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Research article

ENERGY HARVESTING – NEW GREEN ENERGY

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ABSTRACT

Energy Harvesting is the technique of capturing ambient energy in physical systems which often dissipates into a less usable form to the environment and converting it into usable electric power. Energy harvesting is beneficial in powering the electronics where there's a need to replace or monitor conventional power sources, making them a more expensive option. The use of energy harvesters eliminates the need to run wires or make frequent visits to replace batteries, thus contributing to green energy savings. This short letter reports the 3 new designed energy harvesting systems based on the electromagnetic and piezoelectric effect from two Universities, i.e. Lublin University of Technology (Poland) and University College Dublin (Republic of Ireland) binding the cooperation between universities in the EH Dialog project. The proposed systems can be used as a power supply for low-energy devices or in diagnostics.

KEYWORDS: energy harvesting, electromagnetism, piezoelectric effect, diagnostics

1. Introduction

Due to rapid economic growth in XXIst century, conventional energy sources reliant on fossil fuels are no longer solely enough to meet growing global energy demands [1,2]. One of alternatives are renewable energy sources like mechanical vibrations, rotations, light or wind, which can be a promising solution to manage the energy crisis. The recent trend is focused on the phenomenon of Energy Harvesting (EH), which refers simply to the conversion of dissipated ambient energy from structural systems into equivalent electrical energy [3]. Admittedly, EH systems are miniature and their power generation is in the order of milliwatts. Nonetheless, these small harvesters can be highly beneficial in instances of hard-to-reach structures such as the ones deployed in the open sea, underground or in space. Mostly EH apparatuses are developed in accordance with autonomous wireless electronic systems mostly assembled as wireless sensor network (WSN) [4]. By conversion of external energy sources by the application of EH system, it is possible to obtain a self-powered system for a lifetime with minimal servicing requirements. Most EH devices can be classified as kinetic, thermal and solar powered. This article is specifically motivated towards EH systems of the first kind. Here, a part of the kinetic energy of the moving elements is recovered as electrical energy by utilizing one of the four electro-mechanical effects i.e., electromagnetism, piezoelectricity, triboelectricity or electrostatics [5,6]. In this short paper we would like to focus on a few application of the Vibration EH systems studied in laboratories of Lublin University of Technology (Poland) and University College Dublin (Republic of Ireland), from the point of view of young researchers. In the following sections we would like to demonstrate the aforementioned concepts with the help of two electromagnetic EH systems namely the pendulum [7,8] and the piezoelectric EH systems [9,10]. The novelty of presented pendulum-based concepts refers to the impact influence [11,12] on the pendulum’s dynamics and study of dynamically changing magnetic interference [13,14] between fixed and moving magnet on the pendulum. In a subsequent example, the electrical energy is obtained from the fluid flow. The fluid-flow system is equipped with the bio-molecular sensors [15,16], which is the relatively new lead-free environment-friendly technique, which is being tested in the area of energy harvesting. Its advantages are high accuracy, selectivity and signal-to-noise ratio. The aim of the paper is to popularise concepts of EH Systems and propose EH as a solution to the problem of global growing demands on electrical energy consumption.

2. Electromagnetic EH systems with pendulum

Over 200 years ago, Michael Faraday's experiment revolutionised the world with its first electric generator. Simple test depended on the horseshoe magnet and the disk by its rotation inducing the voltage formulating the fundamentals of electromagnetic induction phenomena and continued by Danish scientist Hans Christian Oersted. This phenomenon is still deployed in many prototype developments and has an important contribution to the development of EH systems. One of physical systems showing the idea of electromagnetic induction is the pendulum-based system, in which a permanent magnet mounted at the pendulum alternately goes in the area of the induction coil creating the variable magnetic flux. In this article, we present 2 pendulum-based electromagnetic EH prototypes developed at Lublin University of Technology.

The first of the presented systems (see Fig.1) can be a fine implementation for studying nonlinear dynamics’ effects caused by impacts. The prototype characterises two vertically mounted flexible stoppers with regulation about 1cm, that changes the angle of pendulum’s oscillation influencing also the induced voltage. By the change of stoppers’ position, more or less voltage can be induced that the magnet mounted at the tip of the pendulum can get in the cross-section of coils fully or partially. The experimental results showed, that the system’s characteristic frequency is between 8.5-10Hz (see Fig.2), however the system's performance by neighbouring frequencies is also promising but without observed impacts.

