59th ILMENAU SCIENTIFIC COLLOQUIUM
Technische Universität Ilmenau, 11 – 15 September 2017
URN: urn:nbn:de:gbv:ilm1-2017iwk-008:9

MINIATURIZED PUSH-BUTTON ROTATIONAL ENERGY HARVESTING GENERATOR

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ABSTRACT

This work presents a development and miniaturization of a rotational electromagnetic energy harvesting (EH) generator. The energy harvesting generator is driven mechanically by pushing the button. The energy harvester system has an integrated mechanism for movement conversion. This mechanism converts the linear movement of the button into rotation with a rotational speed of 1000 rpm. An electromagnetically part of harvester consists of in FR-4 embedded multilayer planar coils and of multipole NdFeB hard magnets. The miniaturized energy harvester generates a maximum open circuit output voltage of about 500 mV with duration of about 2 s and a maximum short circuit output current higher than 40 mA.

Index Terms - Electromagnetics, Energy Harvesting, Generator, Kinematic Harvester, Energy Management System (EMS), Buck-Boost Converter, Maximum Energy Tracking.

1. INTRODUCTION

In the environment different types of energy sources are available. Using a large number of different physical effects, these environmental energies can be converted into the useful electrical power [1, 2]. An improvement did in the last few years in the field of Internet of Things (IoT) and of Wireless Sensor Networks) (WSNs) boost already research and development of energy harvesting technologies [3, 4]. Energy harvesters (EH) are very useful for enabling an autonomous power supply where a wired power is unavailable or cost extensive.

Regarding the kind of used kinetic energy, electromagnetic harvesters can be oscillatory harvesters using vibrating energy; hybrid harvesters transforming vibrations into rotation; or rotational harvesters using rotational movement for generating the electrical power.

Main advantage of rotational electromagnetic harvester regarding to vibrational harvesters is the independence from the resonant frequency. Rotational harvesters are capable of achieving higher energy density compared to other kinds of electromagnetic transducers [5]. Rotational harvesters are capable to achieve higher energy density as other kind of electromagnetic transducers [6, 7]. A disadvantage is a complex design of the harvester and the dependence between harvester size and output signal. Larger electromagnetic harvesters generate normally higher power outputs [8].

2. DESIGN

The energy harvester consists of mechanism for movement conversion, electromagnetic EH transducer and power management system (PMS) with RF transmitter. The design of first

harvester is described before [9]. In this work the new miniaturized harvester is developed. The volume of new harvester is about 70% smaller than the volume of the previous harvester.
Developed electromagnetic harvester converts the kinetic movement energy into electrical power using electromagnetic working principle. The harvester is driven by pushing a button. The mechanism for movement conversion converts than the linear movement of the button into rotation.
Figure 1 shows the schematics of the harvester working principle. As mentioned earlier, a motion of a driving button is linear translation; therefore the system for movement conversion is integrated in the energy harvester. Using this movement conversion mechanism, the small linear motion of the button of about 10mm is converted in the rotation with rotational speed higher than 1000rpm.

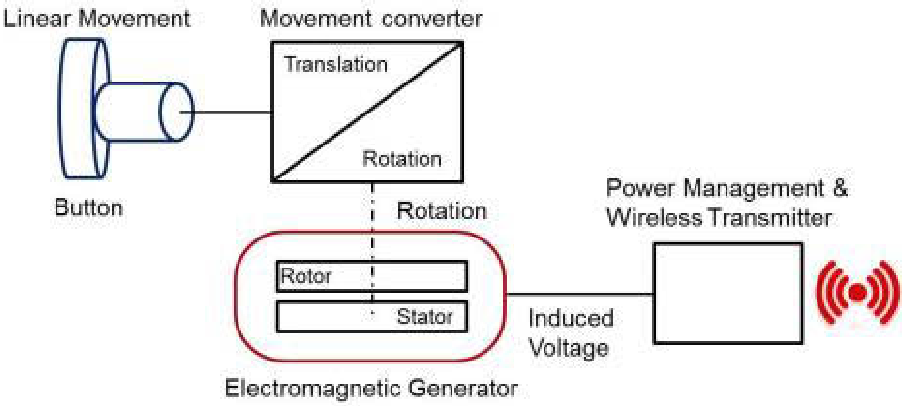


Figure 1: Schematic of rotational electromagnetic energy harvester

The electromagnetic transducer consists of movable part (rotor) and of stator. The rotor has 8 multi pole permanent magnet segments of NdFeB mounted on soft magnetic sheet metal with high saturation flux density. As soft magnetic material a Co-alloy sheet metal Vacoflux byVacuumschmelze is applied. The Co-alloy sheet metal shows very high saturation flux density of 2.3 T. This is important for avoiding the saturation of the system. The hard magnet poles are magnetized perpendicular to the surface of the poles.
As a stator serves one coil system consisting of 4 coils divided in two phases. Coils are embedded into FR-4 material. The coil system is basically a multilayer coil with 10 layers. Each coil has in the sum 100 turns (10 turns per each coil layer). Both parts, the stator and the rotor, are mounted on axis forming a defined air gap in between. Figure 2 shows the design of the electromagnetic part of the harvester.

