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On the Construction and Optimization of a Rail Gun

Introduction:

The purpose of this project is to construct a railgun apparatus, thereby exploring the physical properties surrounding its effect. The device itself is to be constructed as a proof of concept, where the physics of the concept is to be visible.

Design and Construction:

There were several iterations of the design before reaching the final form of the device. The first of which being a simple rail system composed of two 2mm diameter steel rails surrounded by a steel-cored, u-shaped electromagnet. The electromagnet was constructed from simple copper wire; the core from bent plates of sheet steel approximately 1mm in thickness. This design performed terribly, as the electromagnet was woefully underpowered and the rails were, in fact, poor conductors of electricity, due to their finish and composition.

The second iteration of the device was simply a scaled-up version of the initial design with a much larger and more powerful electromagnet and more conductive rails. The second electromagnet was constructed in a similar manner as with the first: u-shaped, steel-cored with multiple turns of wire around the central "u" form. The particulars of this design are depicted in 'Figure 1.' Despite being connected to 18 D-cell batteries connected in series producing amperage near 30 amps, the electromagnet still performed poorly, producing a barely noticeable magnetic field. The rails were constructed from 5mm copper plumbing pipe, which is highly conductive and has the capability to deliver an extremely large current without great ohmic heating due to the large size of the rails. This design also worked rather poorly, barely moving even the smallest of copper wires draped across the rails.

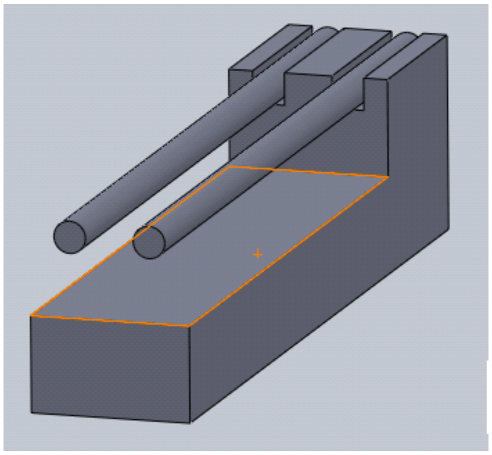

Figure 2

The final iteration of this project maintained the copper rails, but instead of a weak electromagnet, over a dozen Neodymium-Nickel-Boron rare-earth magnets were used to produce the magnetic field. These magnets could not only produce a powerful magnetic field, but could be oriented in a manner with which they would act as a single large magnet. The layout of the magnets was achieved, as shown in Figure 2, through the use of incredibly strong epoxy resin to maintain their orientation. The magnet bar is shown in figure 3. Features of the final design include a 24 Volt power supply (four 6v battery packs soldered together in series), the two copper rails as in the previous version, and the line of magnets to produce a relatively uniform magnetic field. The final design is depicted in figure 4.

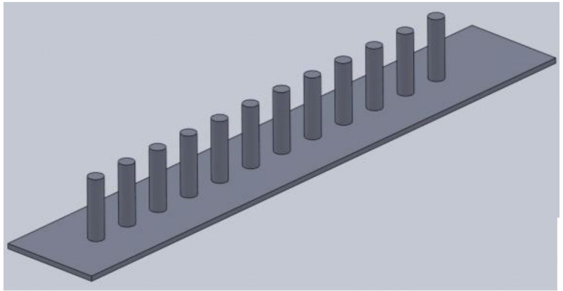

Figure 3

Great consideration was given to the design of the "projectile," as many different materials and shapes were attempted. Some of the projectile designs used were a glider made of plate aluminum, a glider of aluminum foil, a simple copper wire stretched across the rails, steel bars, and ball-bearings. The aluminum plate was too heavy to be moved and served as a poor conductor due to its finish. The aluminum foil, despite its light weight and malleability, was not nearly robust enough to handle the kind of current being forced through it. It melted. Steel bars were attracted to the magnets, therefore useless. The copper wire was most effective, but the larger diameter seemed too heavy and the smaller diameter acted as a lightbulb filament. Namely, it glowed bright orange and quickly vanished, thoroughly melted. The ball-bearings I had found were non-ferromagnetic and therefore were not attracted to the magnets directly. The bearings also possess very limited friction with the rails and maintain their integrity even under heavy amperic load.

