Piezoelectric Energy Harvesting for Self Power Generation of Upper and Lower Prosthetic Legs

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Abstract— This works present the design of an energy harvesting system using smart materials for self power generation of upper and lower prosthetic legs. The smart materials like Piezo-Composites, Piezo Flexible Film, Macro Fiber Composites, and PZT have been employed and modified to be appropriately embedded in the prosthesis. The movements of the prosthesis would extract and transfer energy directly from the piezoelectric via a converter to a power management system. Afterward, the power management system manages and accumulates the generated electrical energy to be sufficient for later powering electronic components of the prosthesis. Here we show our preliminary experimental results of energy harvesting and efficiency in peak piezoelectric voltages during step up and continuous walking for a period of time.

Keywords; Piezoceramic, Prosthesis, MFC, Energy Harvesting, Foot Prosthesis

I. INTRODUCTION

Energy harvesting transform natural energy sources into usable electrical energy, for example, solar energy, thermal energy, wind and vibration energy, etc. This technology is very attractive for low power electronic devices which include medical devices, smart implants, camera imaging inside the human body and hearing aid devices.

One of the most interesting sources for energy harvesting is environmental vibrations. The devices that have been used are piezoelectric, electromagnetic, electrostatic, pyroelectric, photovoltaic and thermoelectric. The conversion of harvesting energy is very good in scalability, capability, high energy density and compatible with standard electronic technology. In addition, the piezoelectric could be coupled to a mechanism to perform opening of the contacts in the switching devices [1,2].

The green energy harvesting here will emphasis use of piezoelectric devices in Prosthetic legs. Geometric parameters, beam, mass and resistive electric loads significantly influence the output power [3]. The piezoelectric CMOS harvesting could bypass the input voltage. Invest and recover some energy to increase the energy during negative piezoelectric voltage [4].

II. PIEZOCERAMIC ENERGY HARVESTING

A. *Piezoelectric PZT*

The smart material used for energy harvesting is piezoelectric PZT (Lead Zirconate Titanate) as shown in Figure 1. This piezoelectric PZT comprises two arms formed from a single metal substrate and two piezo-ceramic plates [2]. The first arm of the piezoelectric produces a downward movement which provides an angle for the movement amplification of the second arm as shown in Figure 2.

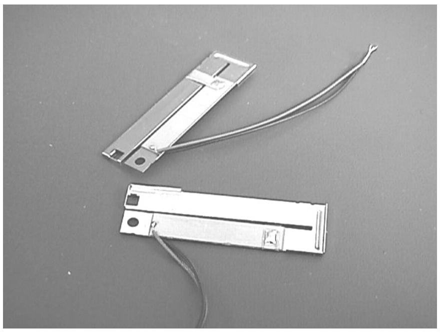

Figure 1: Piezoelectric PZT

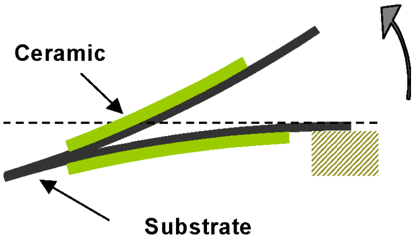

Figure 2: Diagram of the PZT piezoelectric

The advantage of the planar bimorph structure is that it forms an effective pivot point approximately half way along the length of the Piezoelectric [5] as shown in Figure 3. This would help to produce significant amount of power generated from piezoelectric.

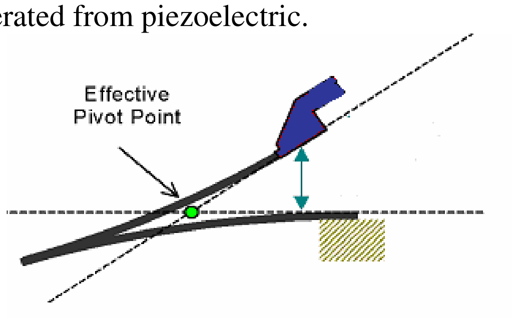

Figure 3: The effective pivot point

B. *The Macro Fiber Composite (MFC)*

The MFC consists of rectangular piezo ceramic rods sandwiched between layers of adhesive and electrode polyimide film. This film contains interdigitated electrodes that transfer the applied voltage directly to and from the ribbon shaped rods [6]. As a thin, surface conformable sheet it can be applied, normally soldered to various types of structures or embedded in a composite structure. The structure of MFC piezoceramic. The interdigitated electride pattern on polyimide film on both and bottom permits in plane polling of piezoceramic d_{33} (elongator mode) versus d_{31} (contractor mode) advantage. In addition, the structure epoxy inhibits crack propagation in ceramic bonds components together.

