The Magnetic Physics and Mechanics of a Coil-Gun

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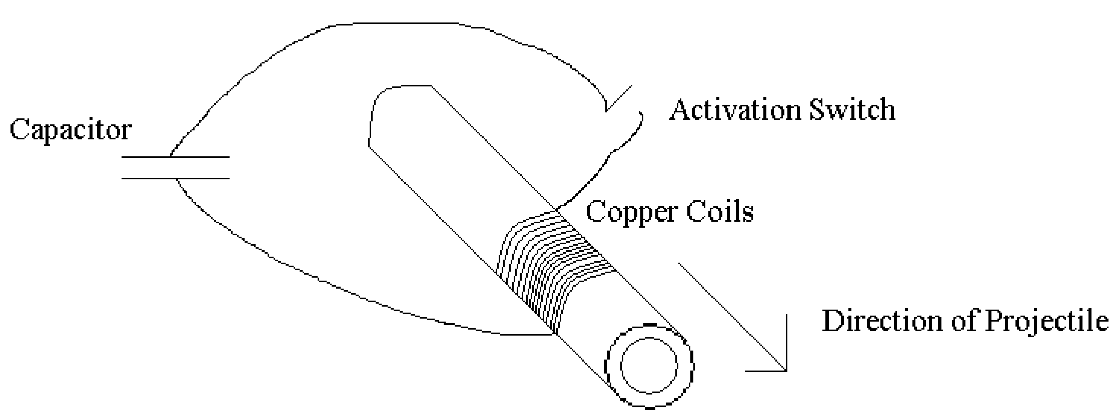
A coil-gun, like a rail-gun, uses magnetism to propel a projectile. The purpose of this honors project was to create a system that mirrored the effects of a coil-gun without actually creating a dangerous weapon. While this technology was patented back in 1900, its progression has been surprisingly minimal.

Building a Basic Coil-Gun:

The materials used include a length of .5 inch diameter PVC pipe, 22 and 30 gauge enameled copper wire, electrical tape, a disposable camera, a solder iron with solder, an electric on-off switch, and a small ball-bearing.

The disposable camera was the key to the whole process. A special thank you goes to Wal-Mart for providing the disposable cameras free of charge. The camera's purpose was to provide a reasonably sized capacitor as well as a very easy method to repeatedly charge the capacitor. The camera's front and back panel must be removed to access the circuit board where the capacitor is. With board fully exposed, the camera is set down and the building of the coil-gun begins. A six inch section of wire needs to be cut off and saved for a later time. Then the rest of the 30 gauge wire is then wrapped around one end of the PVC pipe. The wrapping is started about 0.5 inch inward from the edge of the pipe, and is then wrapped repeated over about a 1.5-2.0 inch area until the spool is emptied. Six inches of wire needs to be left open from the start and end of the wire to connect to the capacitor. After the wrapping, wrap the coils with a few layers of electrical tape. This, although not nearly perfect, will help contain the electric field created. This will concentrate it more inside the pipe, amplifying its effect on the projectile. Both of the ends of the wire also need to be sanded to remove the enamel coating; otherwise no charge will be able to get through. All the pieces are now in place, everything now needs to be connected into a single system.

On the camera's circuit board, there are two contact points where the capacitor's ends are soldered. The end of one of the wires coming from the PVC pipe needs to be soldered to one of these contact points. It is important to note that the other end cannot simply be soldered to the other contact point. Without a switch to break the system, the coil-gun would simply act as a resistor that would drain the battery charging the capacitor without ever letting the capacitor fully charge. So, to avoid this, the other wire coming from the pipe needs to be soldered to one of the prongs on the switch. The switch used in this case is just a small switch bought from Radio Shack. The six inch length of wire saved from before is now used to connect the other prong on the switch to the other contact point on the circuit board. Once this is soldered, the system, and therefore the coil-gun, is complete. It should look something akin to:



To test out the coil-gun, make sure the switch is set to the 'off' position, and then place the battery in the disposable camera. Once the battery is in, press the button on the front of the circuit board to charge the 'flash'. A little orange light on the back of the board will glow when the capacitor is fully charged. Next, while making sure the PVC pipe is completely level, place the ball-bearing in the pipe. It needs to be placed so that its center is aligned with the back end of the coils. Then, flip the switch. The ball bearing will be shot out of the PVC pipe.

Physics Behind a Coil-Gun:

