## Project Title:

A Meta-analysis And Study Into Fundamentals and Enhancements Of Solenoid Based Accelerations

## Abstract:

From initial research under the electrical engineering capstone the project of a coilgun or electromagnetic accelerator it has been determined that they are typically hyper inefficient. There are many factors that come into the design and operation of solenoids which make them complicated to utilize efficiently. The goal for this analysis is to do a large dive into the topics of solenoids, magnetic domains, feedback, external influences, and more. These topics have been lightly covered in ECE and would require further review from meeting with professors, scholarly article review, and textbook research. To get this data and review its interpretation a committee for a Honor’s Thesis has been formed. Furthermore, to enhance the data retrieved from this project there is the capstone coil-gun that is to be manufactured. This allows for additional testing of multiple designs and documentation of modifications to one concept as well as testing alternative concepts that come about through this process.

## Project Description:

To optimize a coil-gun’s design there are near endless variables to adjust which result in changes to outputs of the system. In recognition of this the goal of this research is to look at various principles of design and what their effects are and how altering some of these will affect other parameters to the design and the outputs of the system. Initially, these topics were determined to be the following electromagnetic principles, technology, and systems. Electromagnetic principles are properties of reality that dictate the conversion from electrical energy to another, or how certain technologies work in a system. Technologies is a category of devices utilized that operate certain stages of a circuit, this is documented to cover details of their operation for later use and design. Systems is a broad category as it dictates how a device receives inputs, processing methods, and response type which can have numerous effects based on previous categories. These topics each have their ins and outs which will be combined through research to determine optimization points, requirements, losses, and how they are related to each other. These topics and their importance are discussed in sub-categories below.

## Electromagnetic Principle

This area accounts for properties of electromagnetics such as resistance, inductance, magnetic flux, and so forth. These combined dictates how a design once constructed interacts with physics. For example, a resistor is similar to a valve in a sink the higher the resistance the less current flows which is like choking the water coming out of a faucet. These topics become rapidly complex and have many nuances such as how a resistor and inductor in series have a unique charge rate which influences the magnetic field around the solenoid.

### Academia:

This category of research is specifically physics but physics tied to the operation of electrical devices. This allows for students to generate new systems that interact with these physics to generate new technologies. Examples of these being, electric motors, solenoids, coilguns, semiconductors, and any device that takes a usb cord.

### Methods:

To get data on the principles and the effects of their operation two classes taken will be reflected upon ECE 351 {Fields and Waves} and ECE 453 {Microwave Engineering}. These two classes have covered topics in electromagnetics and further more can be reflected upon by their textbooks {*Fundamentals of Applied Electromagnetics*}¸ contacting Prof. Mauricio Pereira da Cunha for his specialty in this field, as well as independent only research.

## Technology

Technology is an extremely broad field of things, but for this section it aims to cover what devices are used a solenoid based system. These technologies will affect how the system works in tandem with electromagnetic principles as these devices may limit or alter inputs and outputs by their own methods. For example, one could draw a comparison between lightswitches and solid state relays. Lightswitches rely on mechanical based input, mechanical contact pads for continuity, and have a short life-cycle. Whereas solid state relays rely upon voltage inputs, semiconductor circuitry, and can cycle millions of times before failure.

### Academia:

These are the tools derived from electromagnetic research and invention, which electrical engineers use to solve problems in new systems. Also, with theses technologies it saves engineers from constantly having to reinvent technology. I work at the Advance Manufacturing Center on campus and have designed various systems by noting the parameters of these devices in order to create new systems and machines for consumers.

### Methods:

This section is going to be tied to what has been taught throughout the ECE curriculum such as ECE 342 and 343 {Electronics} and ECE 465 {Intro to Sensors}. The details of these devices will be understood and reflected upon based on their datasheet parameters as well as their unique properties which can affect the system. To gain the most out of this area the systems and other parameters from other’s experiments will be documented here to see if a designer was relying on a unique part of device operation here. An example of this would be a flyback diode, which can prevent a short circuit in one direction but in the other allow for rapid dissipation of energy. This section will get review from the Thesis committee and potentially and few other peers to get the most insight into the devices and their operation. This review will include details like datasheet specifications, device principles, and combined effects of device layouts.

## System and its Losses

This section aims to combine the research from the previous sections and from the capstone project to realize faults in the system. These features will document details such as supply power, connections to and from devices, programming routines, and details that may have been left out from the technology section. The previously two sections combined will be used here to reach into how a system works in operation to make conclusions about system shortcomings and how they can be mitigated or changed to eliminate them.

