Building and Characterizing a Ferromagnetic Electrosurgical Pencil

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ABSTRACT

Monopolar electrosurgical pencils cut and coagulate tissue by delivering current from an active electrode, through the patient, and into a dispersive pad placed on the upper thigh. This modality generates an electric field, interfering with implanted medical devices and risking thermal injury at the exit site [1]. This project explores using ferromagnetism as an alternative energy modality to monopolar devices. Ferromagnetism sends a radio-frequency alternating current through a ferromagnetic material to maintain a stabilized temperature called the Curie point, delivering pure heat to the surgical site while maintaining electrical silence [2].

INTRODUCTION

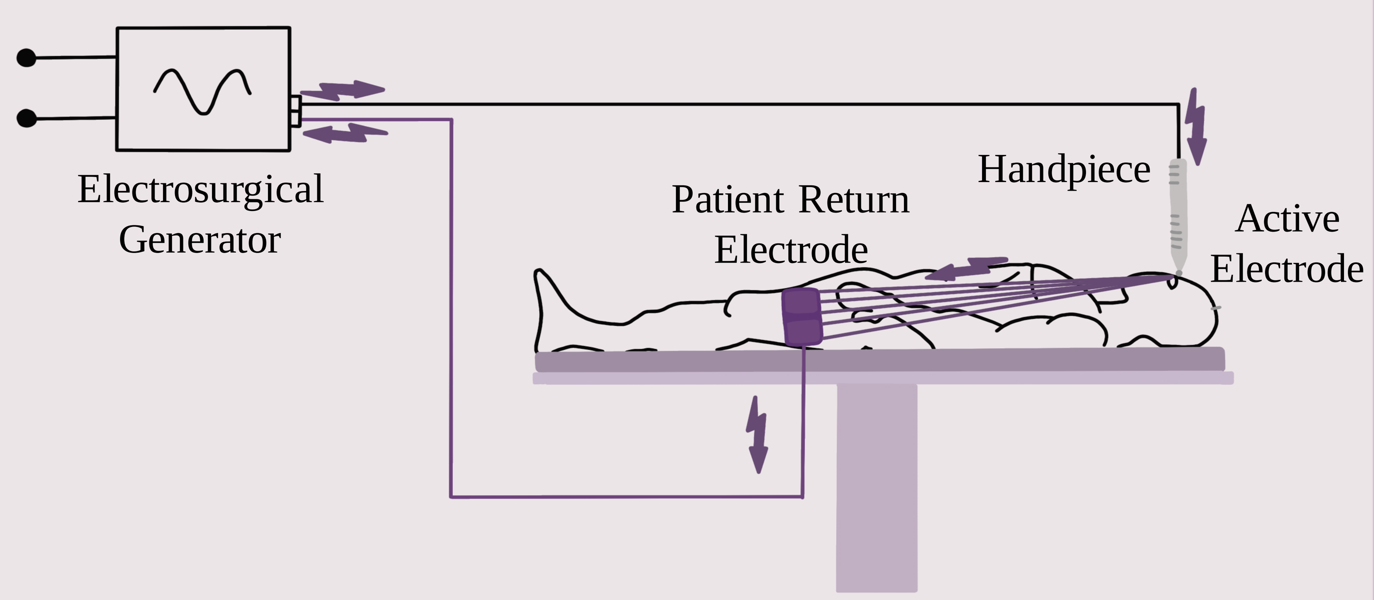

Figure 1. System Diagram of Monopolar Electrosurgical Pencil

Electrosurgical pencils use an active electrode and return electrode pad to cut (200 - 400 °C) and cauterize (60 - 80 °C) tissue to maintain hemostasis [3]. The generator sends a current through the patient from the monopolar active electrode, interfering with implanted devices.

