Energy Harvesters: A Novel Approach to Leadless Pacemaker Battery Life

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ABSTRACT

One of the most crucial limiting factors of modern leadless pacemakers today is their battery life. Due to size constraints, their current battery life is around 9 years, forcing countless patients to undergo multiple replacement procedures throughout their lives. [1]

Our proposed device aims to house the pacemaker within a stent and utilize the deformations on the stent via expansion and contraction of the heart to recharge the pacemaker, increasing its lifespan to 15 years. We would generate small voltages via electromagnetic induction, then amplify these signals and feed them back to the battery.

Our team has created electromagnetic field simulations for induction as well as mechanical simulations to test the fatigue characteristics of various stent designs. With our benchtop mechanical test setup, we can confirm these findings. The overall functionality of the device will be confirmed with a 3x scaled prototype.

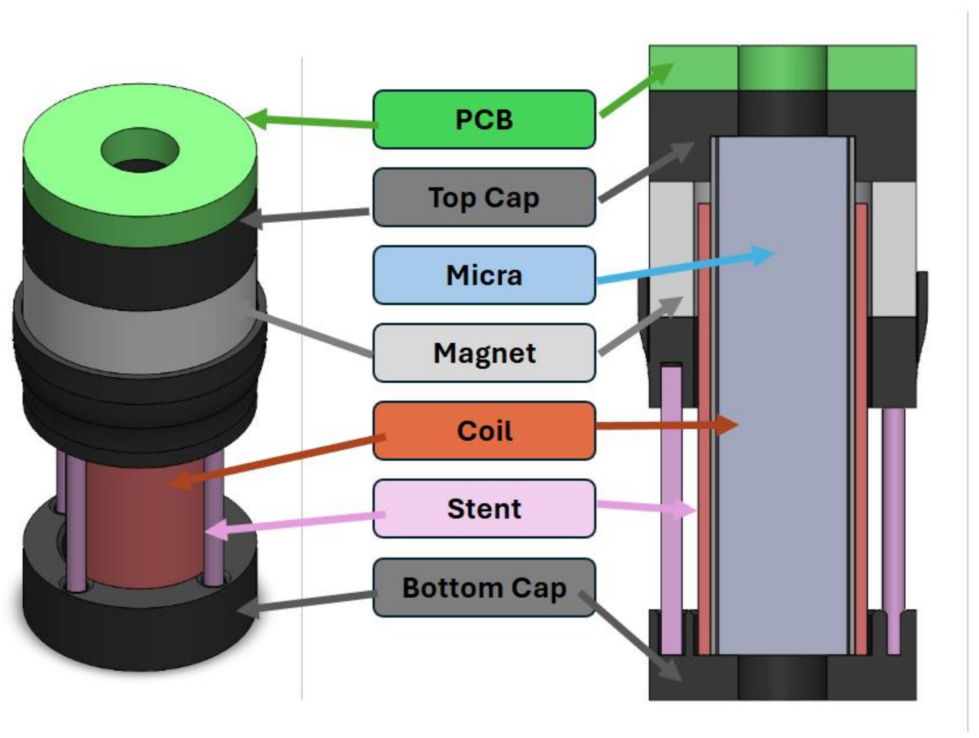


Figure 1. Overall schematic of Rechargeable Pacemaker

OBJECTIVES

- Perform simulations that test stent expansion and compression in order to determine ideal fatigue properties of various stent designs
- Execute fatigue analysis on the stent designs to understand structural integrity of design
- Design an amplifier circuit capable of strengthening a millivolt-scale AC signal to a DC signal at a voltage high enough to charge a pacemaker battery.
- Manufacture a prototype that demonstrates the compatibility of the stent, magnet, and electrical system.

METHODS & MATERIALS

Circuit designs were created with KiCAD and tested with physical components and LTSpice. To simulate the induced voltage signal, we are using a function generator. Readings are taken by an oscilloscope at various nodes of the circuit.