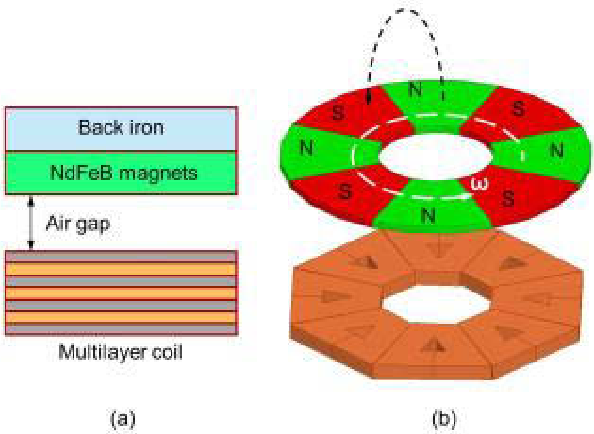


Figure 2: Design of electromagnetic part of the harvester

The movement conversion mechanism consists of a button, round gear rack, spring, and gear with one-way clutch. For this harvester type, is important to generate a rotation only in one direction. The rotation in opposite direction generates a negative voltage signal and the sum of the induced voltage is zero. Therefore, the one-way clutch is applied to allow the rotation in only one direction. The gear is a standard mechanical part and the round gear rack is easy for fabrication by the mechanical machining. By using of standard parts and easy-to-fabricate parts, the costs of the harvester system can be reduced.
By pressing the button, the spring is loaded and the energy is stored in the spring. During releasing of the spring, the button and round gear rack are moving in the starting position back. The round gear rack moves the gear and the one–way clutch allows the uninhibited free rotation of the rotor with assembled permanent magnets. The rotational speed achieves the value of about 1000rpm.

3. PROTOTYPE OF THE HARVESTER

The rotational electromagnetic harvester is designed as a planar generator with very simple structures. The energy harvester was simulated using FEM (Finite Element Method) simulation. As a simulation tool Ansys Maxwell is applied. The aim was the miniaturization of the existing harvester but also to keep the induced voltage as high as possible at high voltage level of about $V_{peak\text{-}peak}$~1000mA or higher.
Expect the simulation of an induced voltage; the aim of simulation was to find an optimal coil design with good ratio between electrical resistance and coil inductance. To achieve high induced voltage, it is necessary to have as high as possible number of turns. During miniaturization, the size of coils decreases. Requirement of small size and high number of turns causes increasing of coil's electrical resistance. In order to find out the optimal design, the coil size, and number of turns are varied. For coil fabrication a PCB multilayer embedding technology is applied. Taking into account the fabrication aspects, the final coil design is defined. As a good match between inductance and resistance, coils with turns width of 125µm and distance between turns of 125µm is chosen. Multilayer fabrication technology for 35µm thick copper is applied.
One coil layer consists 10 turns. Based on simulation results, proposed minimum number of turns was 300. Therefore, the idea was to implement special PCB multilayer folding technology. This technology is available at Würth Elektronik CBT. At the moment we were not able to implement this approach. Therefore, we fabricated the coil system based on standard multilayer embedding technology. The 10 layer approach is implemented; therefore each coil has 100 turns (10 turns per 10 layers). Figure 3 shows first prototype of fabricated coil systems (a) and of miniaturized harvester (b)

Figure 3: Comparison of miniaturized and previous harvester : (a) coil systems and (b) completed harvesters

Figure 4 shows a cross-section of the miniaturized rotational energy harvester with main dimensions. The total dimension of the harvester is 50mm x 40mm x 40mm.

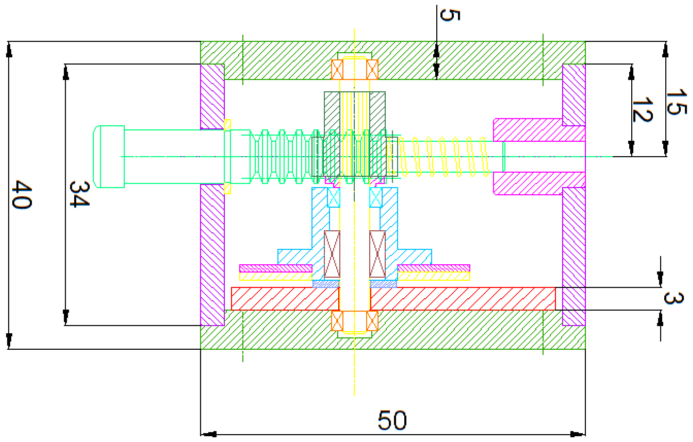


Figure 4: Cross-section of the energy harvester system

Fabricated coil system is tested. Measurement results are summarized in the Figure 5.

