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SURGICALLY IMPLANTED ENERGY HARVESTING DEVICES FOR RENEWABLE POWER SOURCES IN INSECT CYBORGS

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ABSTRACT

This work details the implantation process of an energy harvester platform within a *Manduca sexta* Hawkmoth for the purpose of creating a cyborg insect. Also included is an evaluation of energy harvesting with respect to present lightweight battery technology and the magnitudes of ambient energy available for the cyborg insect application. Specific emphasis is given to kinetic energy harvester development, with theory and fabrication of the devices detailed.

INTRODUCTION

Recent advancements within biocompatible systems have turned towards renewable energy storage devices to prolong the lifespan of implants. The reason for the push away from primary battery operated systems is clear; technological advancements have made great strides in minimizing the power consumption of in-vivo devices, while development within battery technology has not been able to meet their long-endurance demands.

An energy solution that we present in this work is to scavenge ambient energy from the local environment to recharge the implant's power source. Typical types of available energy are in the form of thermal energy, solar energy, kinetic energy from motion, etc. In this work, the kinetic energy harvesting is explored using external transducers, such as piezoelectric bimorph designs, that are connected to the implanted device. To prove the viability of such systems, these devices are attached to biocompatible implants inserted within *Manduca sexta* Hawkmoths, whose flight pattern is similar to that of hummingbirds. The motion of the flight is partially utilized for transferred kinetic energy to electrical energy by inducing a stress or strain on the transducer elements. While the magnitude of the oscillation during the flight is small, the frequency is quite large, approximately 24-26 Hertz. Thus, since power is proportional to the square of the amplitude and the cube of the frequency, the power available from flight is substantial to intermittently supply energy to the implant itself for recharging purposes, proving its functionality as a renewable energy source.

The primary focus of this paper is the extended study of biocompatible materials for *Manduca sexta* implants over previous studies performed [1-3], the explanation of the procedure for implantation along with an evaluation of its influence on the biological system, and the structural design for attachment and optimal performance of the kinetic energy harvesters.

The application of this research is to create long endurance remote power systems using ambient energy as a means for a renewable energy source. This is part of a larger program, whose aim is to create flying insect cyborgs, which have up to one gram implanted systems onboard consisting of sensors, actuators, and energy harvesting devices. These devices are embedded into the cyborg insects to not only provide sensory suites for telemetry, but also to control or aid physiological processes such as flight direction, on/off control, etc. in order to manipulate their actions. In designing these types of systems, the mass and power consumption of these systems are critical factors in order to enable and observe/control flight. In addtion to these critical design considerations, available onboard energy remains a difficut task due to the lifespan in which these cyborg insects live as adults, from a few weeks to a few months. Thus, our focus has been on developing biocompatible implantable systems with high specific, yet renewable, energy, or renewable ambient energy transducers, to allow endurance functionality of the onboard cyborg devices. The findings of this research extend past our application to a wide variety of implants using ambient energy as a solution for extending functionality of any electronic implant, or remote access, device.

NOMENCLATURE

A_{p1} = Transformed piezoelectric 1's cross-sectional area
A_{p2} = Transformed piezoelectric 2's cross-sectional area
A_{ss} = Support structure cross-sectional area
E_d= Mass specific energy density