic kinetic harvester for oceans drifters

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**Abstract** –Harvesting the mechanical energy of ocean motion are finding different applications for offshore exploration and ocean monitoring. Because of the very low and varying frequency, from 0.1Hz to 2Hz, harvesting this energy has an important hurdle. In this paper, we provide a comprehensive study of a new idea to supply low power oceanic drifters using an electromagnetic vibration harvester. Therefore, this work presents a solution on how to generate power from low frequency driven electromagnetic energy harvester for an ocean drifter self-powered system. A prototype with a proposed electronic harvesting system is built and tested in a real medium, showing the results before concluding the article.

**Keywords** – energy harvesting, marine instruments

## I. INTRODUCTION

The ocean drifters are basically small-size spheres with just enough room to accommodate power source, communications modules, antennae, sensors and data processor. The energy requirements of low power electronics have steadily decreased with advancements in efficient circuitry. With further effort, the power consumption of these devices has been reduced to the order of mW level. Therefore, a new and interesting research area has been open; supplying energy to these micro systems as an alternative to batteries, which have a finite life and are large in size. However, providing powering solutions for long term deployments pose many challenges, especially related to the ocean areas where harvestable energy is available, such as the ocean currents and waves.

Nowadays, some studies use the piezoelectricity to harvest energy from vibrations [1-6] and some using the mechanical impacts to obtain energy [7-11]. The main problem in all referred cases, is that the configuration used in all of these studies is highly dependent on the resonant frequency of the piezoelectric element; thus presenting a real hurdle to use these methods in slow

motion environments, where the obtained energy could be of one or less microwatt [3].

This paper reports a new energy scavenger capable of producing steady power in a wide frequency band that is predetermined by the design parameters. Power generation is realized by electromagnetic induction, of a ball shape magnet moving freely inside a donut shape cylinder.

## II. SYSTEM

We have developed a semi-analytical model for predicting the behaviour of electromagnetic kinetic harvester for ocean drifters of the form shown in Fig. 1. These comprise a donut shape hollow cylindrical structure that houses ball shape permanent magnets [12]. A portion of the cylinder is wrapped in a multilayered coil. The magnet moves freely within the container. The coil is formed by winding enamelled wire around the outer surface of the container.

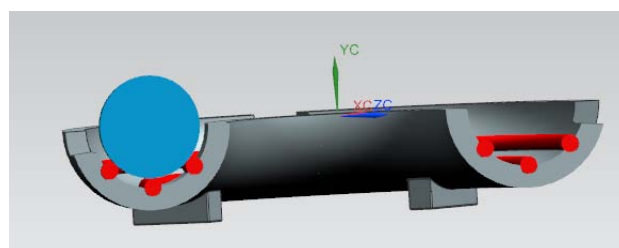


Fig. 1. Section-views of the electromagnetic kinetic harvester.

The movement of the ball inside the energy harvester is a movement composed essentially of circular movements generated from the angles of roll (roll) and pitch (pitch) of the harvester body. Considering that in our study the angle of pitch, will be significantly larger than the roll, this study estimated the dynamics of the ball rotating along the circular path depending on the pitch angle (pitch) that takes the body of the collector.

In Fig. 2 are illustrated the three coordinate systems considered: a coordinate system fixed to the ground ( $X_0$ ,

$Y_0, Z_0$ ), a system for the body of the collector loop ( $X_C, Y_C, Z_C$ ) and another coordinate system corresponding to the ball ( $X_b, Y_b, Z_b$ ). As for the angles have been considered:

- $\varphi$ : angle of roll along the axis  $X_C$ .
- $\alpha$ : pitch angle along the axis  $Y_C$ .

$\gamma$ : angle of displacement of the coordinate system of the ball and the sensor coordinate system (rotating with respect to  $Z_C$ ).

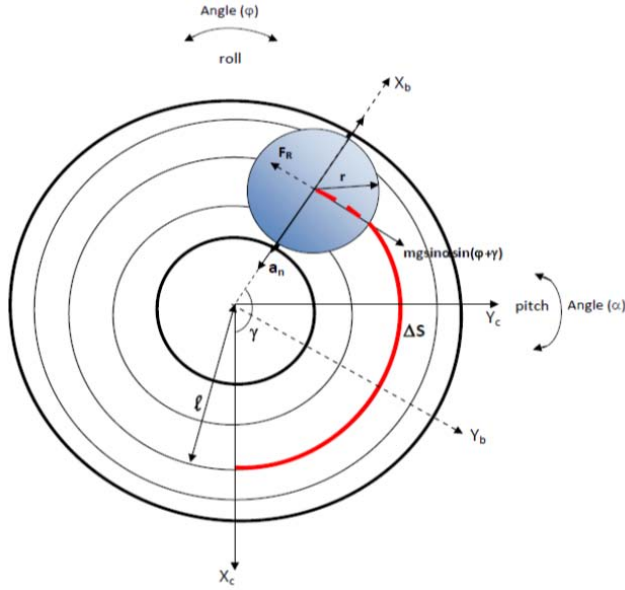


Fig. 2. Model of the energy harvesting system

During the rotation motion of the harvester, the momentum of the ball motion is given by the flowing expressions:

