An impacting energy harvester through piezoelectric device for oscillating water flow

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Abstract- ***The reduced power requirements of miniaturized electronics offer the opportunity to create devices having their power supply based on energy harvesters. In this paper a new idea is proposed and studied to supply underwater low-consumption devices using low-cost disk piezoelectric elements. The system scavenges energy from water motion induced in depth by surface gravity waves using piezoelectric materials and the characteristic oscillating movement of bodies with positive buoyancy that are attached to the seabed with flexible cords, similar to an inverted pendulum. The piezoelectric components that are subjected to impacts produced by the movement of the pendulum create an electrical power generator that harvests the mechanical energy brought by the sea movements. A prototype with the proposed electronic harvesting system is built and tested. The average power output of the prototype is 2.2 ± 0.3 µW, which can be increased significantly with further optimization.***

Keywords— Energy harvesting, piezoelectric, sea currents, marine sensors networks, impacts.

1. INTRODUCTION

The increase of sea electronic instrumentation, system and sensor deployments to study the maritime medium has led to an epoch where powering these devices is a key point in order to minimize wiring or maintenance costs. Sea water motion provides big amounts of kinetic and potential energy that can be converted into electrical power.

Recently a high number of sea motion energy harvesters have been proposed, especially based on the energy generated by waves on the surface, but also systems that generates energy near the seabed [1-5]. However, the systems located near the seabed pose certain advantages such as the reduce losses in the transport of energy from the surface to the bottom or that are not disturbing the activities that take place at sea.

This conversion of energy can be accomplished, between others, using piezoelectric elements, which deliver electrical charge from an applied deformation in their molecular structure. Because of the low frequency of the sea motion, usual bending piezo elements are not really convenient [6] and low-cost disk piezoelectric units are used instead in this work, together with a new impacting method. These piezoelectric devices produce electrical energy when a mass impacts them, providing higher power levels for low-frequency mechanical harvesting environments [7]. This is possible due to the resonance achieved in each impact if the element has the possibility to move freely at its center, where the impact occurs.

2. IMPACT PENDULUM-BASED ENERGY GENERATOR DESCRIPTION

The piezoelectric energy harvester is fixed inside of the buoyant cylinder fixed to the seabed by an flexible cord (figure 1). As the cylinder oscillates in a swaying water motion, the inner pendulum is impacting in the inner strip of bimorphs, so that the eight disk piezoelectrics (mounted on the strip) are forced to vibrate. The prototype of the energy harvester (figure 2) was realized based on this design. For testing, the prototype was mounted in a water tank (figure 2), which uses a submerged pump to reproduce the water motion in shallow water.

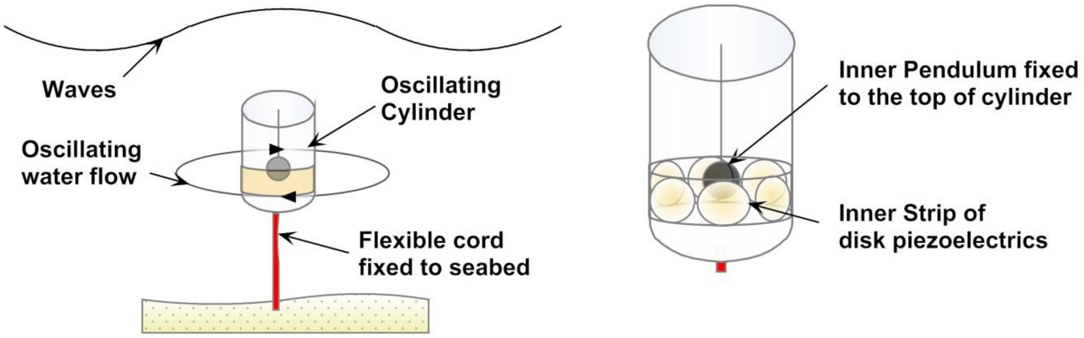

Figure 1 Sea water flow piezoelectric harvester. It is anchored to the seabed by a flexible cord. Inside the cylinder are placed a number of disk piezoelectrics, which are impacted by the pendulum as the cylinder oscillates during water flow.