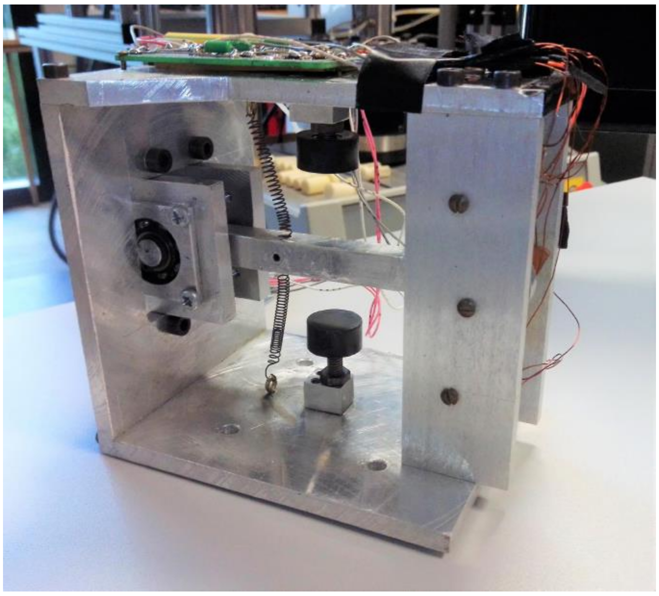

Figure 1. Pendulum-based EH system with mechanical stoppers developed at Lublin University of Technology

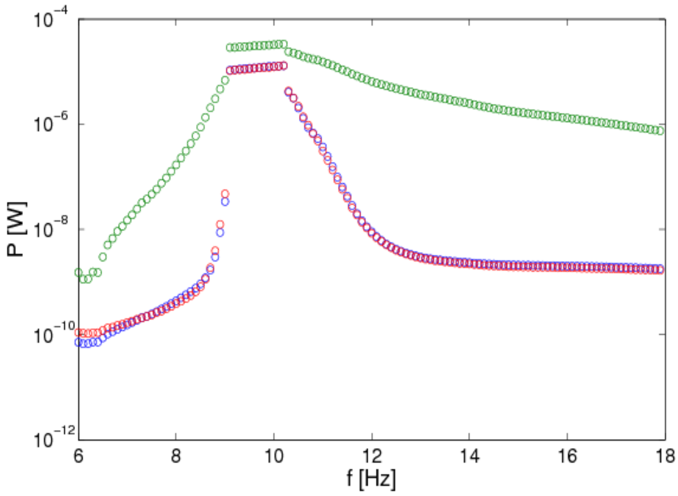

Figure 2. Plot of the output power in applied frequency range (green plot – coils in the middle, blue plot – coils in the bottom, red plot – coils at the top)

The next system is fully fabricated in 3D printing (FDM) (see Fig.3) and other non-magnetic material to avoid the electromagnetic coupling between installed magnets and housing. The proto- type characterises with variable magnetic force, which can be controlled by the distance of movable permanent magnets placed inside coils. Moreover, in the system it is possible to obtain oscillating and rotating solutions depending on the frequency of external excitation. There are 6 pairs of coils connected parallel and to obtain the full performance of the system the rotating magnet on the magnet must make a full rotation. The operating range of frequencies recorded for the system is between 10-15 [Hz], which is shown in Figure 4. Then, in the system there is full rotation of the pendulum. The measuring circuit connected with the system is presented in Figure 3, and the performance of the system is described in the following paper [17].