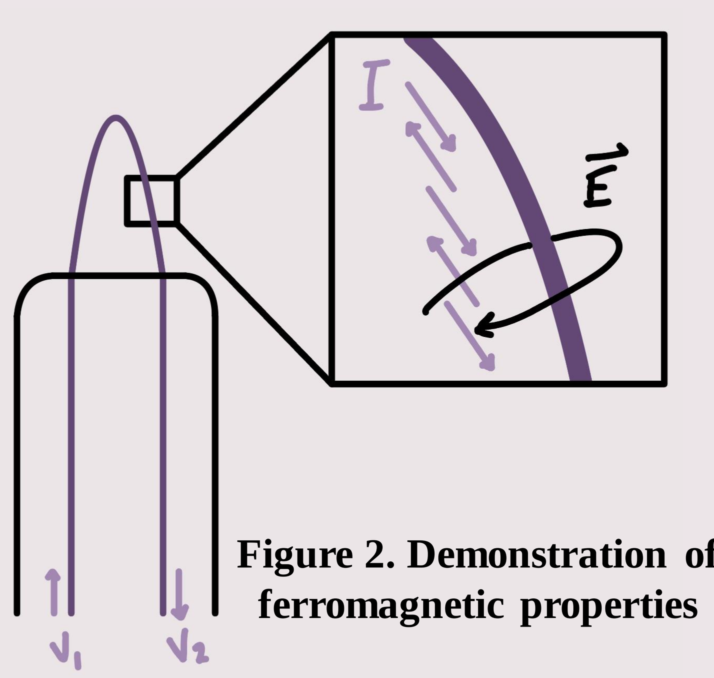

Figure 2. Demonstration of ferromagnetic properties

Ferromagnetic energy uses a radio-frequency alternating current coupled with a ferromagnetic material to operate at the specific Curie temperature, and unlike monopolar, does not require a return electrode [2]. At the Curie point, the material transitions from ferromagnetic to paramagnetic and the temperature stabilizes within seconds.

Using a high-frequency alternating current through the ferromagnetic material creates a real resistance and reactive impedance that opposes the direction of the generated current. An impedance-matching circuit creates a conjugate impedance to maximize the power delivery and minimize reflected power.

