**Introduction**

The objective of this senior physics student research project was to design a functional electromagnetic accelerator (i.e. railgun), with considerations for size, portability, modularity, and weight. This has been accomplished through practical design application of electromagnetic principles and streamlined construction to study effects of various projectile designs. The railgun has been successfully tested with an estimated speed of 300 m/s and an efficiency of approximately 0.6%.

**Theory**

Railgun theory has long been in existence since the 1896, when Hedrix Lorenz discovered how magnetic fields interact with charged particles.

\[
F = \frac{1}{2} \mu_0 I^2 r^2 = \mu_0 I^2 r^2 \quad \text{where} \quad r = \frac{2m}{e} \quad \text{and} \quad e = \frac{2m}{e} \quad \text{in} \quad \text{N} \quad \text{at} \quad \text{m} \quad \text{amps} \quad \text{m} \quad \text{amps}^2 \\
\]

Loelett Force Law

\[
F = \frac{1}{2} \mu_0 I^2 r^2 \quad \text{where} \quad r = \frac{2m}{e} \quad \text{and} \quad e = \frac{2m}{e} \quad \text{in} \quad \text{N} \quad \text{at} \quad \text{m} \quad \text{amps} \quad \text{m} \quad \text{amps}^2 \\
\]

Boil-Savart Law

\[
\gamma = \frac{1}{2} \mu_0 I^2 r^2 \quad \text{where} \quad r = \frac{2m}{e} \quad \text{and} \quad e = \frac{2m}{e} \quad \text{in} \quad \text{N} \quad \text{at} \quad \text{m} \quad \text{amps} \quad \text{m} \quad \text{amps}^2 \\
\]

Testing efficiency via the ratio of the projectiles kinetic energy to the systems electrical energy

\[
E_{\text{projectile}} = \frac{m v^2}{2} \quad \text{and} \quad E_{\text{system}} = \frac{1}{2} m v^2 \quad \text{in} \quad \text{J} \quad \text{at} \quad \text{m} \quad \text{amps}^2 \\
\]

**Design**

The design of the Railgun consisted of several parts as a gas injection system or gas gun, a containment structure, the stand, the discharge load, the capacitor bank and the ballistic pendulum for testing.

**Gas Injection System/ Gas Gun**

- Used to pre-accelerate projectile/amature
- Modifying a paintball marker as a heavy gas gun
- CO₂ is more stable and safer to store than compressed air

Basically a low pressure single stage gas gun with a velocity of 300-400 ft/s

**Containment structure**

The rail containment material was GPO-3, A flame-retardant fiberglass laminate, the containment was 12” X 3” X 1.5”. Twenty 1/4” stainless steel bolts were used for the truss of bolts used

**Projectiles/Amatures**

The projectiles/amatures were milled from C110 – ETP (Electrolytic Tough Pitch) copper, with an average mass of approx. 2 grams and a bore dimensions of .25” x .25” and varied slightly in length.

**Rails/Conductors**

The rails were cut from C110 – ETP copper. The rails were separated into a primary (12” X .125” X .5”) and a secondary system (12” X .125” X .375”). The primary were connected to the capacitor bank and the secondary to ease rail replacement after firing.

**Capacitor Bank**

Created from 96 individual electrolytic capacitors rated at 2200 MFD

These were placed in to 16 parallel sub-banks of six capacitors also placed in parallel

- Peak Voltage - 450 V
- Peak Current - 31.5 kA est.
- Total Capacitance - 2112 F
- Peak Energy - 21384 J

**Discharge Load**

To safely discharge the capacitor bank when charged a load bank of five serialized 90 W light bulbs were used.

**Ballistic Pendulum**

The ballistic pendulum was constructed from a paint filled with GPO-3 squares tiles for backstopping and mortar mix for filler, with total weight 13.5 lbs.

**Finalized Concept of the Railgun and Finished Railgun**

Three test firings were accomplished the first and second being inconclusive due to the projectile welding to the rails, the third test firing was successful. A ballistic pendulum was used to measure the velocity, and calculate the kinetic energy of the projectile.

**Testing and Results**

- Capacitor Bank charged to 350 volts
- Peak Current - 27.6 kA est.
- Peak Energy - 12936 J
- Projectile welded to rails

**Second Test Firing**

- Capacitor Bank charged to 400 volts
- Peak Current - 31.5 kA est.
- Peak Energy - 16895 J
- Projectile welded to rails

**Third Test Firing**

- Capacitor Bank charged to 400 volts
- Peak Current - 31.5 kA est.
- Peak Energy - 16720 J
- Successfully fired
- Sheared both terminal bolts at primary rails

**Conclusions**

The initial and second test firings yielded inconclusive results due to projectile welding; this was most likely due to positioning of the secondary rails in relation to the primary, this was corrected for the second test firing and liners were placed so as to position the secondary rails in optimum relation to the primary rails. The second test firings results were thought to be a combination of aching and low injection velocity. The third test firings success was primarily attributed to projectile design, as it was thought to provide adequate contact with the rails without excessive friction. The results of this test firing yielded an approximate speed of 300 m/s with a calculated kinetic energy of 93 J which was a 6% efficiency.

Further improvements to the design would be the use of lighter than air gas to increase the injection speed or a solid state switch, which would provide optimum projectile placements thus reducing arcing.

**References**

- J. H. Benu, W. F. Weldon, An Investigation Into The Potential For Multiple Rail Railguns
- W. F. Weldon, M. D. Driga, H. H. Woodson, Recall in Electromagnetic Railguns
- Phillip Michael Day, Operation of The HERA Railgun Facility At Texas Tech
- J. H. Benu, W. F. Weldon, Active Current Management For Four-Rail Railguns
- Paul BossChet, Railguns,

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