Thomas Ivanoff

UPII Sec: H1

24 November 2008

Honors Project: Coil Gun

A functioning coil gun is a very entertaining way of demonstrating some of the basic ideas of modern physics; they are essentially weapons though—well, mine is not very dangerous, but some can be—and must be worked with carefully. They use an electric current flowing through a coil of wire wound around a barrel to create a magnetic field, which then launches a metallic projectile down and out of the barrel. This idea of using an electric current to produce a magnetic field though is not just limited to coil guns; on the contrary, it is fundamental to the workings of almost all modern equipment.

The main functioning of these devices is governed almost entirely by the principles of the Biot-Savart law. The Biot-Savart Law $\vec{B} = \int \frac{dl \times \hat{r}}{r^2}$ is an equation that links the two forces of electricity and magnetism, where $\vec{B}$ is the magnetic field at the distance r from the section of currentdl, in the length of wire being used to create the magnetic field. This equation is fundamental to understanding how a coil gun works, because it explains how the magnetic field, the force which induces the projectile to move, is calculated. Yet, while it is incredibly important, the Biot-Savart Law is used only when calculating the magnetic field inside the solenoid wound around the barrel; the circuit and the charging and discharging of the capacitors are governed by different laws.

The most vital component to any coil gun is the solenoid and its importance can be explained by two main reasons. The first reason is that a solenoid creates a uniform magnetic field in its interior with a constant current flowing through the wire. For this instance though, the current through the wire changes with time; however, this is necessary for the proper functioning of any coil gun and will be discussed later. Thus, the more specific first reason for using a solenoid is to create a uniformly directed field, not one that is always at a constant strength. The second reason is that a solenoid creates a much stronger magnetic field than just a single wire by itself. This means that a fairly strong magnetic field can be generated in an incredibly localized area. Furthermore, due to the symmetry of a solenoid, the equation for calculating the magnetic field within any solenoid can be solved by the simplified equation,$\vec{B} = \mu_0 n I$; where μ_0 is the permeability of free space, n is the number of turns of wire per unit length of the solenoid, and I is the current in the wire. This equation though, is just a generic formula for an infinitely long solenoid, and is only good at giving a rough estimate of the peak magnetic field at the center of the wound coil. Only the peak magnetic field is needed to be calculated because, as will be discussed later, a coil gun uses just a short burst of current, not a constant flow of current.

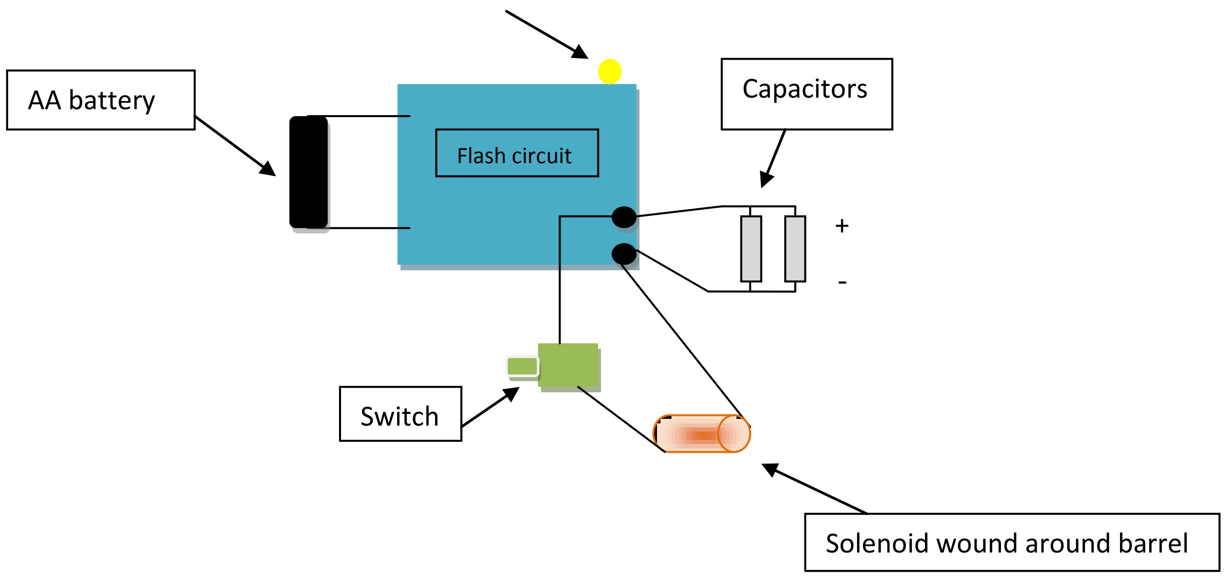
While creating the magnetic field inside the barrel of the gun is important, it is actually only half of the story. The other crucial factors for a coil gun are the type of projectiles that can be used and the timing of the current through the solenoid. To begin, the magnetic field generated by the solenoid attracts the metallic projectile by inducing a magnet moment on it; which essentially turns the projectile into a temporary magnet, allowing it to be affected by the solenoid's magnetic field. This means that only projectiles capable of becoming temporarily magnetized, or ferromagnetic projectiles, can be used in a coil gun. This is not a terrible flaw though, as almost all conventional ballistics use metal projectiles, which are ferromagnetic; so, their adaption to be fired in a coil gun would be relatively easy.