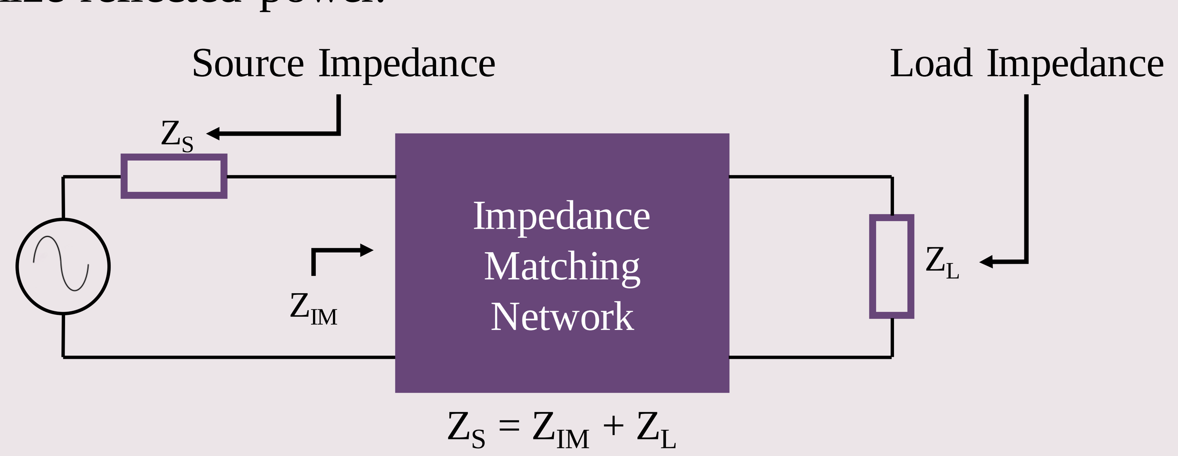

Figure 3. General Impedance Matching Circuit

METHODS

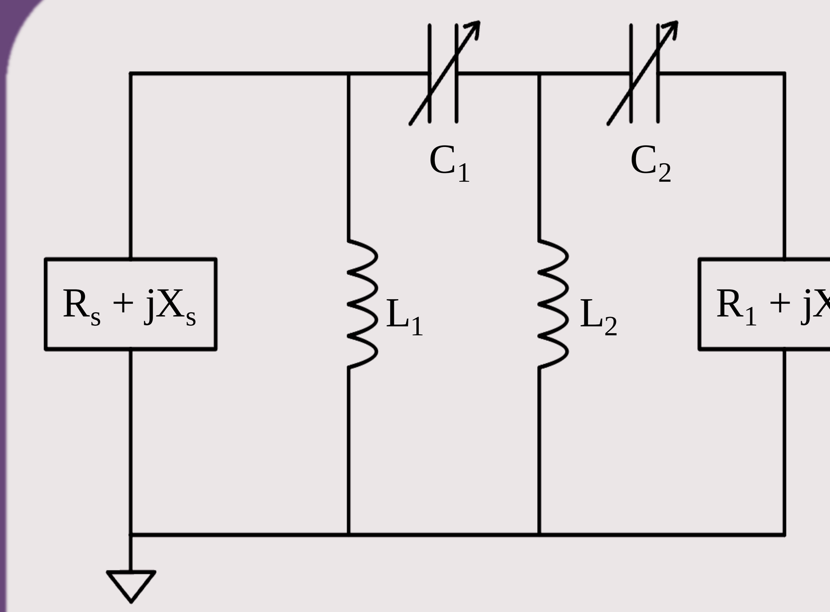

Figure 4. Load Testing Circuit Schematic

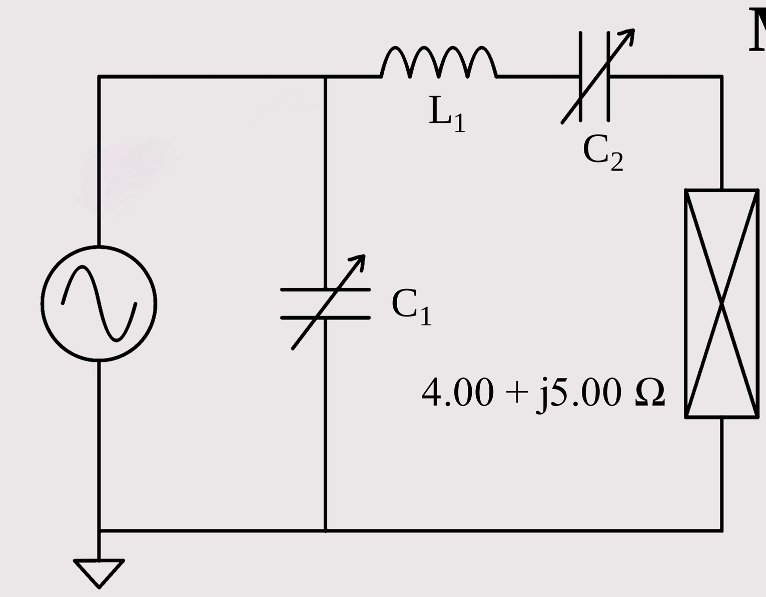

Figure 5. Final Testing Circuit Schematic

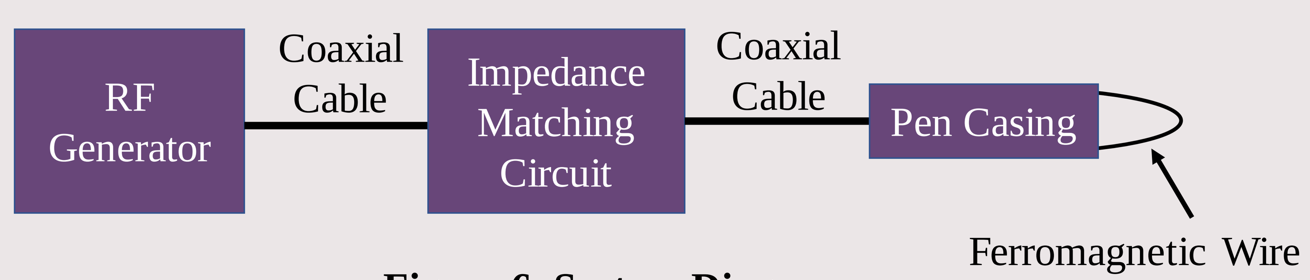

Figure 6. System Diagram

Must deliver between 10 and 25 Watts of power to the ferromagnetic wire with a Voltage Standing Wave Ratio (VSWR) of less than or equal to 1.5 Watts at 10 MHz to reach and maintain the Curie point.