Figure 2. Amplifying Circuit KiCAD Schematic

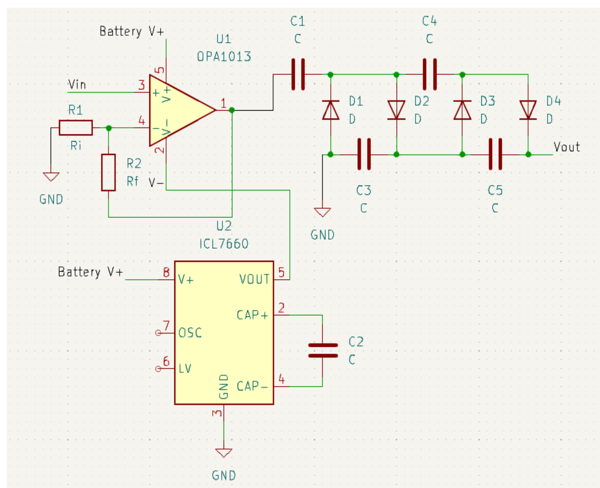
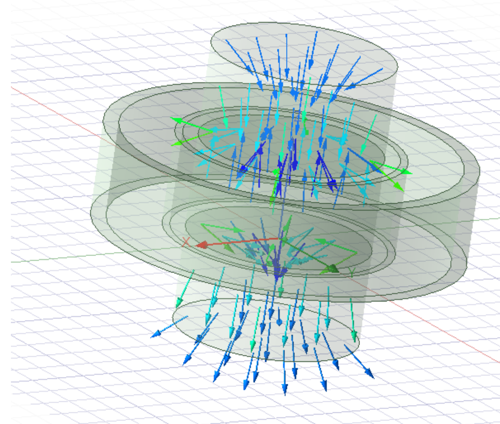


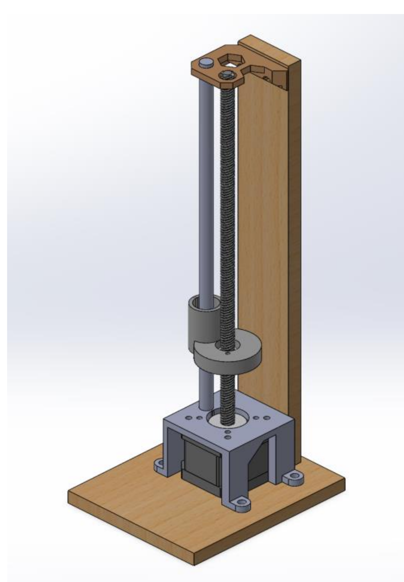
Figure 3. Magnetic Field Simulation



To further investigate induced voltage, we are using ANSYS Maxwell. Neodymium ring magnet models are created and a circular surface (loop of wire) moves in between them. A parametric study is utilized which calculates how the voltage changes as the loop moves from bottom to top.

We utilize 3D printers to manufacture fixtures and stents for benchtop testing along with the caps and stent for the prototype. Our ANYCUBIC Mega X printer has been the primary printer for both benchtop and prototype prints.

Figure 4. Benchtop CAD demonstrating parts to be printed



The ANYCUBIC takes both PLA and TPU filament materials. PLA is used to print fixtures and caps. TPU is used exclusively for stents due to its flexible nature.

Fall Quarter stent:

- Printed vertically
- Brittle
- Poor print quality

Winter Quarter stent:

- Cylindrical pillars
- Less brittle
- Better print quality

Figure 5. TPU stent from fall quarter

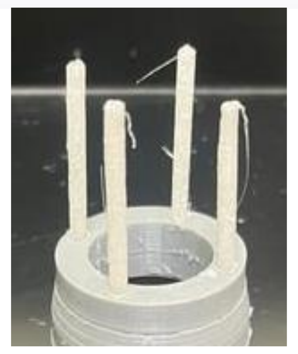


Figure 6. TPU stent "cylinders" from winter quarter

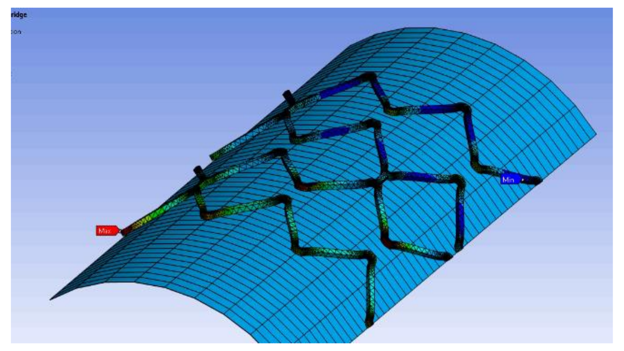


Figure 5. Radial stress gradient of a quarter stent model expanded by 3mm

ANSYS Workbench is used to create an expansion and crimping test via static structural simulations. A two-step simulation setup is used to combine expansion and crimping processes into a single testing cell. [2]

RESULTS

The amplifier circuit was tested with physical components and achieved an output of 20V DC. The input voltage was a 10 Hz sine wave with peak-to-peak amplitude of 10 mV. The +/- output ports of a triple output DC power supply at approximately 9V emulated the pacemaker battery and voltage inverter component.

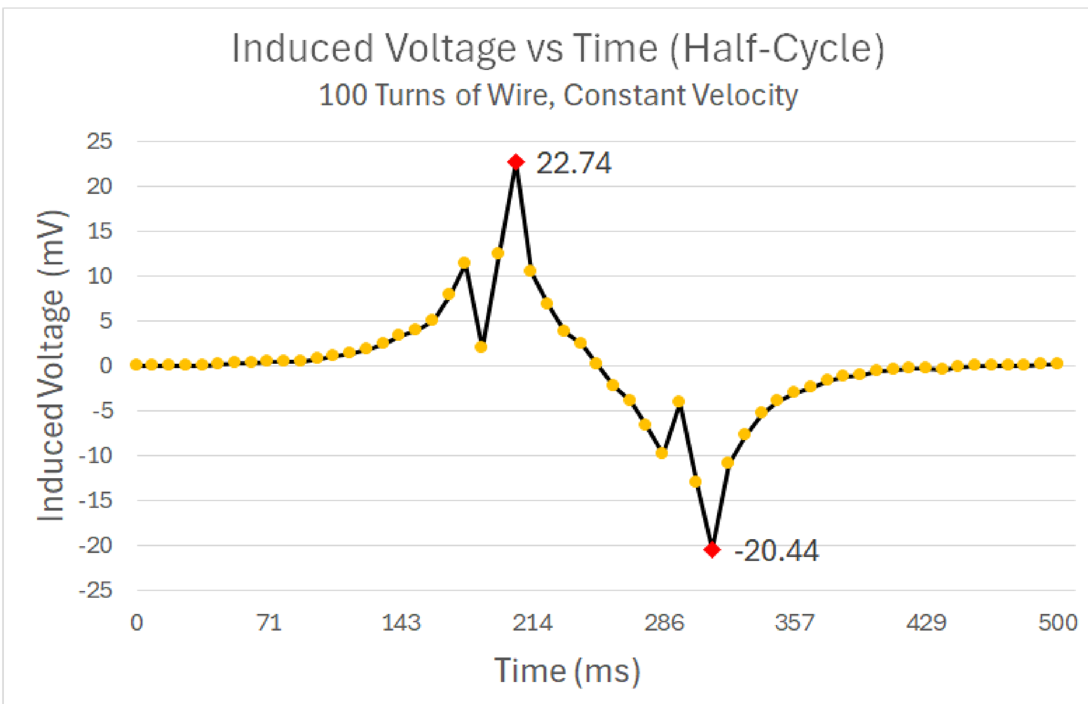


Figure 7. Induced voltage over 500 milliseconds (half of the cardiac cycle) with 100 loops of wire

- Electromagnetic simulations yielded a peak-to-peak voltage of approximately 43 millivolts, assuming 100 turns of wire in the coil.
- Many different variables affect the magnitude of the induced voltage including magnet height and thickness, wire loop displacement, and field polarization.
- Development of our expansion & crimping simulations test allows for initial stent design verification.
- High level test compared Ring & Bridge versus Unit Cell stents. The U-Ring and V-Ring stents were successfully expanded and produce similar principle stress values, which was expected. The Reentrant Auxetic unit cell stent failed the test, despite attempts to recut the stent.