### Academia:

A fundamental aspect of all projects is how it can be done better if it has been done already. The comparison of better is a part of the problem and is what engineers aim to solve. This is similar to buying a car, some want reliability above all, others want speed, most would benefit from fuel efficiency, but college kids usually want to maximize all three. Engineers do this as well, optimizing cost, complexity, efficiency, and more dependent on the problem. This can be done for any system constructed in ECE as no student wants to use 2000 wires and 30 chips when 10 wires and a sophisticated chip can accomplish it all.

### Methods:

To combine all aspects of a system one must look at all the above details and recognize their faults. To accomplish this advance academic and experimental research will be documented and referred to for their conclusions. On top of that verification from a meta-analysis will help in verifying the documents. As well as review from the Honors committee.

# Importance:

This research aims to cover a multi-variable optimization including terms of wire cost, wire size, cooling system, cooling size, current, force, capacitor vs constant power source, solenoid layout, and likely more variables. This research in tandem with documenting others’ research will lead to many optimization programs based on what purpose of design one is doing. These topics could be solenoid valves which require long on periods and cannot suffer of overheating. Magnetic acceleration from solenoids may require high speed responses which may become a property of many aspects of the solenoid such as wire size (resistance reduction), solenoid shape (vertical vs horizontal), and overall projectile shape. Another case, is when the target is fixed and solenoid principles need optimization separately.

Another aspect of this is that most if not all aspects of a solenoid will be documented. These will include standard and experimental concepts to try to further document solutions such as fluorinert liquid pumped through the solenoid to help deal with hear conductance/convection. Different conductor shapes as to optimize conductance and field shape.

Overall, the combined effect of this document is to enhance the understanding of solenoids from one source and in tandem with that explain current systems. With a conclusion focused upon generating an optimization routine based on inputs that can be accessed from many sides of the optimization problem.

## Timeline:

For this project is tied between the Thesis and Capstone processes so both of these processes are documented below:

## A screenshot of a computer Description automatically generated

## Budget Justification:

This project aims to fund both sides of the research {Thesis and Capstone}. The main focus of investment is experimentation and documentation of the device. As well as funding partial construction of the coilgun project. As the capstone provides $150 for the construction of the project and that will cover a small portion of the project. The goal for this is to alleviate the burden of funding the parts and time to test and alter this device past capstone requirements.

For the supply side of the capstone implementation an estimate was made last semester to discuss how expensive it was. The total cost of this project came out to $868 before more research into the design. However, the main components have been determined off of this list, these being transformers, enclosures, wire, and structural aluminum.

Transformer: This has been changed to be oversized to ensure that it will not be damaged from overcurrent/overheating/switching loads. This model is a 240/480Vac to 120/240Vac 5kva transformer which will be used as a 120Vac to 60Vac transformer at 2.5Kva {linear decrease by current requirement}. Part number is [t2530144s](https://www.automationdirect.com/adc/shopping/catalog/power_products_(electrical)/transformers/encapsulated_core_general_purpose_transformers_(nema_rated)/t2530144s) 1x$575

Enclosure: This is a small enclosure to mount exposed power electronics such as 60vac to 83..2vdc, 120vac to 5vdc circuit, and circuit to control the solenoids. This is beginning to be modeled and should not be larger than a 10x10x4 enclosure. Part numbers are [sce-12n1004lp](https://www.automationdirect.com/adc/shopping/catalog/enclosures_-z-_subpanels_-z-_thermal_management_-z-_lighting/enclosures/wall-mount_enclosures/sce-12n1004lp) and [sce-12n10mp](https://www.automationdirect.com/adc/shopping/catalog/enclosures_-z-_subpanels_-z-_thermal_management_-z-_lighting/enclosure_parts_-a-_accessories/subpanels/sce-12n10mp) total of $82

Wire: From research into wire sizes the best seems to be 16awg wire which has the maximum benefits of being the cheapest and coldest wire would be 16awg wire at ~82ft at 200 turns or ~41ft at 100 turns. There will be 6 stages, which means ~492ft or ~246ft spools. The price for the spool above 492ft (625ft) is 1x$103.71. Part number is [16HNS5](https://www.digikey.com/en/products/detail/remington-industries/16HNS5/11612796?s=N4IgjCBcoOwBxVAYygMwIYBsDOBTANCAPZQDa4ADAMxxwwgC6hADgC5QgDKrATgJYA7AOYgAvoQBMVMFUQgUkDDgLEyIACwBWAJxaETEGw7d%2BwsaNFA).