$$\sum \vec{M} = I_{Gz} \cdot \dot{\omega} = r \cdot F_R \quad (1)$$

where  $r$ : is the ball radius [m],  $F_R$ : Friction force [N],  $I_{Gz}$ : Moment of the ball with respect to the axis passing through the centre of mass [ $Kg \cdot m^2$ ], and  $\dot{\omega}$ : angular acceleration of the ball [ $rad/s^2$ ]:

$$\dot{\omega} = \frac{a_t}{r} \quad (2)$$

Therefore, the tangential acceleration of the ball is:

$$a_t = \frac{5}{7} g \sin \alpha \sin (\varphi + \gamma) \quad (3)$$

And the friction force is:

$$F_R = \frac{2}{7} m g \sin \alpha \sin (\varphi + \gamma) \quad (4)$$

This gives us the critical angle of the harvester balance from which the ball but it no slip. Therefore, the value of the friction force should be  $F_R \leq \mu_e N$ , where  $\mu_e$  is

the friction coefficient and the reaction of the  $N$  contact guides of ball-harvester body. Therefore, the crucial angle is given by the following expression:

$$\operatorname{tg} \alpha \leq \frac{7}{2 \sin (\varphi + \gamma)} \mu_e \quad (5)$$

Taking into account the expression for the critical angle which will permit the magnetic ball to roll inside the harvester body, and considering that the angle of roll  $\varphi$  is between 1 and 3 degrees, and angle of displacement  $\gamma = 0$ :

$$\operatorname{tg} \alpha \leq \frac{7}{2 \sin (\varphi + \gamma)} \mu_e = \frac{7}{2 \sin (2^\circ)} 0,3 \approx 30 \quad (6)$$

Based on the experimental validation of the motion of the ocean drifters which has provided us the mean pitch angle, and the size constrains we have developed the first prototype illustrated in Fig. 3.

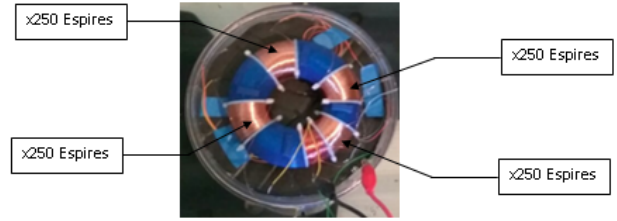


Fig. 3. Fabricated energy harvesting system

### III. RESULTS

Our system model was validated by comparing predictions with measurements with the harvester subjected to wave motion. Measurements were taken for frequencies in the 0.1–2 Hz range. As illustrated in Fig. 4 output voltages between 5 V and –5 V was obtained in the first experimental evaluation.

A harvester was implemented with the characteristics described in Table 1, where we test different configuration of the coils. Two resistive loads were chosen: 102 k $\Omega$ , for analysing a quasi-open-circuit voltage; and 5.6 k $\Omega$ , for maximizing the power transfer to the load.

In Table 2 are given the results for the configuration described above, using the 102 k $\Omega$ , for analysing a quasi-open-circuit voltage.

Based on these results, the two options with clearly inferior output are the test with coils connections start-start and end-end, as their characteristics would clearly affect the efficiency of the collector.

Of the three remaining options with similar results, the combinations of two coils of 125 turns are also discharged.

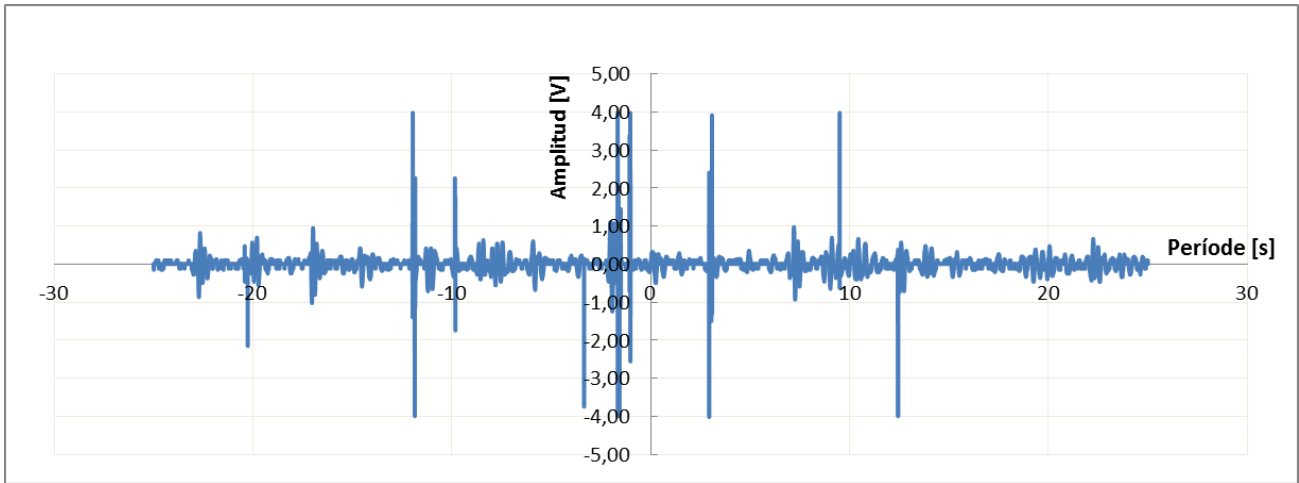
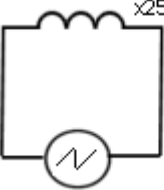
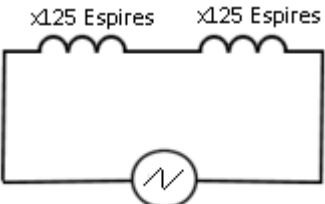
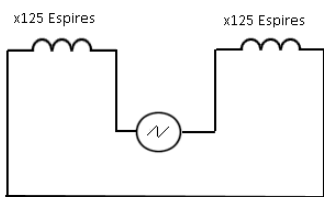
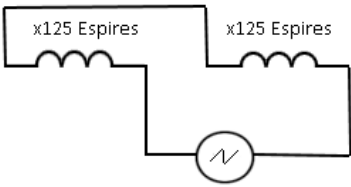