- Estimate the impedance of the Anomet A52 wire to get a range of values needed for impedance matching
- Design and simulate different impedance matching circuits using LTSpice
- Test the designed impedance matching circuits by implementing adjustable capacitors
  - Match the circuit such that the reflected power is less than 1W
- Perform preliminary tests in reflected power by submerging the ferromagnetic wire in a saltwater bath
- Redesign circuits and repeat tests

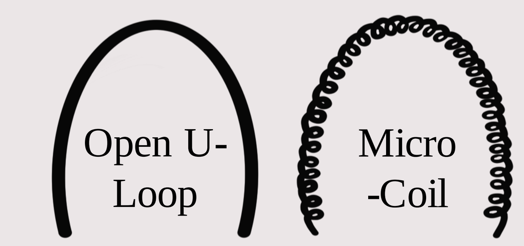

Figure 7. Loop Configurations

RESULTS

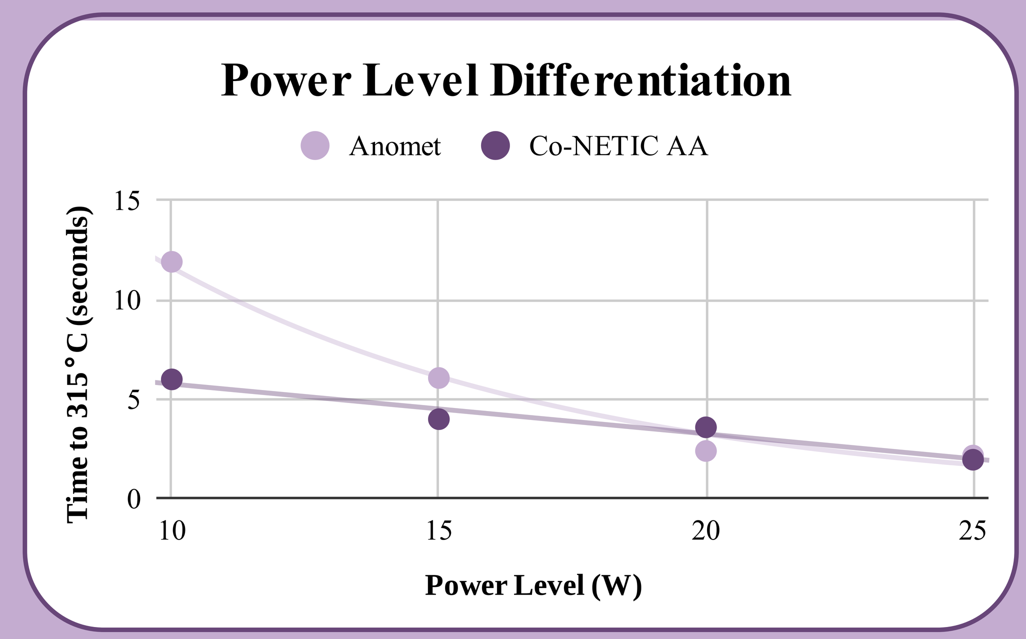

Figure 8. Power Level Differentiation

- Determine the relationship between variation in power levels and the time to reach 315 °C
- Standardized in a U-Loop configuration, at 10MHz, matched under 1W