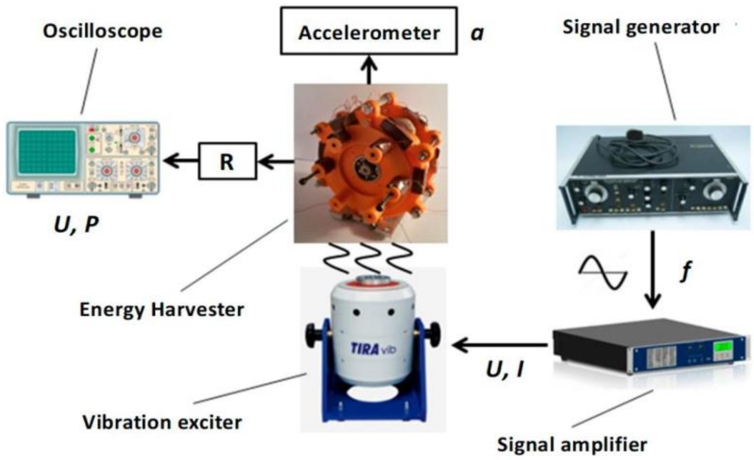

Figure 3. EH system with rotational pendulum developed at Lublin University of Technology

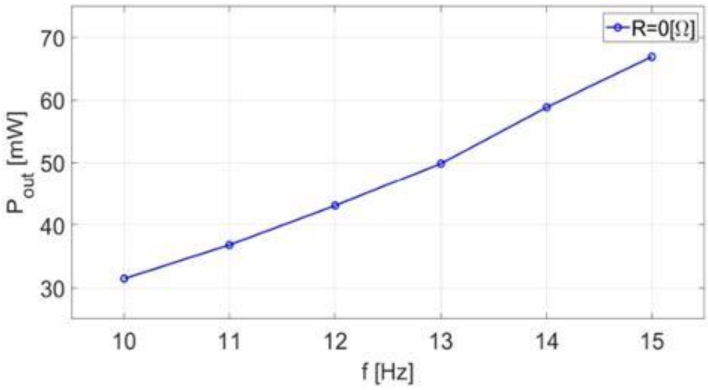

Figure 4. Plot of the output power in operating frequency range without additional load

3. Pipe flow experiments with alternative materials for EH

The availability of potable water is the most basic need for sustainability of human life and well-being. However, about 2 billion people are still in the dearth of it, making the mitigation of this issue as one of the 17 key sustainability development goals set by the United Nations targeted to be achieved by 2030. Furthermore, an estimated 50 percent of water is lost to leaks in North-America's piping system, for instance. Thus, it becomes imperative to detect water leakage. This can be done by piezo-electric energy harvesters bonded onto the pipe and developing a voltage proportional to the strain rate on the surface of the pipe. These harvesters can then be installed in remote locations with limited accessibility. Furthermore, contamination of water is also an area of concern. To evade the toxic heavy elements in the current commercial piezo-electric harvesters, one can opt in for bio-molecular sensors. These amino-acid based sensors are capable of real-time detection with piezoelectric strain and voltage constants of 0.9pC/N and 60mV m/N [18]. In the lab based experiments carried out in an in-house fabricated rig (see Fig. 5), a peak voltage of 2V is recorded in the low di-electric film at high flow rates and large leak size. The results were corroborated with high fidelity simulations in ANSYS Fluent®. Currently, another novel material consisting of diphenylalanine nanotubes (FFNTs) is being tested [19]. The conductivity of these sensors can be improved from 0.12V to 0.40V, when hit by a tuning fork, upon addition of graphene oxide to create a nano-composite.

Figure 5. In-house pipe flow rig developed at University College Dublin

It is observed for a flexible amino-acid based sensor that the time-signals had a distinct change in recurrent patterns [20], [21] once the damage was introduced; see Fig. 6(a). Here, the damage was introduced after 3000 sample readings were taken at a sampling rate of 20 samples/s. Furthermore, the different leak apertures segregate out distinctly in the parameter space of the recurrent entities, unlike the case of a conventional polyvinylidene sensor; see Fig. 6(b,c). The continuous wavelet spectrogram also picks up the distinct frequencies in the different undamaged and damaged time segments.