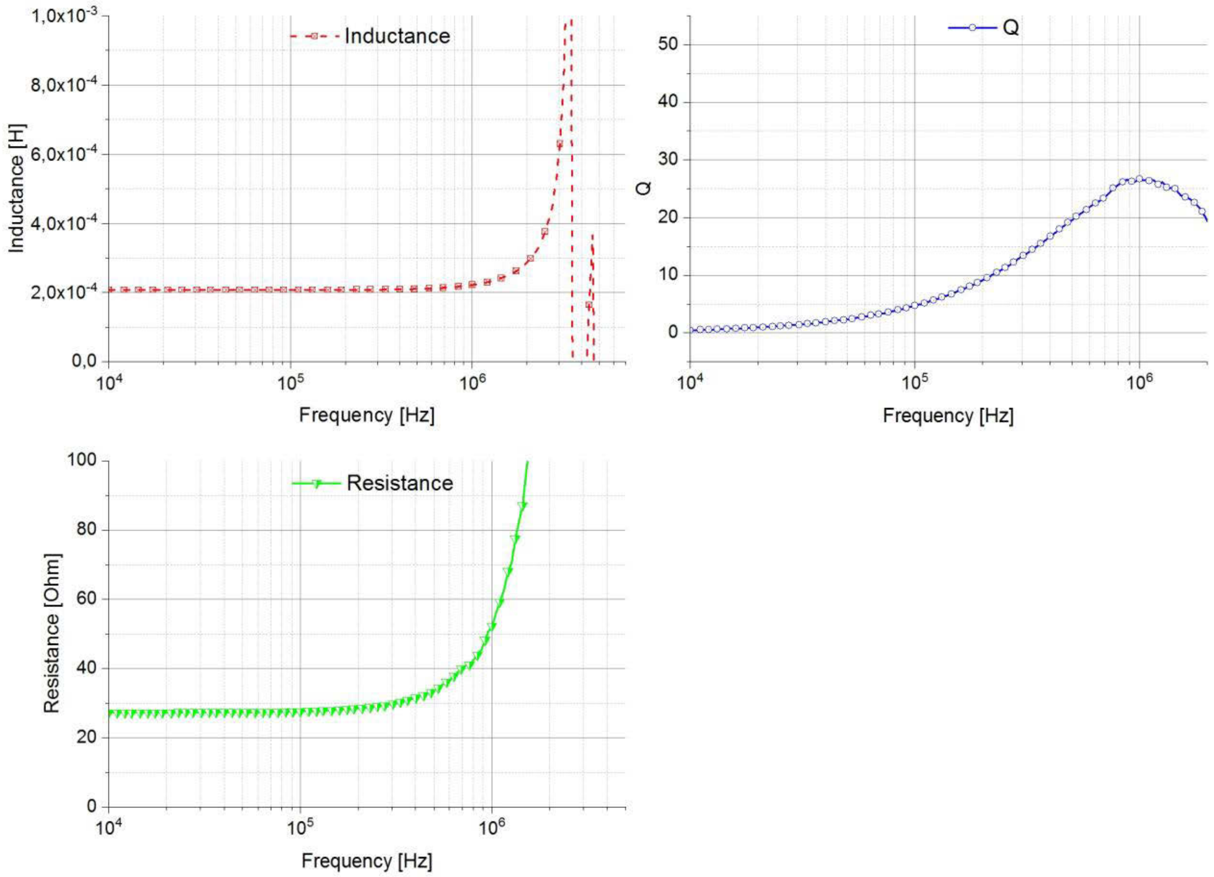
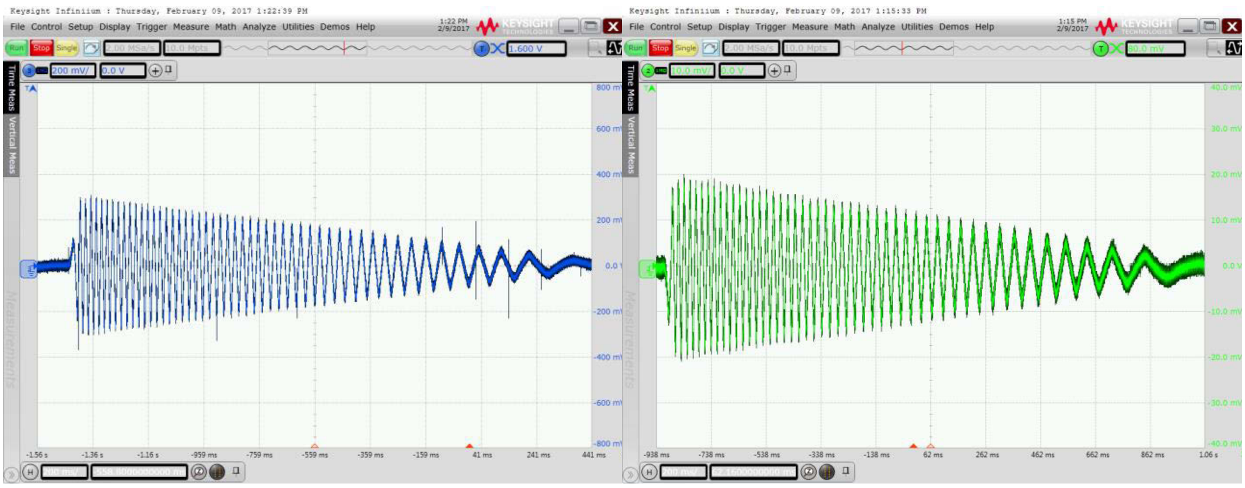