C. *Energy Harvesting System*

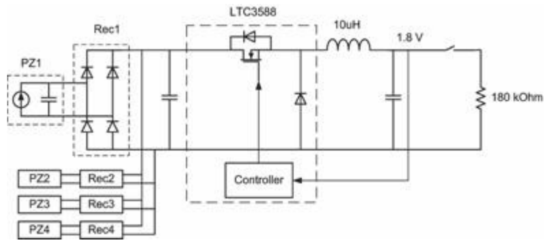

Figure 4: PZT Energy harvesting circuit diagram

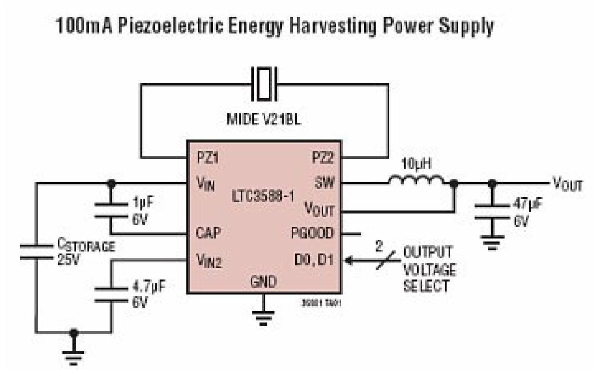

Figure 5: MFC Energy harvesting circuit diagram

The circuit diagram for converting kinetic energy from the movement of the prosthetic legs and foot prosthesis to electrical energy is shown in Figure 4 and 5, respectively. The movement of the prosthetic legs and the foot prosthesis would generate energy directly from PZT and MFC piezoelectric. The integrated low loss full wave bridge rectifier with a high efficiency buck converter was designed to connect directly to PZT and MFC piezoelectric.

III. Experimental Methods

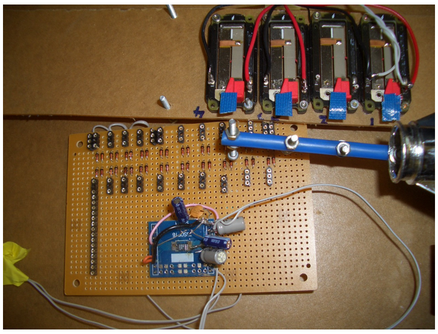

Figure 6: PZT piezoelectric setup

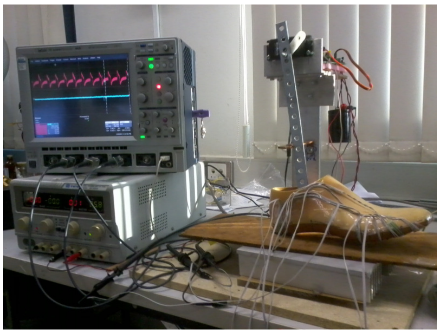

Figure 7: Experimental equipments

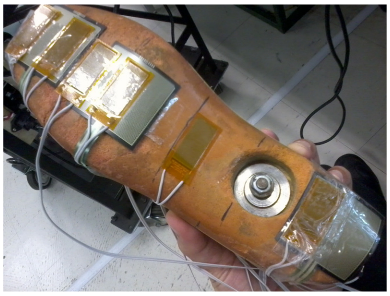

Figure 8: MFC installing in the prosthesis foot

Figure 6 shows the details of the experimental equipment, 4 sets of PZT piezoelectric were used to harvesting energy in the upper prosthetic legs. The platform used to hold a prosthesis foot as shown in Figure 7. This can travel in both of the direction of horizontal and vertical. The angle of foot prosthesis is able to set up the moving from 0 degree to 135 degree. There are 6 sets of MFC Piezoelectric were installed underneath the prosthesis foot. This would use to harvesting power out from the lower prosthetic legs. The 1st position of piezoelectric was at the foot sole as shown in Figure 8.