While the projectiles might be easy to find, the problem of timing still exists. The current in the solenoid generates a magnetic field that allows for the projectile to be accelerated into the solenoid; however, once it reaches the middle of the coil the magnetic field will have the opposite affect and attempt to slow down the projectile if the current is left on. This means that the current through the solenoid must be timed so that it flows before the projectile reaches the center, and it must be shut off thereafter. This fact is related to the magnet moment given to the projectile from the time the current is switch on. The projectile, at first, has a magnetic moment aligned with the moment of the solenoid, thus it is attracted to the center of the solenoid where the field is strongest. Once it passes through the center of the coil though, it feels a force in the opposite direction of its previous acceleration, because it wants to return to the area with the strongest field. Thus, a short, controlled burst of current supplied by a capacitor system is necessary to properly fire a coil gun.

Though most coil guns require a fair amount of current to be effective, they are much quieter and do not rely on any explosive materials, and with future development will most surely become as accurate and efficient, if not more than conventional weapons. With further development and research there is much promise for the more frequent use of coil guns and their related technologies. Once understood, a coil gun is a powerful tool that shows a strong understanding of fundamental physics.

My coil gun system was essentially derived from a disposable camera's flash circuitry. I used the existing circuit to charge two 120 microfarad capacitors, connected in parallel, with a single 1.5 volt AA battery. Connected to the capacitor leads is my coil. It is a one inch long solenoid with about twenty turns and four layers of twenty-two gauge copper wire. The layering of the wire allows for more current to be concentrated in the single one inch space along the firing barrel, so as not to spread out the solenoid's magnetic field and disturb the timing of the current flow. I have also placed a switch in series with the coil to be able to control the firing of my gun. The setup I have built allows for the capacitors to charge only while the switch is flipped to the off position, and only to discharge through the coil when I flip the switch to the on position. I can see when the capacitors are indicated to be fully charged by a small light attached to the camera flash's circuit board, which lights up when the capacitors obtain their maximum potential difference. Thus, once the light becomes illuminated is the optimal time to fire device. When firing, the capacitors discharge their stored energy through the switch and coil at roughly three hundred volts, through a total combined resistance of about one hundred ohms, creating a peak current of around three amps.

Diagram


AA battery
Flash circuit
Capacitors
+
-
Switch
Solenoid wound around barrel

Works Referenced

Harnwell, Gaylord P. Principles of Electricity and Electromagnetism. First ed. New York, NY: McGraw-Hill Book Company Inc., 1938. 287-94.

Howard, Nicholas. *A Basic Coil Gun*. < http://www.geocities.com/njh_howard/mysite/basic_coilgun.html >

Miller, Greg. *Coil Gun Kit Instructions*. < http://www.angelfire.com/80s/sixmhz/cgkit.html >

Paul, James. *Coil Gun Basics*. < http://www.coilgun.eclipse.co.uk/coilgun_basics_2.html >