Figure 5: Measurement results of the coil system: Inductance, Q-factor and electrical resistance over the frequency

The results shown in the Figure 5 shows the values of one phase (two coils connected in the series). One phase has an inductance of 200µH. The inductance is stable up to 1MHz. The electrical resistance of one phase is 27 Ohm.

4. RESULTS

The prototype of rotational electromagnetic harvester is fabricated and tested. Figure 6 shows the open circuit output voltage (a) and short circuit current of harvester. The maximum open circuit voltage $V_{peak\text{-}peak}$ is about 600mV. The rotation takes about 2 s long. The short circuit current is about 40mA.



(a) (b)

Figure 6: Open circuit voltage (a) and short circuit current (b) of completed energy harvester

In order to calculate the behavior and generated energy of the harvester; different loads are connected to the prototype. The output energy varies with the value of the connected load. The generated output energy is calculated by integration of the calculated power over the time. As shown in Figure 7, the harvester produces the maximum energy when it's connected to a load of 10Ω -20Ω. That means a topology that matches this impedance, to track the maximum energy point of the harvester, needs to be developed.

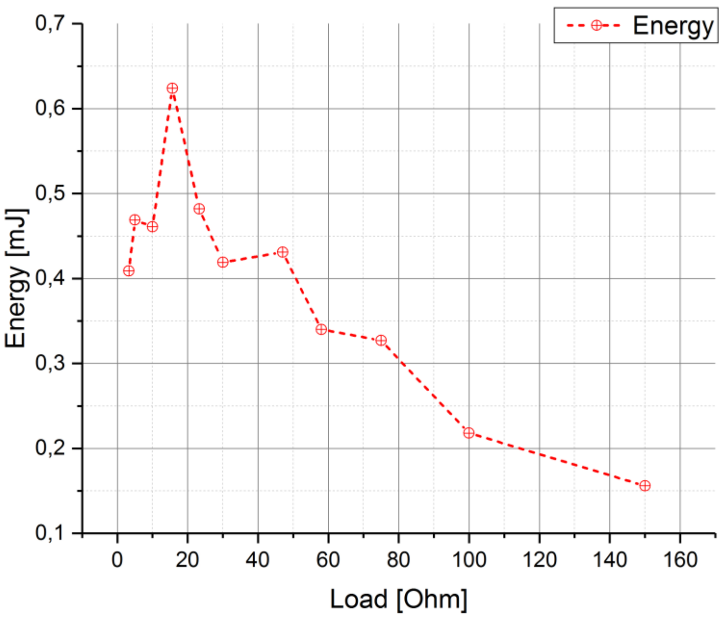


Figure 7: Harvested energy at different loads

Prototypes for both the energy harvesting system and the PMS are presented before [10, 11]. The PMS is built with off-shelf discrete components. The digital controller is realized on FPGA development board.

5. CONCLUSION AND OUTLOOK

The prototype of miniaturized rotational electromagnetic energy harvester, which generates the electrical power from kinetic energy by pushing the button is developed and fabricated. The generated energy is measured, and the maximum harvested energy is about 600µJ at load between 10Ω-20Ω. The generated energy is higher than the energy of similar non-rotational energy harvesters. Similar non-rotational harvester generates at the moment the energy of about 330µJ. A digitally controlled PMS should be, in the future work, tested with developed miniaturized energy harvester. The PMS is able to convert ac-to-dc voltage in a single stage which allows the topology to operate with low-voltage and ultra-low voltage harvesters. Currently, the work on development of coil system with higher number of turns (300 turns) with new fabrication technology is continued. With new coil system is expected a 3 times higher induced voltage and output energy of the harvester. The volume of the electromagnetic transducer is reduced of about 70% and the expected maximum output voltage should be about 2V.

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