Abstract

Implantable biomedical devices improve chronic disease patients' quality of life. These systems require constant power, feeding and this turns out into a frequent battery replacement surgeries, raising patient risks and healthcare expenses. In this context, piezoelectric vibration energy harvesting (PVEH) seems as a promising approach for capturing and converting biological vibration mechanical energy to extend battery life for pacemakers especially for pediatric application. New piezoelectric energy harvesters are being developed to recharge pacemaker batteries using heartbeat energy and decrease the need for recurring surgery. This Ph.D. research designs, optimizes, and validates a piezoelectric vibrational energy harvester to convert heart vibration into electrical energy and operate the pacemaker. The system was developed to create electrical energy from heartbeat mechanical stress and to be located on the heart's exterior surface. To meet European RoHS (Restriction of Hazardous Substances) laws and assure patient safety, biocompatible and nontoxic materials were used instead of lead-based piezoelectric devices. In that sense the product looks sustainable and compliant with the green and blue economy currently developed to face problems of eco-mourning. Project development included system modeling, prototype fabrication, and experimental validation to meet those goals. COMSOL ® Multiphysics was used to create two electromechanical models to find the best energy conversion configuration. The initial model had trapezoidal cantilevers radially arranged in a circular frame with test masses on their free ends. The shape had to be changed since computer analyses showed resonance frequencies too high for the application. Thus, a second model with spiral arms and a shared core mass was created to lower resonance frequency and increase structural flexibility for heart vibration situations. Next, the device was prototyped using additive manufacturing for the substrate and micromachining for piezoelectric film deposition and shaping. Materials were selected for biocompatibility, sustainability, and electromechanical performance. PA12 (Nylon), a biocompatible and flexible polymer, was employed for the substrate, even according to indications available in the medical surgical literature, and PVDF , lead-free and environmentally compliant, were used for the piezoelectric film. The fabrication phase includes electrical integration, using silver-based conductive paints to connect the electrical terminals for steady conduction without reducing device flexibility as already applied and used in some other applications as space. The prototype was experimentally validated to ensure its proper operation. Dynamic testing measured frequency response (FRF), modal analysis determined resonant frequencies, and power production tests in open circuit and with electrical load. The system also included an energy management circuit, with a diode bridge and storage capacity to maximize energy conversion and electrical charge storage. LTspice XVII® software was used to simulate the system behaviour and determined the best approach to voltage management and energy storage of the piezoelectric device to cover the energy flow of the pacemaker battery.

The results suggest that the system can generate enough energy to extend pacemaker battery life by several years, minimizing the need for replacement surgery. Experimental validation showed the system's consistent energy output and good conversion efficiency under actual vibrating settings. However, the device's long-term reliability and integration with commercial pacemakers need further study and clinical trials, i.e. a complete activity of industrial engineering especially to refine and automatize the manufacturing process. This research showed that a compact, biocompatible, and environmentally compliant green piezoelectric energy harvester for pediatric biomedical applications is possible. A major advance in biological energy harvesters, the technology could lead to applications in additional implanted devices and autonomous sensor powering. Environmentally friendly materials and innovative manufacturing methods demonstrate the need of technological innovation in developing alternative energy options for future medicine.