Fig. 4. Output voltage acceleration response of the fabricated harvester

Table 1. Coils configuration

 <p>x250 Espires</p>	1 coil of 250 turns
 <p>x125 Espires    x125 Espires</p>	2 coils of 125 turns connected in serial (start-end)
 <p>x125 Espires    x125 Espires</p>	2 coils of 125 turns connected in serial (end-start)
 <p>x125 Espires    x125 Espires</p>	2 coils of 125 turns connected in serial (start-start)

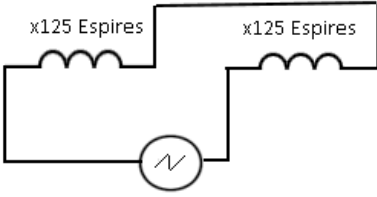
 <p>x125 Espires    x125 Espires</p>	2 coils of 125 turns connected in serial (end-end)
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Table 2. Summary of the experimental results

	Mean amplitude [V]	Maximum amplitude [V]
1 coil of 250 turns	$\pm 0.23$	1.047
2 coils of 125 turns connected in serial (start-end)	$\pm 0.24$	1.203
2 coils of 125 turns connected in serial (end-start)	$\pm 0.23$	1.093
2 coils of 125 turns connected in serial (start-start)	$\pm 0.18$	0.530
2 coils of 125 turns connected in serial (end-end)	$\pm 0.18$	0.625

Although the set of the two coils connected in series give a slightly higher output than the single 250 turns coil, these are best adapted to the prototype design and can provide better long-term results and fewer operating problems. Therefore, it is established a final design of four 250-wire coils, connected in series distributed throughout the harvester. In order to obtain the useful energy generated by the sensor, a circuit was made capable of transforming the alternating electrical energy produced by the sensor in a continuous current from a rectifier bridge with 4 diodes as illustrated in Fig 5. This continuous current was stored in a supercapacitor for one hour of energy production of the non-linear sensor. The circuit was design with an impedance of 5.6k  $\Omega$  for maximizing the power transfer to the load.

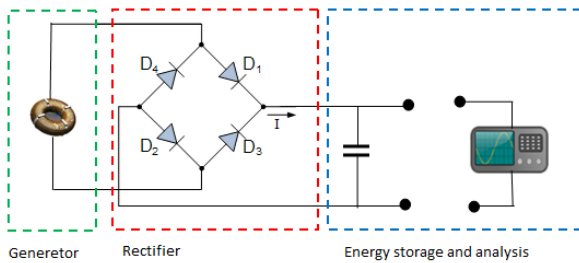


Fig. 5. Energy harvestre electrical circuit for power measurmnts and storage

Performing the connection described above the total charge of supercapacitor varies based on the test time. Therefore, the experimentation carried out a measurement after an hour to observe this increase in voltage as shown in Table 3.

Table 3. Experimental results for the supercapacitor charging

Initial charge, $V_i$	111 mV
Final charge, $V_f$	193 mV
Discharge time	69 s

The resulting energy obtaining in this experiment was:  $\Delta E = 8'405 \cdot 10^{-3} J$ .

In order to make a comparison with the rest of the energy harvesters and to be able to observe the one that presents the most appropriate efficiency ratio based on the volume they occupy, the relation between the generated power and the volume occupied by the collector has been calculated. The capacitor presents a volume of 135.11  $cm^3$  therefore the sensor has a power density of  $9.015 \cdot 10^{-4} mW / cm^3$ .

#### IV. CONCLUSIONS

In this paper, we study a new harvesting device, featuring electromagnetic generator to obtain electrical energy from thesea motion. This paper provides useful information about the harvesting prototype which has been built and tested in the water tank, and the results of how much power can be obtained with this type of

systems. The simulation and prototype results have confirmed that this system can be implemented and applied to power small nets of ocean drifter, which was the main aim of this investigation. This nets would acquire position data and communicate with the base node every certain time, remaining in asleep mode the rest of the period.

#### V. ACKNOWLEDGMENT

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