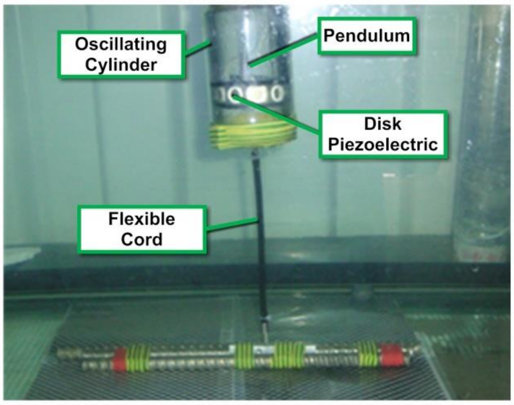

Figure 2 The energy harvester mounted in a shallow water simulator.

The energy harvesting features are eight bimorphs mounted on the inner strip and a pendulum mounted in the center of the cylinder. The disk piezoelectric bimorphs, referred to as DP1 to DP8 in this paper, are of type PZT-4 ceramic disk. The main selection criteria for the bimorph were commercial availability and appropriate dimensions to give a combination of compact size and good energy output. The bimorphs were mounted within a mechanical fixtures (cylindrical strip). The pendulum was made as a ball of 24 mm – diameter lead and attached to the top of the cylinder with a rod of 78 mm-length. The distance between the pendulum and the bimorphs is 25 mm. The prototype harvester occupies a volume of 713 cm3 and has an approximate mass of 710 g.

During testing, the water flow in the tank was generated by a submerged pump (Turbelle® stream 6105 from TUNZE® Aquarientechnik GmbH) controlled by a pump driver (Multicontroller 7096, same supplier), which received control signals from a computer via a serial.

In order to characterize the piezoelectric elements, a test-bench is built to control the mechanical energy provided by a free-falling ball which impacts a disk piezo element. This energy is calculated using the initial height, ball mass and final measured deformation, as well as subtracting the loss of energy due to the rebounds presented in the impact. Table 1 shows some results obtained from testing the impacts of different round bodies to the piezoelectric elements in a free-fall, using a 100MΩ probe.

Table 1. Free-fall characterization with 100MΩ

Height [cm]	Weight [gr]	Voltage [Vpeak]	Rebound [ms]	Deform [µm]
6	3.2	63.8	53.36	17.5
6	4.63	77	72.63	23.8
6	12.539	128	93.35	60
8	3.2	55.6	60.72	21.7
8	4.63	84	84.92	27.6
8	12.539	155	115.75	49.7
10	3.2	70	75.6	26.9
10	4.63	106	95.47	38.6
10	12.539	169	119.5	84.8

Table 1 is used to find the relationship between the output voltage and the applied force, calculated with the weight, height and deformation, where finally a mean value of V/F = 754.4mV/N is obtained.

3. RESULTS

Kinematic data derived from marker-based dynamic analysis of offshore marine systems is the method used for the characterization of the cylinder attached with the flexible cord to the seabed. For this investigation, OrcaFlex simulation software [8] was used. Kinematic data collected from simulation with environmental parameters found in OBSEA [9] has shown that the cylinder oscillates in the water manly because of the surface waves, reaching approximately 40º (figure 3), at waves of 2 m-height and a period of 15 s.

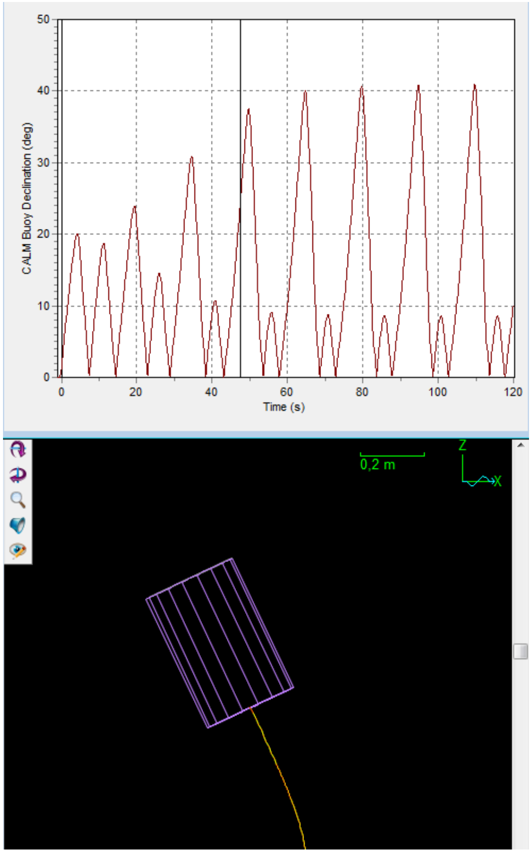

Figure 3 Mean angular displacement of the cylinder attached to the seabed with flexible cord, simulated with OrcaFlex

