A Hip Implant Energy Harvester

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Abstract. This paper presents a kinetic energy harvester designed to be embedded in a hip implant which aims to operate at a low frequency associated with body motion of patients. The prototype is designed based on the constrained volume available in a hip prosthesis and the challenge is to harvest energy from low frequency movements (< 1 Hz) which is an average frequency during free walking of a patient. The concept of magnetic-force-driven energy harvesting is applied to this prototype considering the hip movements during routine activities of patients. The magnetic field within the harvester was simulated using COMSOL. The simulated resonant frequency was around 30 Hz and the voltage induced in a coil was predicted to be 47.8 mV. A prototype of the energy harvester was fabricated and tested. A maximum open circuit voltage of 39.43 mV was obtained and the resonant frequency of 28 Hz was observed. Moreover, the power output of 0.96 μW was achieved with an optimum resistive load of 250Ω.

1. Introduction

Failure of joint replacements damaging the surrounding bone results in difficult surgery and rising costs of health care [1]. In-vivo monitoring of joint replacements has been proposed to address this problem and to predict faults in advance. However, effectively electrical supplying energy to power instrumented hip implants remain a challenge.

The inductive power link has previously been used in-vivo to power the instrumented hip joint [2], [3]. The main components of this power system are a primary coil wrapped around the patient's thigh and a secondary coil embedded inside the hip prosthesis. Such components are uncomfortable for patients, limited activities of patients and place energy constraints on the operation of the instrumented implants. In addition, three kinetic energy harvesting mechanisms have been presented by Silva et al [4]: translation-based electromagnetic, rotation-based electromagnetic, and piezoelectric harvester. The amount of energy that can be harvested depends on the amplitude of hip movements, relative movement velocity between magnets and coils, and the axial force on the prosthesis during the human gait cycle. According to [4], a regular human gait frequency of 3.94 Hz is required to generate useful power for enabling operation of a Bluetooth protocol (BLE112 from Bluegiga) up to 50 seconds. This may not be possible due to poor mobility of patients who have a hip replacement. To address this difficulty, we aim at designing an energy harvester operating at low frequencies around 1 Hz which is associated with body motion during routine activities of patients.

A magnetic spring has been used to achieve a compact energy harvester and this enables the spring constant to be adjusted by varying magnet strength. In this paper, we present design of the first prototype of the energy harvester in hip implant including a comprehensive simulation and experimental results. Such results will be a benchmark to develop a practical device.

2. Harvester design

A prototype of energy harvester with magnetic spring is shown in figure 1. Two design challenges of the generator are the limited space available (volume of femoral head and femur is about 8 cm^3 and 20 cm^3 respectively) and the low frequency associated with human movements. Due to the constrained volume of the hip prosthesis, the size of the prototype was designed to be 2 cm in length with a diameter of 4 mm and the harvester is to be embedded at the top of femur as shown in figure 2.

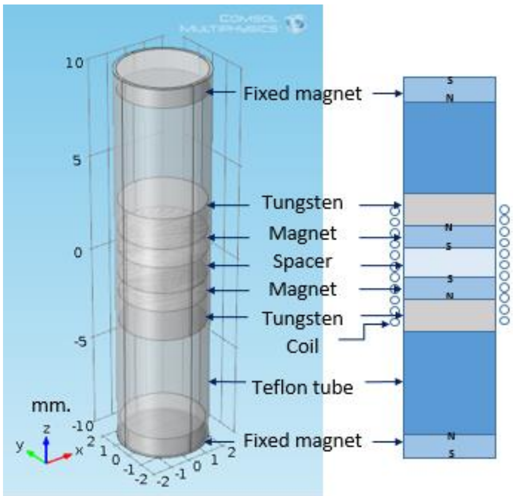
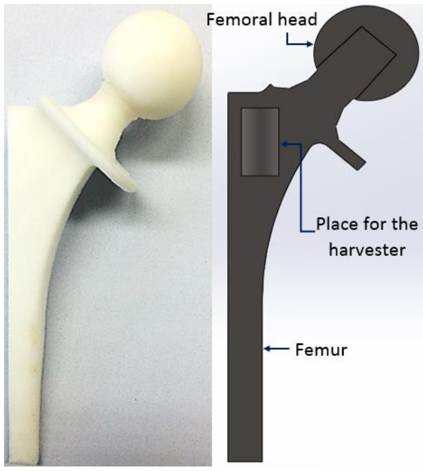


Figure 1. Schematic of magnetic spring harvester.



(a) (b)

Figure 2. Schematic of hip prosthesis: (a) 3D-printing model (b) cross-section diagram.

