A Feasibility Study of a Ferrofluid Derived Cardiac Energy Harvester for Micro-Pacemaker Devices

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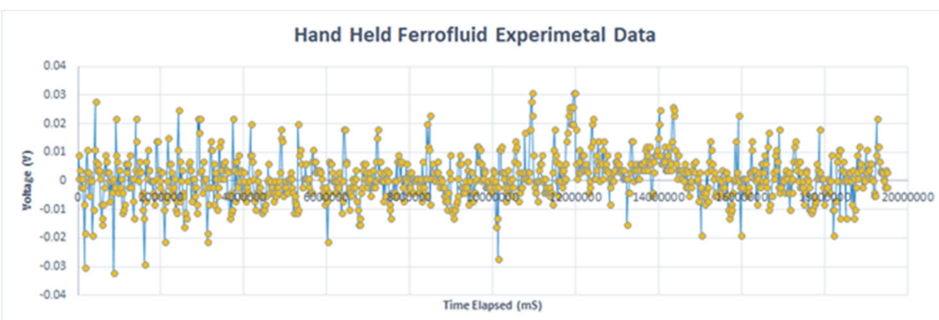
Introduction: Pacemakers have evolved in recent years to become small enough to fit inside the ventricle cavities of the heart. This decrease in size, however, brings a significant reduction in battery capacity, i.e., from a typical 10-year battery life to as few as 5 years [1]. The present undergraduate team has designed and prototyped a novel device to address this issue using the basic concepts of dynamic pressure and electromagnetic induction to harvest the hemodynamic energy within the left ventricle.

Materials and Methods: This team completed benchtop and finite element experiments using both solid core and ferrofluidic magnets to prove our device's feasibility. In the benchtop conditions, a robotic arm oscillated the solid core magnet at a rate of 1 Hz through a copper coil as a proof-of-concept test to prove a magnetized ferrofluid through a coil can produce significant voltage. The device included, EHF1 ferrofluid of 400 gauss strength, two magnetic caps, made of 3 N42 (2455.1 Gauss) and 3 N52 (3627.4 Gauss), were placed to provide a permanent magnetic field to stimulate the ferrofluid. The electrical coil used included a 160 turns , 3/4" outer diameter and 1/2" inner diameter being 8.3 cm long with a 20 AWG wire size. In addition, finite element analysis studies were performed to analyze the mechanics of using pressure to move the ferrofluid as well as the oscillatory motion of a magnetized core in an induction coil.

Results and Discussion: Two trials were executed, one with a solid core magnet (to ensure validity of the system) and one with the experimental ferrofluid. With the first test proving successful at a large scale, we moved to demonstrating the product by replacing the solid core magnets with ferrofluid. Results are demonstrated below to show the integrity of the study and the possibility to simulate the experimental conditions. Notable is the ~4 mV output which correlates to the 6 mV, before 10x amplification, output of the experimental study.



Lastly, this team conducted a finite element analysis of the benchtop tests using a 2D axisymmetric COMSOL FEA. With finite element simulation aligning with benchtop results at a 4mV maximal output voltage this team looks forward to utilizing this tool for further configuration studies

Figure 1: Coil voltage found during preliminary oscillatory ferrofluidic core experiment. Peak voltages noted were ~4 mV

Conclusions: This team has taken the concept of a ferrofluid energy harvester and proven its feasibility in hand calculations, finite element analysis studies, and experimental studies to provide the necessary 10 μW to recharge micro left ventricular pacemakers. Specifically, hand calculations showed a minimal 5 mV necessary to induce the 10 μW needed for a functional energy harvester. Finite element studies showed a 4 m V output correlating to the 6 mV output from the experimental ferrofluid studies. These numbers translated to approximately 7.2 μW. Furthermore, we have invested into the manufacturing design of the device and showing its feasibility to be made.

References: [1]Skevos Sideris, et al, *Leadless Cardiac Pacemakers: Current status of a modern approach in pacing, Hellenic Journal of Cardiology*, Volume 58, Issue 6, 2017, Pages 403-410, ISSN 1109-9666