20th International Conference
ENGINEERING MECHANICS 2014
Svratka, Czech Republic, 12 – 15 May 2014

ENERGY HARVESTING ANALYSIS OF BODY MOTION AS ENERGY SOURCE FOR BIOMEDICAL DEVICES

Z. Hadas*, J. Vetiska**

Abstract: *This paper deals with an energy harvesting analysis for a development of an efficient energy harvesting system for the artificial cochlea. The artificial cochlea could be used for a compensation of deafness. This artificial cochlea consists of a MEMS sensor based on banks of mechanical filters, electronics for sensing and electrodes, power supply and packaging. The energy harvesting systems are used for biomedical devices in present time and using of energy harvesting in head area for powering of the artificial cochlea is convenient. There are several types of energy which can be used as a source of energy for this biomedical application. Only 3 types of energy converters are suitable in the head area and the sufficient output power is expected. There are thermal gradient between skin and surroundings, mechanical movement of the head (shocks and vibrations) and bending movement of neck muscles and an artery. The energy harvesting from mechanical movement in head area is analysed in this paper.*

Keywords: Energy harvesting, Mechanical energy, Mechatronics, Biomedical device, Cochlea.

1. Introduction

This paper deals with an analysis and development of an efficient energy harvesting system for the artificial cochlea. The artificial cochlea is a biomedical device for a compensation of deafness. The operation of our artificial cochlea is based on the active MEMS sensor with bank of mechanical filters. Therefore, the power consumption of the active MEMS sensor is lower than using of passive sensor with a microphone and speech processor. The mentioned artificial cochlea consists of the MEMS structure with mechanical filters, electronics for sensing and electrodes, power supply and packaging. Batteries are usually used as the power supply for biomedical devices in present time. However several biomedical devices with very low power consumption are assumed for using with energy harvesting system (Beker et al., 2013). The energy harvesting is an alternative way how to provide electricity to any autonomous devices from surroundings without any fuel consumption or physical connection to outside power supply. The energy harvesting systems in head area can be used for sufficient powering of the developed artificial cochlea.

The whole artificial cochlea is mechatronic system based on several engineering's domains and our aim is the development of this complex device with respect on the mechatronic approach. The correct operation of the artificial cochlea depends on the sufficient power source and simultaneously the artificial cochlea has to operate in very low level of power consumption because the level of ambient energy in the head area is very low. The aim of this paper is analysis of harvested power for biomedical device in the head area.

There are several types of energy which can be used as a source of energy for this biomedical application, e.g. (Abdi et al., 2013), (Khaligh, 2010), (Delnavaz and Voix, 2014), (Lay-Ekuakille et al., 2009). On the base on the initial analyses and experience with energy harvesting systems only 3 types of energy converters in the head area appears as sufficient power sources. There are thermal gradient, mechanical movement (shocks and vibrations) and bending movement of neck muscles and an artery in the head area. The energy harvesting from any mechanical movement in the head area is analysed in this paper. The energy harvesting from mechanical movement can be harvested by these physical principle of electro-

* Ing. Zdeněk Hadaš, PhD.: Institute of Solid Mechanics, Mechatronics and Biomechanics, Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896/2; 616 69, Brno; CZ, hadas@fme.vutbr.cz

** Ing. Jan Vetiška, PhD.: Institute of Production Machines, Systems and Robotics, Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896/2; 616 69, Brno; CZ, vetiska@fme.vutbr.cz

mechanical conversions: piezo-electric, electro-magnetic, electro-static and magnetostriction physical principle.

2. Analysis of Body Motion

The mechanical energy harvester is usually based on a resonance mechanism which is excited by ambient energy of mechanical movements (Hadas & Singule, 2011). The movement can be in a form of vibrations (usually in engineering applications) or in a form of body shocks (movement acceleration). The inertia forces provide a relative movement of a seismic mass in the resonance mechanism. This relative movement is converted by any physical principle of the electro-mechanical conversion. This principle is shown in Fig. 1.

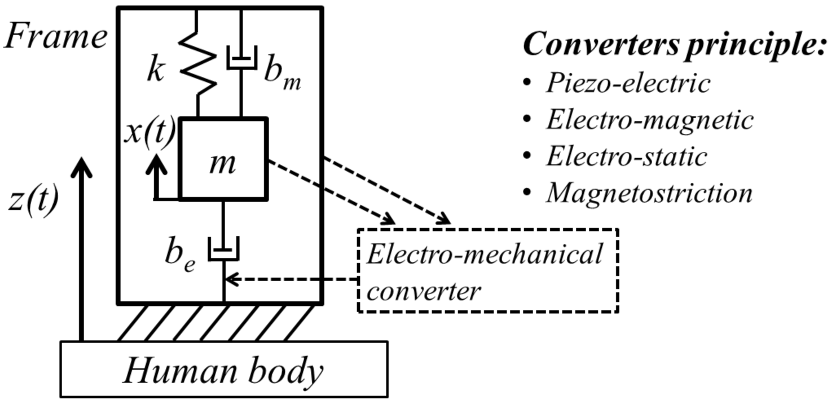

Fig. 1: Energy Harvesting Principle from Human Body Motion.