IV. Reults and Discussion

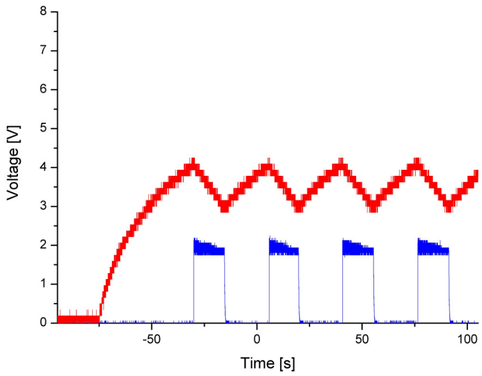

Figure 9: The voltage and current of the PZT

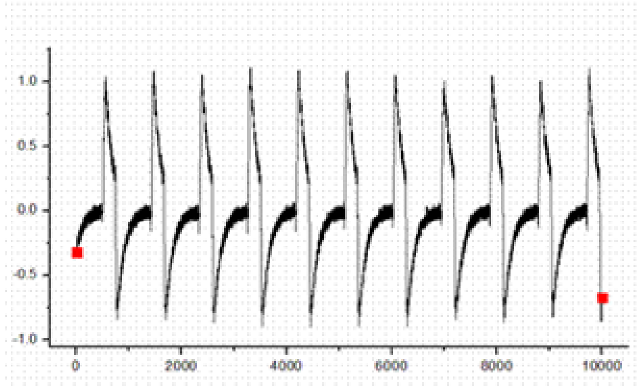

Figure 10: Typical waveform of MFC

The experimental results from the PZT energy harvesting as shown in the Figure 9, the peak voltage at capacitor is approximately 4 volts and the current out is approximately 2 A. The peak power is approximately 88.8 μW. which is more than 80% higher than D. Kwon et al [4] but lower than [3] by 76%. Figure 10 shows the typical waveform of MFC piezoelectric energy harvesting which installed underneath the prosthesis foot. The maximum voltage is approximately 1 volts when the foot sole reach the ground. The maximum of the peak voltage, as shown in Figure 11, is about 1.8 Volts and maximum peak power is about 12.5 µW. at the 1st MFC piezoelectric location.

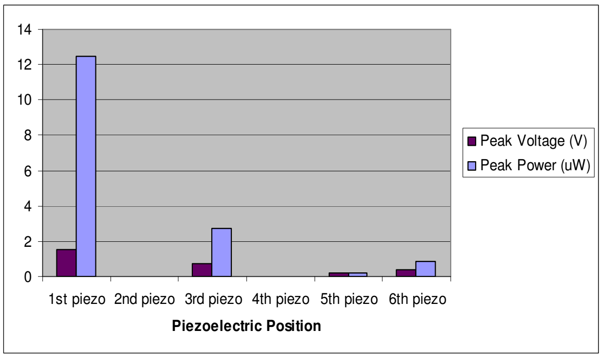

Figure 11: Peak voltage and peak power at 6 MFC locations

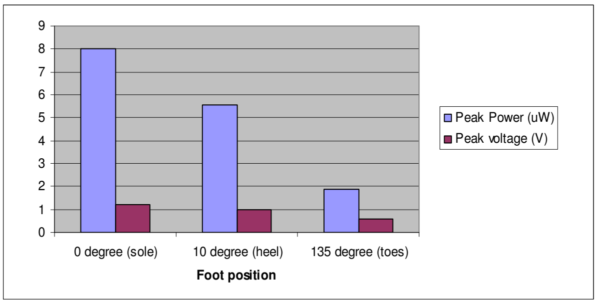

Figure 12: Peak voltage and peak power at prosthesis foot positions

Figure 12 show the highest energy harvesting when the foot sole reach the ground, the maximum of the peak voltage is about 1.2 Volts and the maximum peak power is about 8 µW.

V. CONCLUSION

Generating energy from human body vibration is one of the current challenges. In this work, the maximum peak power and peak voltage energy harvesting from PZT piezoelectric generated is much higher than MFC piezoelectric. This shows that the upper leg could generate power more than the lower leg at prosthesis foot. This shows the same results as [7]. The degrees of walking [8] also have an effect on the power output. In addition, the prosthesis foot position produces the most energy when the foot sole reach the ground. However, there needs more study and experiments in the load resistor, piezoelectric type and shape, etc in order to gain more energy harvesting from prosthetic legs.

ACKNOWLEDGMENT

The authors would like acknowledge the financial support from the NSTDA (Thailand), ATPER (Europe), EEDA (UK), BCCN (Germany) for research funding, We would like to thank K. Carpenter, CEO from Rehabilitation Research Institute (RRI), Seattle, WA, USA for donate the prosthetic legs.

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