The design consists of two fixed magnets at top and bottom of the tube and a moving mass inside the tube. A Teflon tube was used in order to reduce the friction between moving mass and inner surface of the tube. The moving mass consists of two magnets with a ferrite spacer placed between them in order to join such magnets and concentrate the flux density [5]. The thickness of the spacer was optimized for the purpose of avoiding saturation in it. As shown in figure 3, the thickness of 1.4 mm is the point that balances magnetic flux density between spacer and magnets. Moreover, two tungsten pieces were attached on moving magnets to increase inertial mass thus the output power as well as to reduce the resonant frequency of the energy harvester [5].

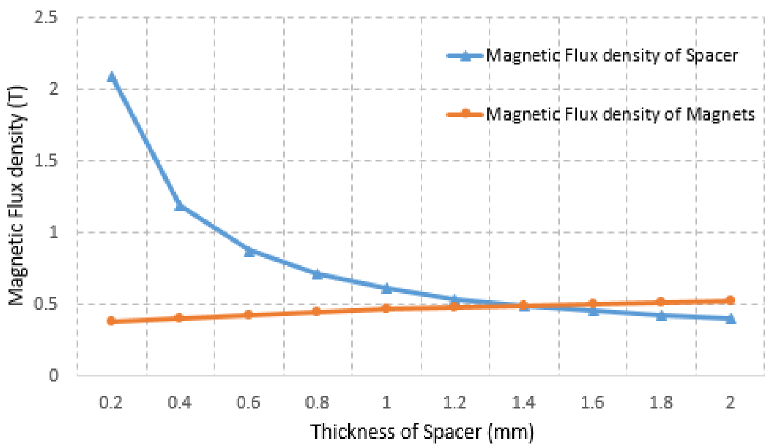


Figure 3. The optimal thickness of spacer.

3. Fabrication and Experimental arrangement

Figure 4 shows the assembled harvester. Two 4mm-diameter SmCo cylindrical magnets were attached at top and bottom of the Teflon tube which has a coil wound from 50µm-diameter Copper wire with 1100 coil turns. Two cylindrical Tungsten pieces, two SmCo magnets and a ferrite spacer have been glued together to be the moving mass and placed into the tube. After that the harvester was placed in the holder as shown in figure 5(a) and tested on the shaker which was shaken in the vertical direction.

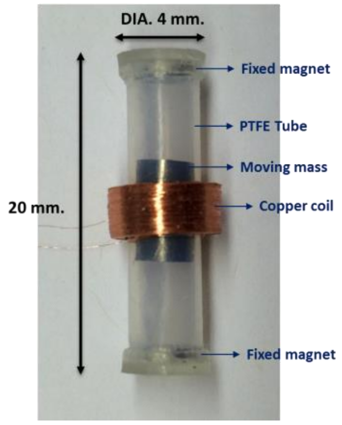
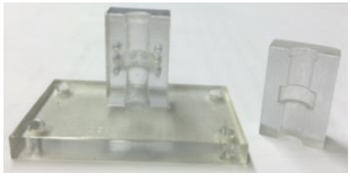
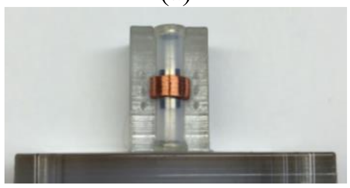


Figure 4. Fabricated energy harvester.



(a)



(b)

Figure 5. Experiment settings: (a) holder (b) holder with generator.

4. Results and discussion

4.1. Simulation results

The proposed model was simulated in COMSOL to study magnetic flux variation, the resonant frequency of the harvester and voltage induced in a coil. The magnetic flux density along the tube is shown in figure 6. According to COMSOL simulation, the resonant frequency of the device was found to be 30.17 Hz and a peak voltage of 47.8 mV was induced in a coil when excited at 800mg (figure 7).