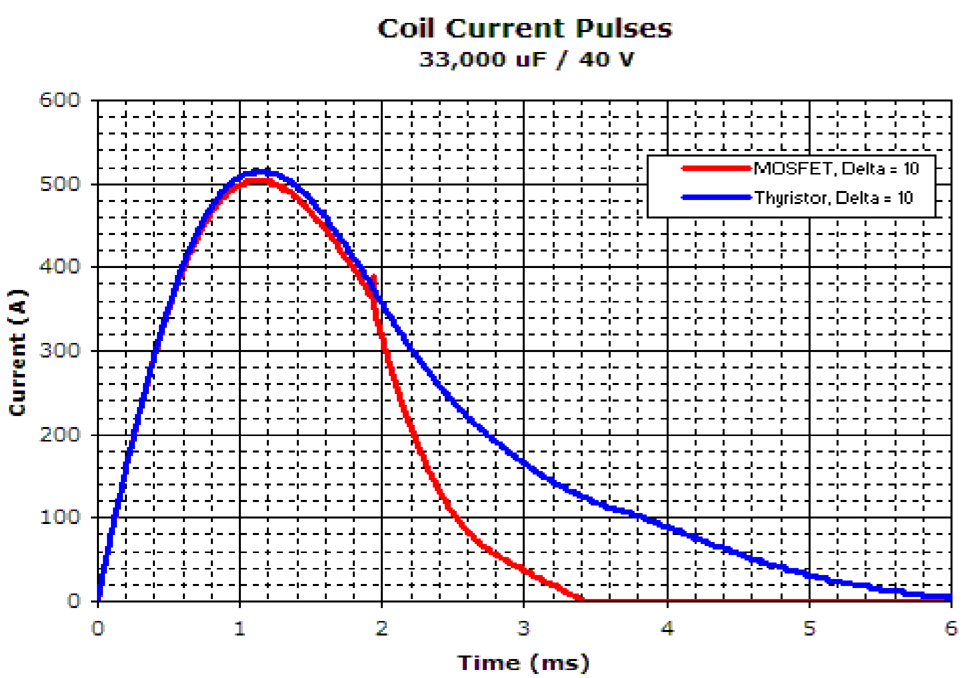
With the mechanics of a basic coil-gun explained, the magnetic physics behind it can be made clear. When charged, the capacitor is storing a significant amount of energy. This amount can actually be calculated using the formula:

$$U = .5(Q\Delta V^2)$$

The charge and voltage capabilities of a capacitor are labeled on its side. The capacitor used in this project had a charge capacity of 80μFarads and a voltage rating of 330Volts. Plugged into this formula yields:

$$U = .5(0.00008F*(330V)^2) = 4.356 \text{ Joules}$$

When this energy is run through the coils, the moving current creates a field that is directed toward its center. However, due to the quick dissipation of the capacitor, the field only lasts for a fraction of a second. If this were not true, then the projectile would simply oscillate around the center of the coil until the field collapsed. Because of this quick dissipation though, the projectile is rapidly pulled toward the center, then, with the field gone, its own momentum carries it out of the launch barrel. The graph of Current vs. Time would look very similar to:



http://www.coilgun.eclipse.co.uk/thyristor_fired_coilgun_results_conclusions.html

The velocity at which the projectile exits the launch barrel is relatively simple to experimentally calculate with a weak coil-gun as in this project. The velocity calculations need to be broken up into its 'x' and 'y' components. The simplest way to do this is to set the barrel completely horizontal on an elevated surface before launch to make the 'y' component of the muzzle velocity equal to zero. The exact point the projectile lands after it is launched is important for this calculation, so laying contact paper near where it should land will aid in the measurements. Next, after the projectile has been launched a few times, the average landing point should be taken from all the launches. This distance will be the 'x' component. The distance to the floor from the center of the PVC pipe also needs to be measured as the 'y' component. With these two values in place, calculating the muzzle velocity is just a matter of relating a few kinematic equations.

First, the time the ball-bearing took to hit the ground must be found. To do this, start with the basic 'y' acceleration formula for a projectile on Earth:

$$a(t) = -9.8\frac{m}{s^2}$$

This is just stating that the only force affecting the projectile is gravity, which pulls at 9.8 m/s^2. Next, integrate the formula to form the 'y' velocity formula:

$$v(t) = \left(-9.8\frac{m}{s^2}\right)t + C_1$$

Where 't' is time in seconds and C is the constant of integration. This constant can be found using one of two ways: intuitively realizing that it equals the initial velocity, or by plugging into the formula the initial constraints of the system v(0) = 0. Both are fundamentally the same, the second option explains in a more clear manner though, why C=0. So, the simplified 'y' velocity formula is:

$$v(t) = \left(-9.8\frac{m}{s^2}\right)t$$

Then, once again, this formula needs to be integrated to form the position of the projectile at any time 't'. Integrating it yields:

$$y(t) = \left(\frac{-9.8}{2}\frac{m}{s^2}\right)t^2 + C_2$$

where C_2 is a new constant of integration. The same methods can be used as above to find this new constant of integration. Using the initial constraints of this problem, y(0)= 0.5715m, C_2 is found to be equal to 0.5715m. The final position formula:

$$y(t) = \left(\frac{-9.8}{2}\frac{m}{s^2}\right)t^2 + 0.5715m$$

can now be used to find the time it took for the projectile to reach the ground. This can be accomplished by setting the entire equation equal to zero.

$$y(t) = 0 = \left(\frac{-9.8}{2}\frac{m}{s^2}\right)t^2 + 0.5715m$$

$$(-.5715m)\left(\frac{2}{-9.8}\frac{s^2}{m}\right) = t^2$$

$$t = \sqrt{0.11663s^2} = 0.3415\ s$$

Now, knowing the total time the process took to complete, the muzzle velocity can be found. It will be equal to the total 'x' distance travelled divided by the total time it took to travel the distance.

$$Muzzle\ Velocity = \frac{0.5588m}{0.3415s} = 1.636\frac{m}{s}$$

In Conclusion:

While there are some very positive pros to a coil-gun, especially over the guns we typically use now, such as the absence of moving parts, noise, and the need for combustion, mass production and usability at this point and time for militant purposes is unrealistic. As technology progresses though, this technique for projecting an object may become very useful, not only for weapons for possibly for projecting objects into space without the use of massive amount of fuel. Magnetic propulsion definitely has potential to become extremely useful, however at the current time, it has not developed enough financially and practically to reach its potential.

References:

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