The second order differential equations of moving mass (1) is ordinary used for solving of displacement x, velocity $\dot{x}$ and acceleration $\ddot{x}$ of the mass m. The system operation is effected by mechanical damping b_m and stiffness of the mechanism k. During harvesting of electrical energy this dissipation of energy provides feedback by electro-mechanical damper b_e. This system is excited by ambient vibrations or shocks with acceleration $\ddot{z}$.

$$m\ddot{x}(t)+b_m\dot{x}(t)+b_e\dot{x}(t)+kx(t)=m\ddot{z}(t) \quad (1)$$

The energetic analyses of this differential equation of the mechanical energy harvester was published several times, e.g. (Hadas et al., 2010) and (Williams and Yates, 1996). This model corresponds with lab results and it can be used in technical engineering projects. However, the human body is not a machine from steel and the human body reacts against the relative oscillation inside resonance mechanism. The human muscles and skeleton provide damping forces which effects ordinary motion equations and this equation cannot be used for power analyses. Unfortunately several papers, e.g. (Accoto et al., 2009) and (Goll et al., 2011), do not reflect this fact and analyses presented in this paper are biased.

This effect can be presented on a simple experiment. The commercial piezo-electric converter from Company MIDE was used. This piezo converter consists of flexible beam and two thin film layers from piezo-electric material with electrodes. Electrodes of the piezo layers are connected in series. The beam of piezo converter provides stiffness of the resonance mechanism with own mechanical damping. The seismic mass 8 grams was fixed on the beam end.

This simple energy harvesting system is used for energy harvesting analysis in our paper. This system was excited by initial displacement of the beam end and the system response was measured for different places. These responses are shown in Fig. 2. The first response, labelled “Table”, was measured with energy harvesting system on the hand and the hand was propped on a table. The second response, labelled “Hand”, was measured in free hand and the last response, labelled “Head”, was measured on the head in an ear area. The measured responses confirm that using of the motion equation (1) is not correct for energy harvesting analyses in case of biomedical devices. The human body damps energy harvester oscillation. The differential equation (1) has to be extended to a model of the human body behaviour and this model has to be verified for design of harvester parameters.

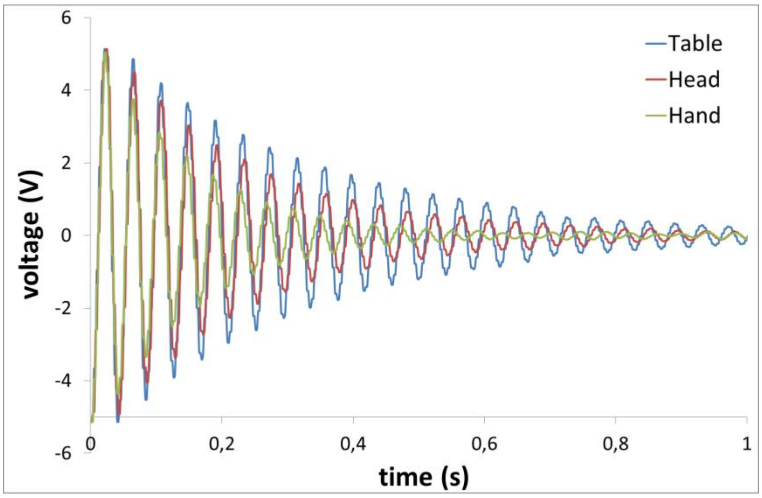

Fig. 2: Response of Piezo-electric converter on initial displacement; for different position of energy harvester (fixed on head, in hand and in hand propped on table).

3. Experimental Analyses of Energy Harvesting from Human Motion

However the presented piezo converter can be used for experimental analyses of energy harvesting from human body motion. The piezo energy harvesting system was fixed in head area and voltage responses were measured. The example of the voltage measurement is shown in Fig. 3. This measurement provides response of piezo energy harvesting system during a fine walking.

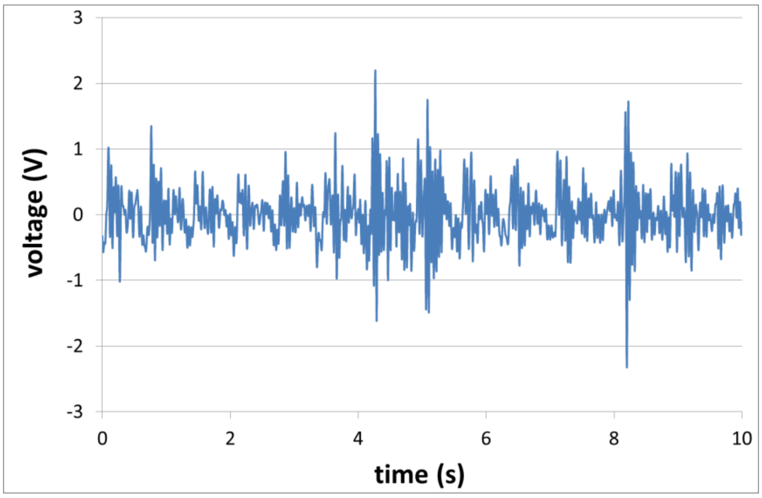

Fig. 3: Response of piezo-electric converter on human walking.