Aluminum: As an estimate before getting into field decay from solenoid gap the overall mounting structure is estimated to be roughly 400cm. Automation Direct offers a decent price at $0.3/cm which comes to a total of 1x$68.70. Part website is [automationdirect](https://www.automationdirect.com/adc/shopping/catalog/structural_frames_-z-_rails/t-slotted_rails/40-4040c).

Test time: As to allow time off to drive to a test location and inspect the device operation is the purpose of the remaining funds. Or, if there is an interest in extreme modification of design such as series resistances or different control structure this fund could go into that as well. 1x$1252.59.

## Does this topic relate to Artificial Intelligence (AI)?:

No

## Does your research project have applications in Aerospace, Space Sciences, or Engineering?:

Yes, as this project is tied directly to electrical engineering. This research ties into the field of electromagnetics. Specifically, magnetic and electric fields in magnetostatics, electrostatics, magnetodynamics, electrodynamics, and kinematics.

## Does your project have applications in Health and Life Sciences to develop transformative medical-based solutions?:

None that have been found in research so far

## Does your research project relate to the COVID-19 pandemic?:

No

## Does your project require the use of Advanced Research Computing (ARC)?:

## No

## Have you taken any Research Trainings?:

I have not taken any form of research training.

## Use of CORE Equipment and Services

**Do you plan to use any CORE Equipment and Services?:**

No

## Please specify which CORE service(s) you propose to use in your project?:

## Briefly describe how your research will benefit from the service:

## What is your estimated cost of lab use fee?:

The experiments for this project will not be done on campus and will be documented by me and have the processes reviewed by committee to verify integrity and focus of each experiment to prevent error. The major test will be the projectile test otherwise additional tests will require equipment to be borrowed to be performed off campus. These could be series current shunts and a datalogger to determine current through solenoids and solenoid voltages.

## Student Information Student Name:

William Poole

## Student MaineStreet ID number:

1083686

## Student Telephone Number:

603-548-6102

## Student GPA:

3.711

## University:

University of Maine

## University of Maine

If, in the previous question, you indicated that you are attending the University of Maine, you will be sent to this section.

## Student Major:

## Electrical Engineering

## Student Program:

Bachelor of Science

## Student’s College:

College of Engineering (COE)

## Are you part of the Honors College Program?:

Yes

## Student Expected Graduation Date:

May 2024

## Are you a U.S. Citizen?:

Yes

## Faculty Mentor Information

Research Interests:

Microelectronics Analog and Mixed-Signal

Integrated Circuit Design

Electronic Materials

Computer Modeling and Simulation Education

Ph.D. Engineering Applied Science, University of California, Davis, 1988

M.S. Engineering Applied Science, University of California, Davis, 1984

B.E.E. Electrical Engineering, University of Dayton, 1981

## Faculty Mentor Name:

David E. Kotecki

## Faculty Mentor College:

COE

## Faculty Mentor Department:

College of Engineering

## Faculty Mentor Telephone Number:

 (207) 581-2248

## Faculty Mentor’s Email:

kotecki@maine.edu

## Has this proposal been submitted to any other funding program?:

No

## Additional Documentation:

If you have additional documentation you would like to add, you may upload it into the Google Drive. Please label it as follows: lastname.firstnameAwardtypeandyear (Example:Smith.JohnAY2324 or Smith.JohnSummer24) and paste the link in the text box provided. Please be sure to make the file(s) shareable with all of the UMaine system so we can access it.

## How did you hear about CUGR and our fellowship opportunities?:

Honors college meeting in intro to thesis class.

## Would you like to opt into the UMaine System’s Micro-Credentials Undergraduate Research Scholar Program?:

## No

## Faculty Commitment Letter:

Faculty commitment letter is a letter from the faculty member who will be mentoring you through the fellowship program. This letter should be submitted by the Faculty Commitment Letter Form. The link for this form is on our website or you can send the form to them directly to be sure we receive it before the deadline. The letter text should be pasted into the text box provided or uploaded to the form as a PDF. They are part of the rubric as well.

* The rubric for the Faculty Mentor Commitment Letter is as follows:
  + 1- Lack of faculty commitment letter
  + 2- The letter is missing both student potential and faculty commitment
  + 3- The letter states faculty commitment but is lacking student potential
  + 4- The letter states student potential but is lacking faculty commitment
  + 5- The letter clearly states both student potential and faculty commitment