Using these results, the energy harvesting prototype has been tested in the water tank generating currents with the submerged pump capable to simulate the kinetic motion of the cylinder seen in OrcaFlex simulations. The time-domain results from bimorphs DP1 to DP8 connected in series present the typical behavior of a bimorphs in the harvester. In the first 15 minutes of 45 minutes of experimental motion (figure 4) the bimorph experiences spaced impacting actions, so that the major impacts following release can be clearly seen (although the 125 Hz resonance vibration of the bimorphs cannot be discerned well at this scale).

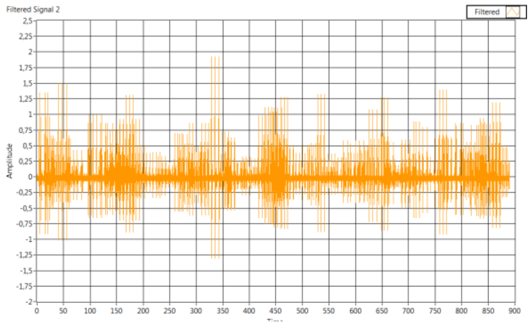

Figure 4 Voltage detected across a 100MΩ equivalent resistor connected to bimorphs strip as a function of time during the water tank tests of 15 minutes.

To power common electronic devices, a regulated 3.3V is obtained from the output of the strip of bimorphs using IPS-EVAL-EH-01 energy harvesting evaluation kit, featuring the high efficiency regulator chip MAX17710 which also manages the charge of an ultrathin THINERGY® MEC battery. The energy provided by the energy harvesting board is sensed over an R=1kΩ load with a control board (figure 5). A dsPIC is programmed to activate the 3.3V regulated output every three minutes. In case there is enough energy in the battery, the output is activated and discharges over the load until it starts to decrease its voltage. When the output voltage reaches a threshold of 2.7V, the control board turns off the output of the harvesting chip. The dsPIC calculates the time period in which the output has been enabled each time.

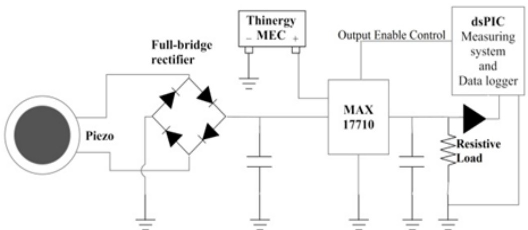

Figure 5 Schematic of the electronic measurement system.

Figure 6 shows the results obtained during 45 minutes where the average power harvested is calculated from the energy measured every time the output was enabled. For the entire test the average harvested power is 2.2 ± 0.3 µW.

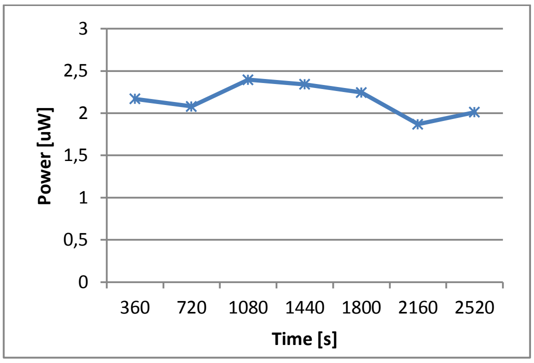

Figure 6 Average Power of the harvesting device

CONCLUSIONS

A new idea about harvesting energy from the sea water is proposed and evaluated, featuring the uncommonly used disk piezoelectric elements to obtain electrical energy from the sea motion using an impact-based system. A prototype was built and tested in water tank, and the obtained results give hope to think that this system can be constructed on larger scale to be installed near the OBSEA underwater observatory to provide energy to small nets of underwater sensors.

ACKNOWLEDGMENT

This work was supported by the Spanish Ministry of Economy and Competitiveness under the research project: “Sistemas Inalámbricos para la Extensión de Observatorios Submarinos” (CTM2010-15459).

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