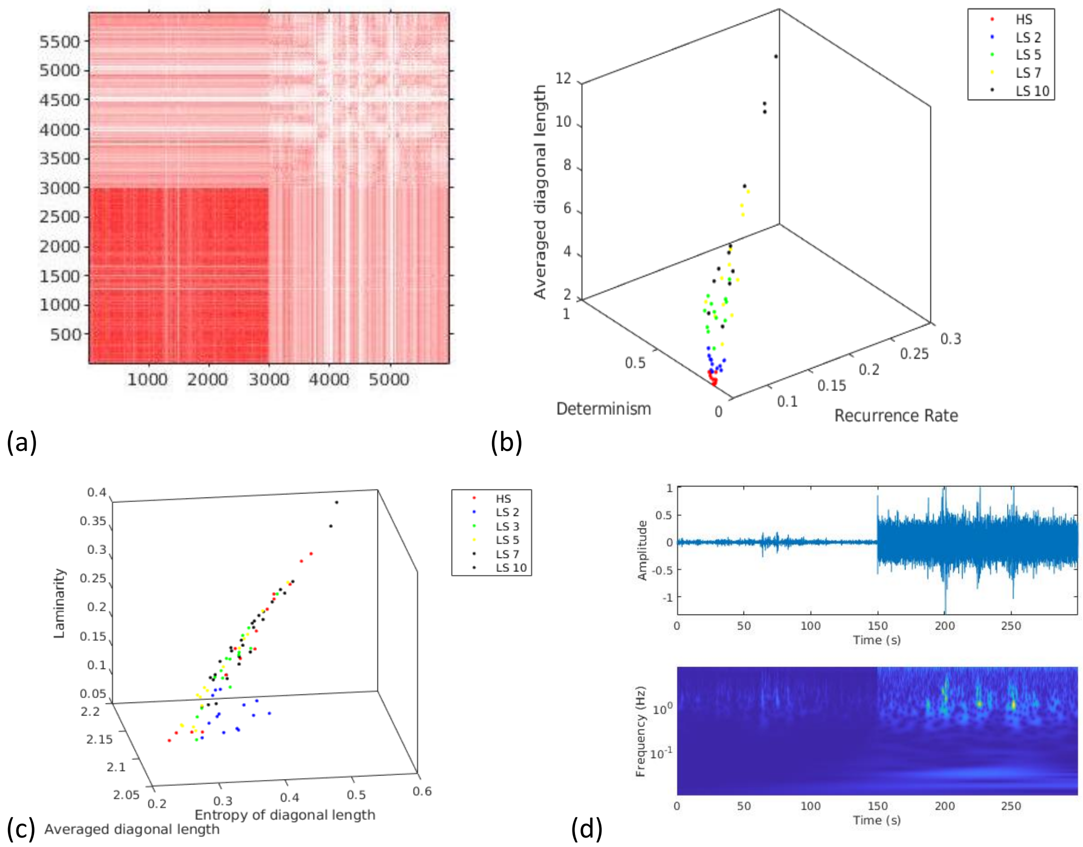

Figure 6. (a) Unthresholded recurrence plot for time signal where initially there was no damage and later a damage was introduced; **(b)** Parameter space with recurrent characteristics for a gamma glycine amino-acid based sensor, **(c)** Parameter space with recurrent characteristics for a PVDF sensor, **(d)** Time history and corresponding wavelet diagram of data recorded from the amino-acid based sensors showing change in frequency when damage is introduced.

4. Summary

In this short-letter, 3 prototypical examples depicting instances where energy harvesting solutions can be deployed have been presented. The authors are optimistic that these EH devices could be used in various applications for powering-up low power consumption sensors, especially in automotive, wireless sensor networks (WSN), structural health monitoring (SHM) of civil structures [22] and piping networks. Despite the relatively low power output of these systems, the produced voltage is enough for constant power supply to remote sensors deployed in conjunction with them. Miniaturised EH systems definitely will not substitute the fossil fuels, but they are a greener-power alternative to batteries that require periodic replacements. A recent review on the development of piezoelectric energy harvesters shows that it is going to take 28.8% of the complete energy harvesting market [23]. Another global challenge, where energy harvesting systems could be used is the development of wireless communication such as 5G [24]. As of today, it is worth noting that the field of research in EH is burgeoning, and in the following decades new EH prototypes would most likely scale up and cater to the growing demands on electrical energy. The global share of EH solutions is likely to grow, eventually aiding universal attempts towards environmental sustainability.

Acknowledgements

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