Electromagnetic Railgun

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Abstract

In this project, we have designed a prototype of a railgun. As this project is only for educational purposes, we have limited ourselves to low power levels of around 100V and 10 Amperes. We hope this project serves as a proof of concept. This prototype can be further developed and deployed in a multitude of applications.

I. Introduction

A railgun is a device that uses electromagnetic force to launch high velocity projectiles, by means of a sliding armature that is accelerated along a pair of conductive rails. Railguns rely on electromagnetic force to propel a projectile at very high velocities(more than $3km/s$).

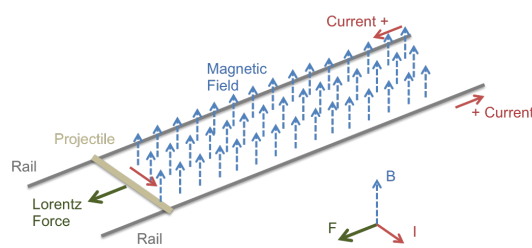
II. Potential Applications

- Railguns are being researched as weapons that would use neither explosives nor propellant.The absence of explosive propellants or warheads to store and handle conventional weaponry come as additional advantages.
- In addition to military applications, NASA has proposed to use a railgun to launch wedge-shaped aircraft with scramjets to high-altitude at Mach 10, where they will then fire a small payload into orbit using conventional rocket propulsion.
- Railguns can potentially be used to aid mining, as a substitute for dynamite for clearing tunnels.

III. Principle

The magnetic force on a current carrying conductor can be modeled by the equation.

Figure 1: *Working principle of railgun*



$$\vec{F} = I_r \vec{l} \times \vec{B} \tag{1}$$

Where F is force, B is magnetic field and I_r is current passing through the rails.

As we are using permanent magnets to supply an external magnetic field, we restrict our power supply to DC only.

We apply the magnetic field as seen in Figure 1 using strong permanent magnets. The magnetic field intensity of a magnet is given by $\vec{B}$

As the magnetic field is perpendicular to the current carrying projectile, $Eq(1)$ simplifies to

$$|\vec{F}| = I_r l |\vec{B}|$$

IV. Approach

Simulation

We began by designing the Capacitor bank charging circuit, using simulink (A MATLAB simulation software).

A detailed schematic of the circuit can be found below in Figure 1.

Figure 2 shows the voltage vs time plot of the charging capacitors.

Figure 2: *Circuit Diagram of simulated charging circuit*

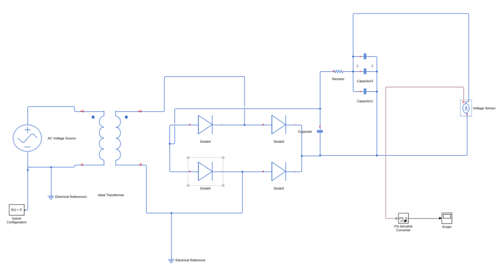
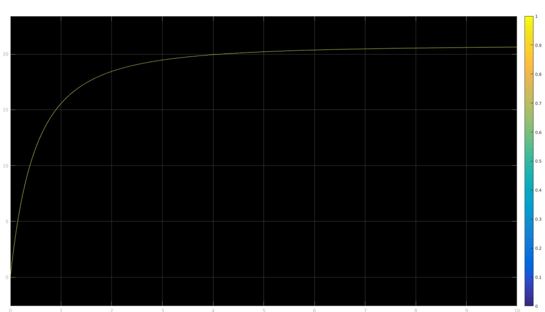


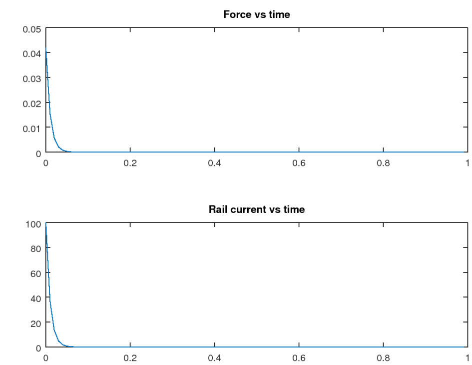
Figure 3: *Plot of voltage across capcitor bank vs time*



We ran calculations using a matlab script and plotted the force on the projetile vs time along with the rail current vs time.(Figure 3)

The script and all other code used in this project can be found in the project github repository. **https://github.com/AravindGanesh/IDP-Sem3**

Figure 4: *Plots of rail current vs time and force vs time*



V. Architecture

Components

- Capacitors - 2.2mF (as power source for the rails)
- Variable Auto-Transformer
- Fullwave bridge Rectifier (uncontrolled)
- Power MOSFET - IR740 (for switching)
- Strong Neodymium Magnets
- High power resistors
- Steel scales as rails
- Graphite rod (as projectile)

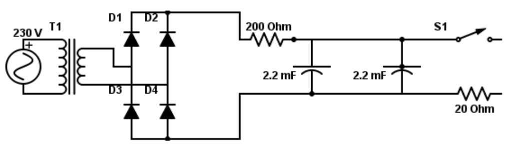
Structure Description

The steel scales serve as rails. The graphite rod is chosen as projectile as it is conducting but not ferromagnetic. If we use a projectile made of ferromagnetic material, it will experience a strong downward force the strong magnetic field.This will, in turn, increase the normal reaction. Frictional force is given by $f = \mu N$ which clearly increases as Normal reaction increases.
The permanent magnets provide strong magnetic field perpendicular to the plane of the rails.
The capacitors are charged with the DC output of the rectifier with input from the variable auto-transformer.
The charged capacitor provides instantaneous current of the order 10 Amperes.

Current flows through the graphite rod (projectile) and it moves under the effect of Lorentz force according to equation (1).
Magnets were placed at the end of the rails to prevent backward attraction as current ceases to flow through the projectile.

VI. Circuit Description

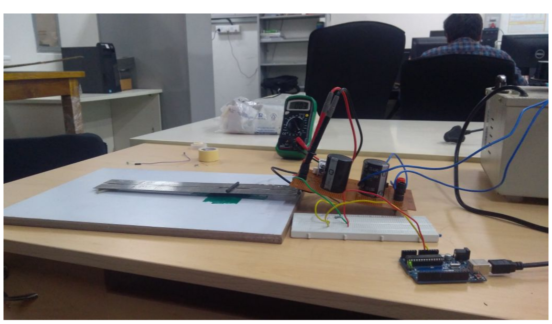
Figure 5: *Schematic of the charging circuit*



- The Turns Ratio of transformer T1 is adjusted such that Output Voltage is 130V rms.
- The capacitors have a maximum rating of 200V
- The Diodes D1,D2,D3,D4 have reverse breakdown voltage of 170V
- To limit the current through the 200Ω resistor while charging, the turns ratio is slowly increased from 0 to its required value
- 20Ω resistor is used to avoid instantaneous discharging of capacitor and also limiting current through the projectile

VII. Results

Figure 6: *Setup of railgun prototype*



After numerous tests, we were able to propel the graphite projectile forward to a distance of about 15 cm. The video of the working railgun can be found in our github repository.

VIII. References

- http://web.mit.edu/mouser/www/railgun/physics.html
- https://en.wikipedia.org/wiki/Railgun
- https://www.princeton.edu/ romalis/-PHYS210/railgun/railgun.html
- www.calvin.edu/p̃ribeiro/courses/engr302/Samples/Railgun %20Paper.doc