Design	Max Deformation (mm)	Max deformation (mm)	Percent Deformation	Min Stress (MPa)	Max Stress (MPa)	Min Strain	Max Strain	Result
V Bridge	2.956	3.1049	100%	2.0965	837.18	0	0.237	Success
U Bridge	2.976	3.1006	100%	1.5257	846.17	0	0.24133	Success
Chiral	0.064433	1.618	53.93%	0.0048202	4649.9	0	3.9699	Failure
Recut Chiral	0.067215	2.9126	97.09%	0.00095707	3346.6	0	2.7336	Failure

Figure 8. Data Table depicting the Deformation, Stress, and Strain Results of an Expansion test on various ring & bridge and unit cell stent designs

The completion of the simulation test also opens the door for exploring stent fatigue capabilities. The life test indicates how many cycles the stent can withstand before failure. Running this test indicates that the V-Ring stent can endure one million cycles of expansion and crimping before failure.

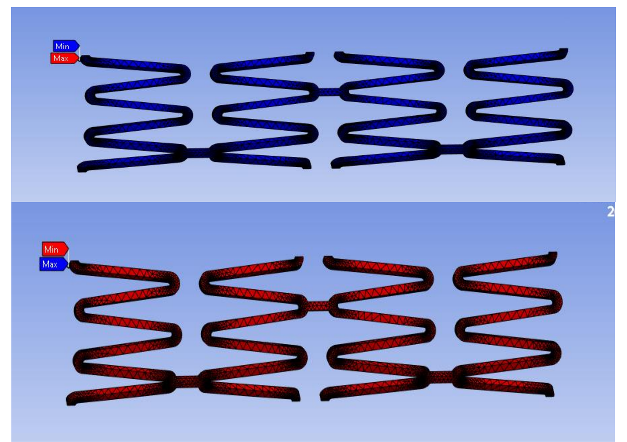


Figure 9. Stainless steel stent has Life factor of 10e8

CONCLUSIONS & FUTURE

Conclusions

ANSYS Maxwell simulations have yielded promising results, accompanied by our design of a high gain amplifier circuit. Additionally, we have created our own modified expansion and crimping test in ANSYS Workbench specifically for testing stent fatigue. A working prototype at 3X scale has been produced alongside a benchtop fatigue tool jig.

Future Directions

We will further verify our ANSYS simulations through stent fatigue tests and magnetic field tests. Stent fatigue can be tested via our mechanical setup. Different magnetic field polarizations can be tested which may demonstrate exhibit greater voltage generation. Power efficiency of our circuit will be investigated through benchtop tests.

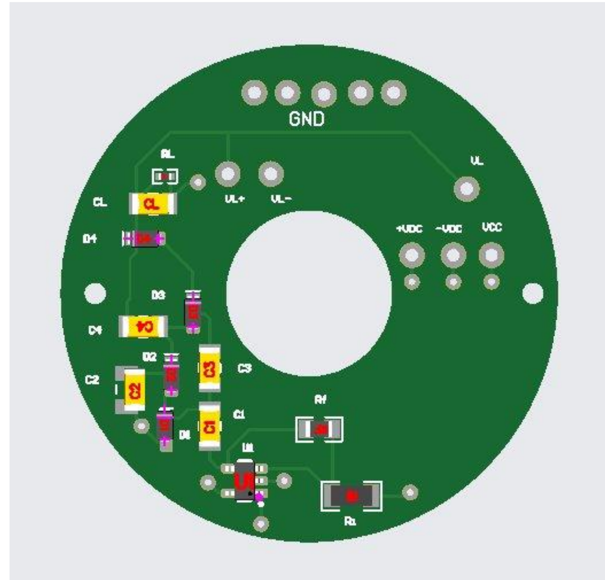


Figure 9: Our Current PCB Schematic

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