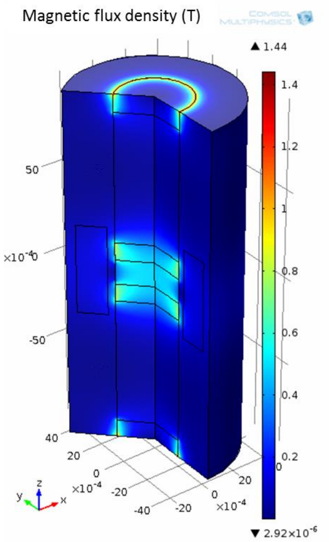


Figure 6. The simulation results of magnetic flux density along the tube

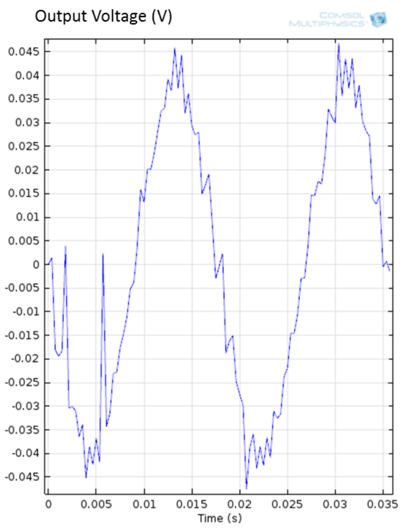


Figure 7. The simulation results of voltage induced in a coil

4.2. Experimental results

The energy harvester was tested by exciting it at 800mg on an electromagnetic shaker. According to the experiment results, the resonant frequency of 28 Hz was reached and the maximum open circuit voltage of 39.43 mV was obtained (figure 8). Moreover, the maximum output power of 0.96 µW was achieved at the optimal load of 250Ω (figure 9).

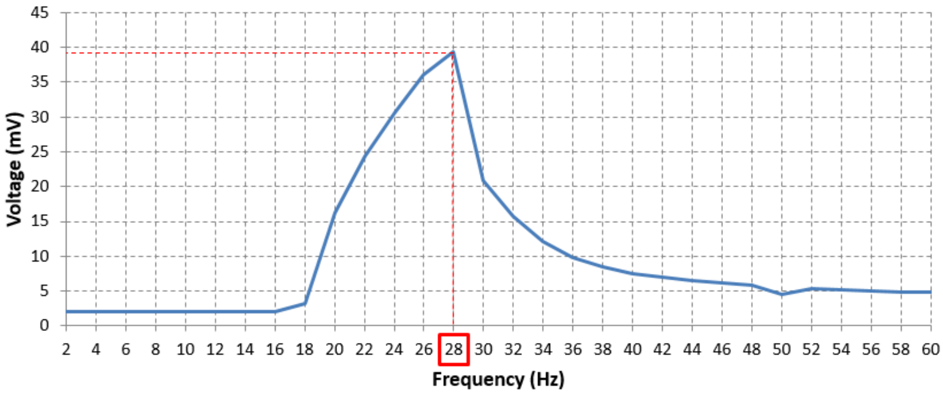
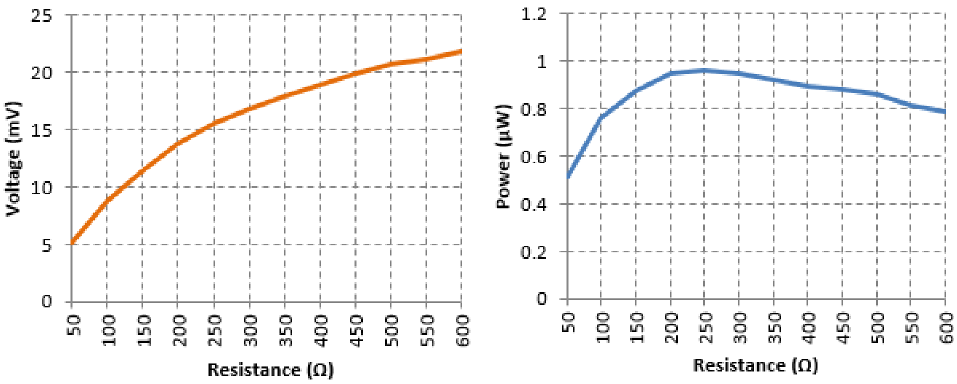


Figure 8. Experiment results: open circuit voltage vs frequency.



(a) (b)

Figure 9. Experiment results: (a) voltage output and (b) power output vs. load resistance of generator at 28 Hz.

5. Conclusion and future work

There are slight differences between simulation and experimental results, i.e. 2 Hz (6.7%) difference for the resonant frequency and about 20% different for the output voltage. At the optimal load of 250Ω, the highest power output of 0.96 µW and output voltage of 15.51 mV can be achieved. According to aforementioned results, the resonant frequency of the presented energy harvester is higher than expected. In order to harvest energy from patients who have had a hip replacement, the operating frequency of the device should be decreased to working frequency which is around 1-2 Hz associated with frequency of patients during free walking [6]. Therefore, overall structure of moving mass will be redesigned, i.e. increase mass. Moreover, coil parameters such as number of coil turns or diameter of coils have to be considered as well in order to increase power output and improve efficiency of the device. Finally, the magnitude of damping effects e.g. tube friction, will be established and its effect on the power output quantified.

6. Acknowledgement
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