# A STUDY INTO THE FUNDAMENTALS AND ENHANCEMENTS OF SOLENOID BASED ACCELERATORS

by

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ABSTRACT

Initial research into coilgun projects determined that they have a common issue of low efficiency and design complexity. This research aims to cover the topics of solenoid applications, magnetic fields, wires properties, and more for specific task optimization. There are many factors that come into the design and operation of solenoids which make them complicated to utilize effectively. These points will be combined for the overall system aspects dependent on application. These applications can be steady state for solenoid valves, high force for coil guns, and response time for chemistry applications. Coilguns have been studied for their unique ability to accelerate an object without adding weight or manipulating their design to allow for launches by alternative means. This advantage is purposely exploited for either a satellite launcher or another projectile accelerator. To get this data and review its interpretation my Honor’s Thesis committee shall be utilized. To prove some of this data, the ECE capstone project coilgun will use these concepts to enhance its optimization.

DEDICATION

If you would like to include a dedication, you can write it here. This section is optional. This would be the first page with a written page number. For these early pages, page numbering must use a lowercase Roman numeral, counting the title, copyright, and abstract pages. All page numbers must be 12-point Times New Roman, centered in the footer.

ACKNOWLEDGEMENTS

An acknowledgments page is optional but recommended. This is a place to thank anyone who helped you and your project get where you are. Like with the dedication page, include a lowercase Roman numeral page number, with page numbering starting on the title page.

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List of Definitions

|  |  |
| --- | --- |
| Current |  |
| Efficiency |  |
| Projectile |  |
|  |  |
|  |  |
|  |  |

### Equations

ω=Angular frequency [Radians]

L=Inductance [Henrys]

L=μAN2/L [H/m \* m^2 / m]

N=#of turns [unitless]

ZL=jωL

TL=L/R

[1] V=L\*di/dt

[2] F=q V x B

[3] H=I\*N/m

[4]

[5]

[6] F=qE + q V x B

[7] m=n^NIA

[8] T=m x B

[9] F=∇ (m . B)

# Introduction

Solenoids are an extremely useful tool due to their ability to generate mechanical force on a shaft to perform many applications. The applications of these devices are typically used in valves for controlling flows of all-sorts of liquids. In addition, solenoids are used in other industries to perform alternative tasks such as induction heating, load acceleration, repeated mechanical oscillations, or some experimental projects. With these different applications they require separate products and varying operational parameters, of which is a focus of this document.

With the expansiveness of this industry, earlier found research will be utilized to discuss commonly manipulated parameters of solenoid design. These documents will consider many parameters so common or similar parameters are to be discussed. Furthermore, the parameters will be discussed in which actual variations can be applied to simulate their effects as many of them are correlated with each other. To supplement these findings meta-analysis will utilized to show levels of gain or loss generated by these changes.

In relation to these manipulations an experimental test system was developed to verify principles of solenoid operation. The system is designed to launch varying magnetic loads with built in speed measurement to showcase how manipulation of loads, materials, and solenoid design can affect system performance. The design of this system will also be discussed as control schemes are also a contributing factor to performance.

# Industries and Applications

Solenoids are utilized in many industries, examples include locking (doors, drawers, or interlocks), medical (medicine flow control, precise measurement, or clamping), and industrial applications (cutting, punching, positioning, measuring or motion) [4]. In addition they are used in extreme situations as a design substitute for their re-usability, non-contact acceleration, controllability, and scalability. Examples include the *Startram*, Coilguns, Nanosatellites, and Liquid hydrogen projects [5,6,7,8]. These substitutions are for large scale propellant based systems such as rockets or vacuum catapults for repeatable launching. Now, for each of these industries many concerns are generated based on the desired inputs, outputs, performance which are discussed below.

The simple use case of solenoid is binary traversal, which means the purpose of the device is to move between two points. These can be locks, valves, or punches but between these applications parameters vary. For example, door locks would be manufactured with low power draw and low holding force as it is not necessary. So, for this application a lower power system with a bi-stable solenoid that only uses power during motion [9]. Valves could be bi-stable but, they may have higher force requirements as the force necessary to hold a valve shut is directly axial to solenoid force requiring to stay on. Presses are unique as they may be high-speed and high force bi-directionally, or slower and requiring more control. With these applications is a concern of power demand, controls, holding force, force magnitude, and force curves.

Alternative applications such as position, velocity, and acceleration control. These uses become very complicated as it involves hard to measure features and non-linear systems with multiple sensitivities. Position control for example is a unique category, whether it is to move a distance to change something like a rudder on a conveyor to a middle position or to detect something at a distance without exerting large amounts of force repeatedly. This is due to the relation of position through acceleration control, furthmore this applies to velocity and acceleration which will require understanding of these parameters dependencies on solenoid and system parameters.

So to utilize these devices appropriately linearization of parameters or advance control schemes may be necessary based upon application. As mentioned with valves, a simple bi-modal state of operation with sufficient force and speed being the only requirement lowers requirements of control and design complexity. Whereas more sophisticated applications such as bi-stable solenoids and coil guns require control to change power based on position. Now, with applications requiring control it may be worthwhile to facilitate linear systems as to reduce complexity of the controller or control logic.

# History

This technology is quite old starting in the early 1900’s with a patent by a Norwegian scientist in 1904 being one of the earliest documents [10]. Past this earlier variant it has fallen into 2 main categories projectile or vehicle acceleration. Projectile acceleration is the gun designed to throw a projectile with the intent to have it destroy something, usually military. An example of this is the Darpa project to enhance mortar systems by replacing propellant weight and increasing distance [11]. Whereas the alternative is something that accelerates a container to deploy something at a distance. One of the vehicle launchers was the NASA super-cooled coil gun or quench gun project for launching liquid oxygen off of the moon for use in spaceships [2]. Allowing this technology to be used for new purposes whenever an object needs to be thrown.

# Research

With this technology being old as this there many documents outlining applications and their manipulated parameters. From all these documents advantages can be selected to fit certain situations dependent on requirements. The sections show manipulated parameters of a solenoid as well as their outcomes, after a brief introduction to how the force is calculated and

## Force Generation

Force generation of a solenoid is a complex topic as typically analytics of solenoids or electromagnetics involve simplifications which become significant in these applications. This can be how wires are wrapped around a core, the extreme energy fields influence materials, or material parasitic. Albeit even in the modeling I have found there are assumptions that alleviate the insignifigant.

For solenoids to generate a force they utilize a circular field so that their field is not uniform across the barrel.

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# Appendices

# Author’s Biography