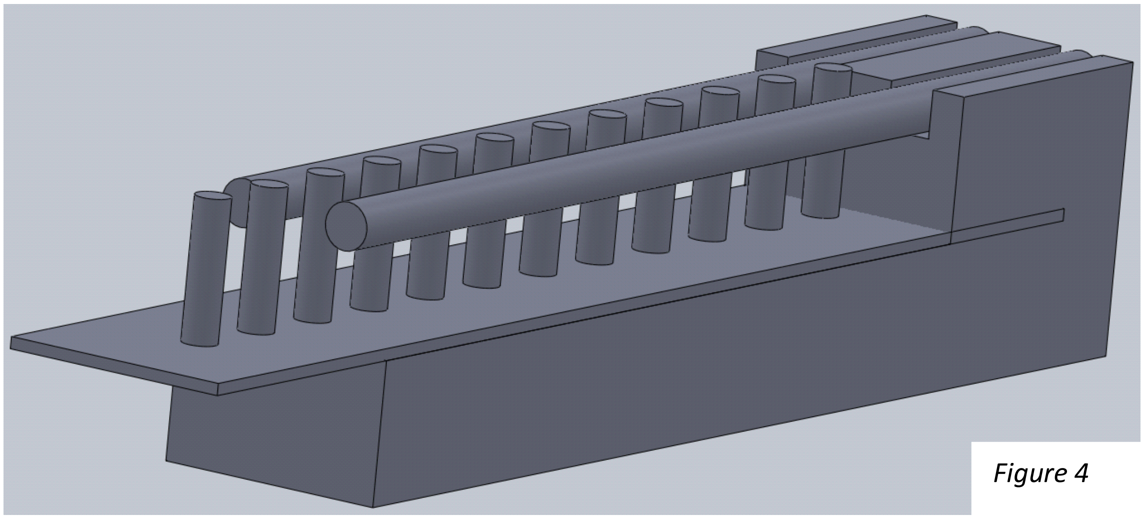

Figure 4

Theory and Mathematics:

The basis of the theory of the railgun is the principle known as the Lorentz Force. The formula to calculate the Lorentz Force is defined by the following function:

$$\vec{F} = \int \left(\rho\vec{E} + J \times \vec{B}\right) dV$$

where F is the force density (force per unit volume), ρ being the charge density and E being the electric field. The cross product of J, being the current density, and B, being the vector for the magnetic field produces a force value in a direction perpendicular to both the magnetic field and the current. This feature of the cross product is the key to the effect of the railgun, that a magnetic field down and a lateral current can produce a force forward.

In its simplified form, such as in the case of a straight, stationary wire, the force can be calculated by the formula

$$\vec{F} = \vec{I} \int dL \times \vec{B}$$

where I is the current, L is the length of the wire within the field experiencing the current, and B is the magnetic field. This integral can be used to calculated the force relatively easily in a uniform magnetic field with a constant current and a straight wire.

Assuming the current through the ball-bearing could be modeled feasibly as a straight wire. With a current of only 20 amps passing through it under a magnetic field with a magnitude of .25 Tesla at the point of the bearing, the force exerted on the bearing could be calculated readily. With this aspect of the mathematics, we could theorize exactly how to produce a larger force. A larger force could be achieved by increasing one of three factors: the current through the projectile, a larger – yet somehow not heavier – projectile, or a more powerful magnetic field. The former and latter of these possibilities are easiest accomplished through the use of copious quantities of capacitors. With large banks of capacitors connected to both the rails and an electromagnet and a simultaneous discharge of both banks of capacitors could generate a massive current through the rails while generating a massive magnetic field for the same instant, propelling the projectile to great velocities.

Conclusion:

The railgun can be constructed with simple materials found in any home improvement store. Through the use of large currents and strong magnetic fields, a projectile can be accelerated to decent velocities. In order to improve on the design laid out in this paper; lengthening rails, adding extensive capacitance, and much larger and more powerful magnets would be required.

Bibliography:

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4. Images produced using Solidworks 3D modeling software, ©2011 Dasssault Systems, Solidworks Corp.
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