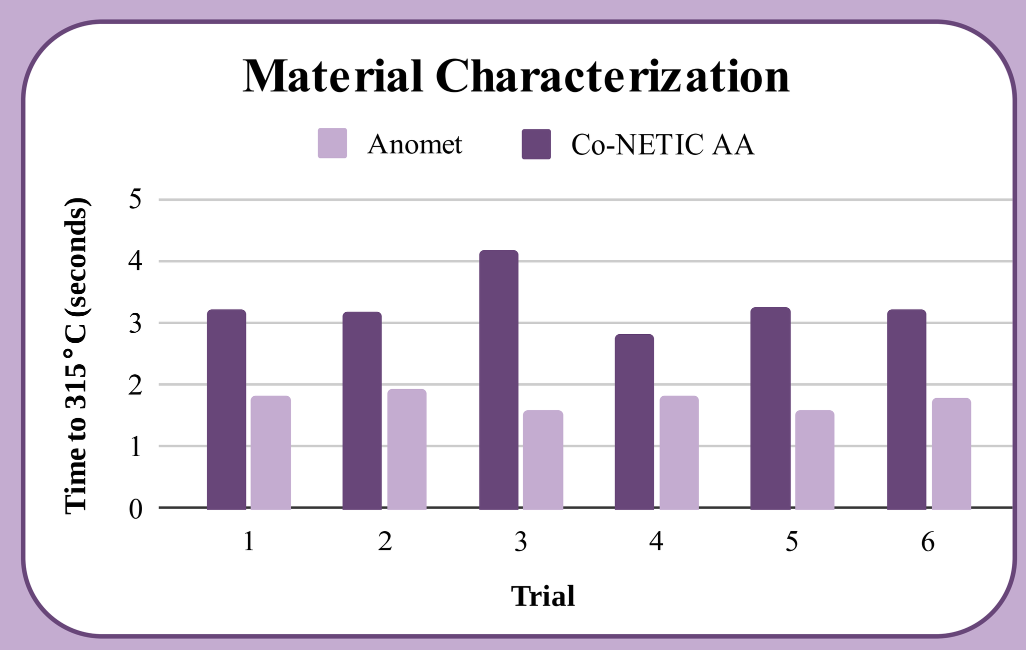

Figure 9. Material Characterization

- Measure the time to 315 °C for various ferromagnetic wires
- Standardized in a U-Loop, 25W, at 10MHz, matched under 1W

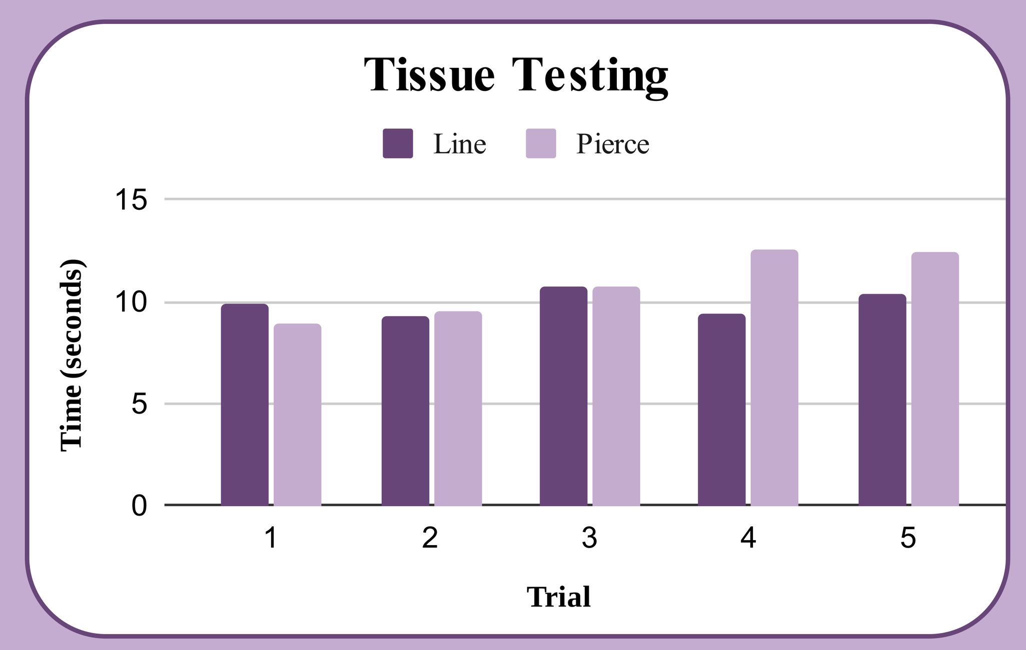

Figure 10. Tissue Testing

- Measure the time to cut a 2 cm line in porcine tissue and pierce through ¾ cm thick tissue
- Standardized in a U-Loop, 25W, at 10MHz, matched under 1W

FUTURE WORK

Coagulation

- Hybrid design with lower Curie point ferromagnetic materials
- Feedback loop + thermocouple for heat regulation under Curie

Wireless

- Improve mobility and reduce clutter in operating room
- Explore miniaturized RF technologies

Smoke Production

- Investigate thermal spread
- Analyze smoke production of monopolar vs ferromagnetism

Active Impedance Matching

- Necessary for configurations other than U-Loop
- Power settings >25W
- Frequencies >10MHz

REFERENCES

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[2] Tok, S., et al. (2015) Ferromagnetic Dissection in a Rat Glioma Model. *Journal of Cancer Therapy, Scientific Research Publishing*

[3] Joseph, D., & Zhao, Y. (2021). *Electrosurgical Instruments and Systems Including Thermal Cutting Elements.* (US Patent No. US20210244465A1). IP United States.

ACKNOWLEDGEMENTS

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