PROJECT DESCRIPTION

Title: *Mechanical Energy Scavenging From Flying Insects*

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Funding Source: DARPA

Project Goals:

As ultra-low-power circuits and microsystems develop, conventional batteries used for these systems could be replaced with smaller-sized and longer-lifetime candidates. In this sense, energy harvesters hold great advantages such as unlimited lifetime, and no need for recharging or power cables. Mechanical energy harvesters are especially useful for environments that are exposed to external vibration and forces, like the wing of an insect. The goal of this research is to develop an efficient microscale power generator that harvests energy of >50μW within a volume of <0.01cc and a weight of <0.2g from live beetles as a part of the DARPA HI-MEMS (Hybrid Insect) Project. This small-energy scavenger could be used in a number of other WIMS applications.

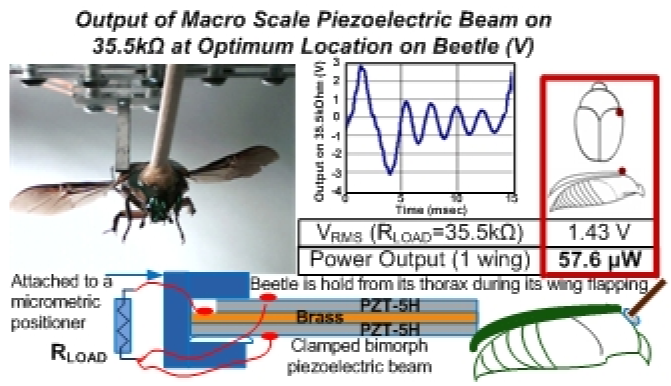

Figure 1: Setup used to find optimum location for energy scavenging, and measurement of available power during beetle's tethered flight.

Approach and Methodology:

A mechanical generator to be mounted on a hybrid insect is powered by a direct force input, so it can occupy small volume and be efficient in mechanical-to-electrical energy conversion at the same time. Piezoelectric energy conversion is the preferred method for power generation, as it enables light-weight designs, and relatively easier fabrication.

Experimental measurements on the specific beetle species showed that maximum-power generation, which is directly proportional to (Frequency × Force × Deflection) input, can be obtained from the wing base of the beetle, where the force input is considerably large and the vibration is at high frequency. Surely, a generator mounted at this location needs to be optimized for minimum disturbance of beetle’s free flight. Thus, spiral beam geometry is employed to maintain a low spring constant in a limited volume for minimum force requirement from the beetle, and to keep stress on the beam below yield point of the material while accommodating large input deflection from the wing. Asynchronous wing muscle of the subject beetle (Cotinis nitida) can provide up to 900mN [1], which means a direct connection to the muscle can scale up the power output by 10 times.

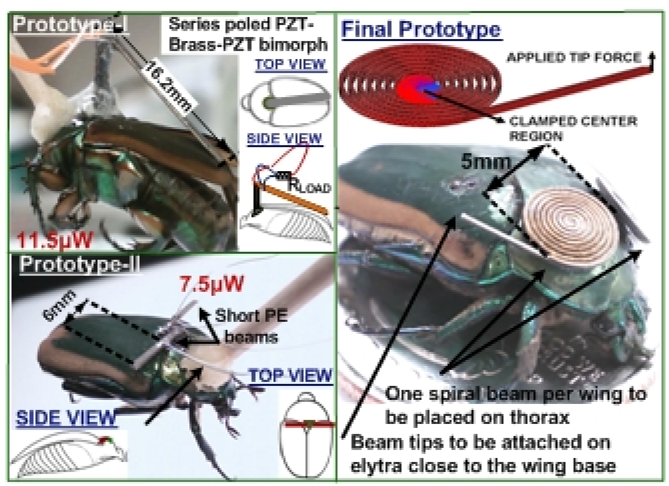

Figure 2: Initial prototypes mounted on beetle with measured power outputs, and final prototype design.

Role in Supporting the Strategic Plan and Testbeds:

The technologies being developed in this project will directly support several other projects in the ERC, enabling future self-powered wireless microsystem designs. Developed design and fabrication methodology for piezoelectric generators will form a significant basis, and ease implementation of future unique generators for many other applications.

Results and Accomplishments:

An analytical model is developed for conventional piezoelectric generators and frequency-increased piezoelectric generators. Available vibration power, deflection, and force measurements are done on the subject beetle to determine the optimum placement of the device for maximum-power generation, and it is shown that vibration of elytra close to the asynchronous wing muscle base can generate up to 57.6μW per wing (Figure 1).

Initial prototypes of the piezoelectric generator (Figure 2) are mounted on live beetles, and 11.5μW and 7.5μW electrical power is harvested in 11mm^3 and 5.6mm^3 device volumes, respectively [2]. A final generator prototype (Figure 2) is designed by utilizing spiral beam geometry to achieve lower-spring constant in a constrained volume (~7mm^3). FEA simulations predict ed >25μW for a single device, which is actuated with 30mN input force from the wing cover, the measured available force from previous prototypes. In order to fabricate the proposed design, femtosecond laser micromachining of piezoelectric materials is studied, and characterized for low damage profile. Fabricated spiral generators are tested by using a piezoelectric actuator imitating a beetle's wing stroke, and 22.5μW is delivered on a resistive load. Two prototypes placed on a beetle suggests >45μW power output.

Plans for the Coming Year:

The final prototype will be mounted on a live beetle, and tested during its untethered flight. The proposed piezoelectric generator design and developed fabrication technology will be adapted to a new design for energy scavenging from ambient vibration.

Expected Milestones and Dates:

- Technology development, fabrication, and bench testing of final prototype *(Completed)*
- Mounting fabricated devices on live beetles, and testing during tethered flight (11/30/2009)
- Fabrication and bench-testing of a prototype for large-sized beetles (Giant Flower Beetles) (12/30/2009)

Expected Contributions, Deliverables, and Company Benefits:

- Prototype development of design and fabrication technology for piezoelectric energy harvesters
- Integration of bulk piezoelectric materials into MEMS devices
- Adaptation of the proposed design to harvest energy from ambient vibration

References and Recent Publications:

1. G. N. Askew and R. L. Marsh, "Review Muscle Designed for Maximum Short-Term Power Output: Quail Flight Muscle," *The Journal of Experimental Biology 205*, pp. 2153–2160, 2002.
2. E. E. Aktakka, H. Kim, M. Atashbar, and K. Najafi, "Mechanical Energy Scavenging From Flying Insects," *Solid-State Sensors, Actuators, and Microsystems Workshop (Hilton Head 2008),* Hilton Head, SC, pp. 382–383, June 2008.