There is advantage than a head area does not provide such damping effect as hands, legs or back. This experiment shows than very low excitation can provide significant voltage response of piezo energy harvester. Several human body behaviour were analysed and the results are presented in Tab. 1. The presented values are range of maximal voltage peak in open circuit for different human body behaviour.

Tab. 1: Generated voltage (open circuit) for different body behaviour.

Body behaviour	**Generated voltage peaks**
breathe	*200 mV*
breathe deeply	*300 - 400 mV*
facial gestures	*400 – 600 mV*
speech	*600 - 800 mV*
walking	*1 – 1.2 V*
jumping	*3 – 5 V*

4. Conclusions

The analytical analysis of harvester power from the ordinary motion equation is not suitable for predict of harvested power from human behaviour such for engineering's applications. This analytical model has to be extended to active human body behaviour for correct energy harvesting analysis for biomedical analyses. Otherwise the presented experimental results are useful for energy harvesting analysis without energy harvester model with correct excitation and human body feedbacks.

The experimental results of the simple piezo energy harvesting system shows that voltage response of thin film piezo element are sufficient for processing with current ultra-low power electronics. Recent advances in integrated circuit technology provides ultra-low power systems for biomedical applications (Chandrakasan et al., 2008) with power consumption approximately in range 10 – 100 μW. The results promise that the energy harvesting system in the head area can provide enough energy for powering of the developed artificial cochlea.

However only open voltage responses were measured and next step of our development is design of power management circuit which can provide optimal power point tracking and output power of the energy harvesting system will be analysed. Generally output power of these mechanical converts depends on their mass. Output power in range 10 – 100 μW are expected from volume for the artificial cochlea but this power is not provided continuously, only in a burst mode such is shown in Fig. 3.

The experimental results during different human body behaviours provided a preliminary view on energy harvesting technology in biomedical applications. Energy harvesting technologies are logical concept for powering of biomedical devices which can improve life of patients, it depends on clinical needs. However there is long way to implement energy harvesting system to biomedical devices.

Acknowledgement

This paper has been supported by the project "Research of the Micro Electro Mechanical Artificial Cochlea Based on Mechanical Filter Bank" GAČR 13-18219S under the Czech Science Foundation (CSF).

References

Abdi, H., Mohajer N., Nahavandi S. (2013) Human Passive Motions and a User-Friendly Energy Harvesting System. Journal of Intelligent Material Systems and Structures .

Accoto, D., Calvano, M., Campolo, D., Salvinelli, F., Euglielmelli, E. (2009) Energetic Analysis for Self-Powered Cochlear Implants. Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference 2009, pp. 4860-4863.

Beker, L., Zorlu, O., Goksu, N., Kulah, H. (2013) Stimulating Auditory Nerve with MEMS Harvesters for Fully Implantable and Self-Powered Cochlear Implants. In: 2013 Transducers & Eurosensors XXVII: 17th International Conference on Solid-State Sensors, Actuators and Microsystems (Transducers & Eurosensors XXVII), pp. 1663-1666.

Delnavaz, A., Voix, J. (2014) Energy Harvesting for In-Ear Devices Using Ear Canal Dynamic Motion. IEEE Transactions on Industrial Electronics 61 (1), pp. 583-590.

Goll, E., Zenner, H-P., Dalhoff, E. (2011) Upper Bounds for Energy Harvesting in the Region of the Human Head. IEEE Transactions on Bio-Medical Engineering 58 (11), pp. 3097-3103.

Hadas, Z., Singule, V. (2011) Energy Harvesting - Opportunity for Future Remote Applications. Edited by V Fuis. Engineering Mechanics 2011, pp. 167-170.

Hadas, Z., Ondrusek, C., Singule, V. (2010) Power Sensitivity of Vibration Energy Harvester. Microsystem Technologies 16 (5), pp. 691-702.

Chandrakasan, A., P, Naveen Verma, Daly D.C. (2008) Ultralow-Power Electronics for Biomedical Applications. Annual Review of Biomedical Engineering 10, pp. 247-274.

Khaligh, A. (2010) Kinetic Energy Harvesting Using Piezoelectric and Electromagnetic Technologies—State of the Art. IEEE Transactions on Industrial Electronics 57 (3), pp. 850-860.

Lay-Ekuakille, A., Vendramin, G., Trotta, A., Mazzotta G. (2009) Thermoelectric Generator Design Based on Power from Body Heat for Biomedical Autonomous Devices. In 2009 IEEE International Workshop on Medical Measurements and Applications, pp. 1-4.

Williams, C.B., Yates, R.B. (1996) Analysis of a Micro-Electric Generator for Microsystems. Sensors and Actuators A: Physical 52 (1-3), pp. 8-11.