Building a Small-Scale Rail Gun

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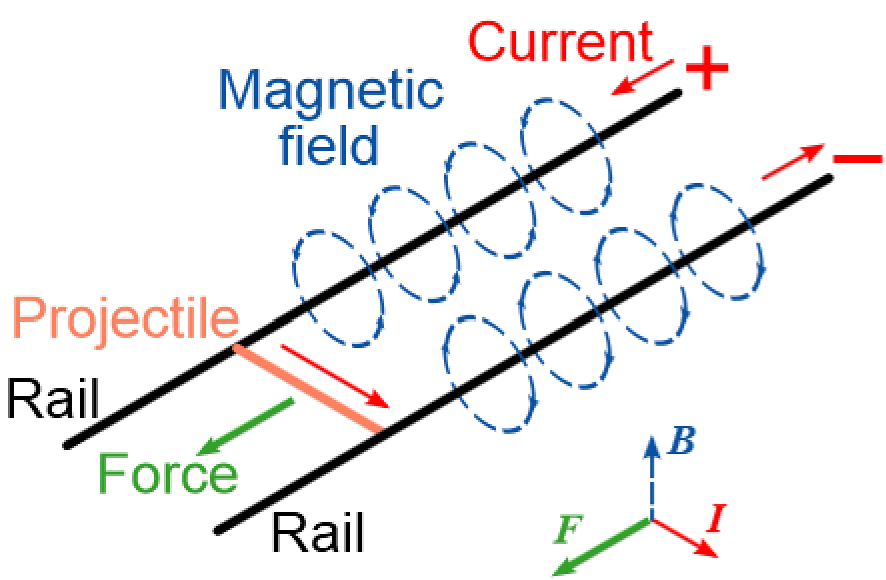
Introduction

A rail gun is a device which utilizes the Lorentz force to propel an electrically conductive projectile along two conducting rails. While the U.S. Navy has tested rail guns as weapons capable of shooting a projectile at Mach 7, or about 2.4 km/sec (LiveScience, 2008), such guns require a huge power supply of many thousands of amps, and therefore small-scale guns have much less ambition in terms of muzzle velocity and energy. The basic design of a rail gun is shown in the diagram below:



http://upload.wikimedia.org/wikipedia/commons/9/9a/Railgun-1.svg

Fortunately, the functionality of a rail gun can be broken down into components, which will be analyzed separately:

<u>The Magnetic Field</u>

The basic concept governing a rail gun's performance is the Lorentz Force, which follows the formula $\vec{F} = q(E + \vec{v} \times \vec{B})$ where F is the Lorentz Force produced, q represents the magnitude of the stationary charge, $\vec{v}$ is the charge's velocity vector, E is the electric field (assumed to be 0 for this project), and $\vec{B}$ is the magnetic field vector (Roters, 1941). However, since we are dealing with a current rather than a point charge, this formula simplifies to $\vec{F} = \vec{I} \times \vec{B}$, where $\vec{I}$ is the current vector. Traditionally, the magnetic field B is produced solely by the rails according to the infinite wire approximation $B = \frac{\mu_0 I}{2\pi R}$ (Stewart, 2011), where R is the distance from the wire to the point in question. It is worth noting that since the wire in question only has current flowing through half of it, the value of B would be halved, but since there are two wires used, this approximation will suffice. However, with the low current used, the rails produce a very small magnetic field magnitude due to the small value of μ_0 $(4\pi \times 10^{-7})$ (Stewart, 2011). For this reason, an external field was added to the system to increase the value of B and thereby the value of F; we will assume the field from the rails to be zero.

Ideally, the added magnetic field would be uniform and pointing either up or down, due to the fact that the cross product of I and B is greatest when the two vectors are perpendicular. Originally, a rectangular solenoid would be placed below the rails to produce the needed field. However, because the wire used was too thick to produce a high value for n (Stewart, 2011), and an appropriately shaped iron core could not be found, this idea was abandoned. Instead, permanent magnets were placed in line with the rails. At first, the magnets were placed directly below the barrel, but it was soon discovered that due to the looped shape of the magnetic fields produced by the permanent magnets, the field produced was very non-uniform, and the field of the outer magnets actually canceled out the field of the inner ones, even though all dipoles pointed in the same direction. Below is a picture of the original design:

It then became apparent that parallel to each magnet's dipole, the magnetic field pointed in the exact opposite direction of the dipole, meaning that if magnets were place outside of but parallel to the barrel, the field would be nearly uniform. This was used for the final design:

Unfortunately, the manufacturer provided no information about the field produced by the magnets, so the value of $\vec{B}$ at the projectile was nearly impossible to measure.

<u>The Current</u>

The current, I, is dependent on two main factors: the power source used, and the resistance of the system as a whole. For the project, a 6V Energizer battery was used as the power source. Unfortunately, because of the nature of contact between the rails and the projectile, it was difficult to calculate the value of current flowing through the system. Nevertheless, in order to minimize resistance, the rails were made out of thick copper wire, and the leads connecting the rails to the batteries were copper foil, which also acted as a switch, depending on whether it was connected to the rail or not. Copper foil worked better than copper wire for this purpose because it allowed more surface contact between the battery leads and the rails than the wire available, and this allowed more current.

The Projectile

A rail gun's projectile must conduct the maximum current possible while producing the least amount of friction possible. This creates a dilemma, because in order to increase the surface area of projectile connected to the rails (and thus the current), friction must also be increased. The standard practice is to roll a metallic bar along the rails. This worked satisfactorily, but the copper bar used could not be launched off of the gun due to the small force it allowed. So, tin foil was used to create projectiles that were both highly conductive and lightweight. This drastically reduced friction, and because the objects were so lightweight, the small forces involved managed to launch one projectile a few feet from the gun. However, because said projectiles were so light, it was difficult to calculate the muzzle velocity produced, as air resistance moved them off track as soon as they left the barrel. Still, the foil paper plane used was aesthetically pleasing and could move with considerable speed.

Also, because projectiles tended to get caught between magnets because of the magnets' semicircular pattern, a paper strip was placed on the inside of the barrel in order to reduce the friction experienced by the projectile and to keep the projectile moving in a straight line. The picture below shows the projectile, rails, magnets, paper strips, and the foil connecting to the battery:

Conclusion

Overall, the rail gun failed to produce the results originally desired. Although the final design worked considerably better than two bare rails and a bar shaped projectile, it still was nowhere near capable of launching a projectile across the room. Still, all of the materials used could be purchased for under $50. Unfortunately, many of the mathematical variables involved could not be calculated, and a more proper experiment would involve more exact measurements. Such experiments would likely involve higher currents and projectiles with more mass.

Works Cited

Roters, Herbert C. 1941. *Electromagnetic Devices*. New York: John Wiley & Sons, Inc.; London: Chapman & Hall, limited, 1941.

LiveScience Staff. “Navy Tests Incredible Sci-Fi Weapon.” LiveScience.com. February 1, 2008. Accessed November 28, 2011, http://www.chicagomanualofstyle.org/tools_citationguide.html.

Dr. Stewart, John and Gay. August 4, 2011. *UPII Fall 2011 Course Guide*. The University of Arkansas.