**Efficiency of an Air-Core Induction Linear Accelerator**

**Abstract:**

The purpose of this paper is to compare the input energy of an Air-Core Induction Linear Accelerator (commonly known as a Coil-gun or Gauss Cannon) to the output energy of the projectile. The input energy is supplied from a voltage discharge from a capacitor which is calculated from the equation E = ½ C\*V2, where C is the capacitance and V is the voltage across the capacitor. Output energy is calculated from the velocity and the mass of the projectile (E = ½ m\*v2). This paper presents a “photo-gate” apparatus which consists of an infrared diode and a photodiode with infrared sensitivity used to determine the muzzle velocity of the accelerator.

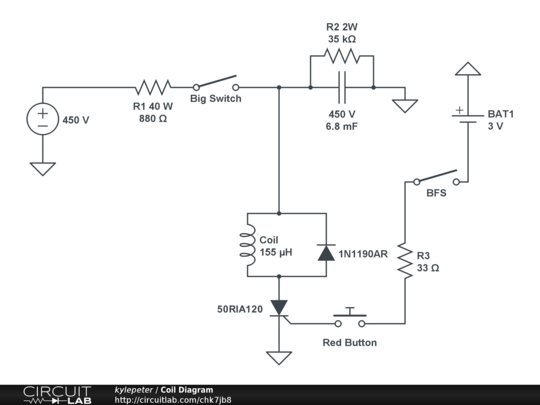
**Introduction:**

An Air-Core Induction Linear Accelerator (which from this point forward will be referred to as a Gauss Cannon or Coil-gun) uses the magnetic field produced by current running though an inductor to accelerate a projectile made of ferromagnetic materials.

Data collection for this experiment was conducted using a programming environment developed by National Instruments called LabVIEW. This application is a “highly productive development environment” which allows users to “rapidly design and deploy measurement and control systems.”[[1]](#endnote-1) In this research, a LabVIEW program was used to control the input voltage across the infrared diode of the photo-gate as well as to monitor the output voltage across the photodiode. The program took as an input the number of samples to be taken, the desired sampling rate, the length of the projectile, the voltage to be placed across the infrared diode, and a voltage threshold which would be used to determine when there was an object in the gate. The program gave the time in the gate, the muzzle velocity, as well as a graph of the voltage measured across the photodiode as a function of time. This graph was used to determine an appropriate voltage threshold level as well as provide the user with a visual representation of the run.

The muzzle velocity is found from detecting the amount of time the projectile spends in the photo-gate and by measuring the length of the projectile that will be crossing through the gate. During data collection, a voltage is applied across the infrared diode in the photo-gate and the voltage across the voltage diode is measured with a sampling rate of 500 kHz. When an object passes through the photo-gate and blocks the infrared radiation produced by the diode from reaching the detector, the voltage level across the photodiode in the gate drops. For every sample that the voltage across the photodiode is below the voltage threshold inputted by the researcher, a variable representing the number of samples the projectile is in the gate is incremented. At the end of the run the number of samples is divided by the sampling rate which results in the time that the projectile spent in the gate. The length of the projectile can be divided by the time spend in the gate to give the velocity. From here, the measured mass can be combined with this velocity to determine the output energy of the Coil-gun.

**Experimental Set-up:**

 The photo-gate detector was designed incrementally from testing the concept with the LED and the photodiode in a breadboard to the final product which was a standalone detector. The final product can be seen in Figure 1 with additional images of the apparatus available in Appendix B. The computer interface was upgraded from a standard USB data acquisition card capable of collecting data at 40 kHz to a modular one capable of data collection rates of 500 kHz. While the concept and the actual set-up of the photo-gate detector didn’t change much, this upgrade in computer interface made data collection much more accurate and made the detector capable of recording objects moving at very fast velocities. The theoretical maximum velocity this device can detect is an object moving at a speed at the length of the object multiplied by the 500 kHz. For the projectile fired from the gauss cannon analyzed in this paper which had a length of 2.6 cm, the detector could theoretically detect it traveling approximately 12.5 km/s. However there are a few limitations of the device which need to be considered when doing error analysis and therefore the actual maximum velocity that it can detect may not be on this magnitude. For the scope of this research however the detector is more than capable of detecting the projectile traveling on the order of tens of meters per second which is the scale that this gauss cannon operates on.

The Gauss Cannon itself has a fairly simple construction. It is a single stage coil gun using an air-core inductor made from 16-gauge copper wire wrapped around a piece of PVC piping (which serves as the barrel), a capacitor, and a SCR switch. Figure 2 displays the circuit diagram for the gauss cannon and the various safety switches and the firing mechanism. Located at the middle of the diagram is the coil-gun labeled coil in series with a LED oriented backwards to combat back EMF. The inductance of the coil is 155 μH. The capacitor is located above and to the right of the coil apparatus with the charging mechanism located to the left of it. The SCR is below the coil-gun with the various switches branching off to the right preventing an accidental firing of the cannon. The capacitance of the capacitor is 6800 μF and has a voltage rating of 450 Volts. The SCR is used as a switch because it allows a large amount of current to flow very quickly through the coil gun. When a small input voltage reaches a threshold point the SCR allows the capacitor to dump a large current across the coil-gun thereby producing the necessary magnetic field to propel the projectile.

**Methods:**

**Determining Uncertainty:**

One source of error to the velocity calculation is due to the uncertainty of the actual position of the projectile when the photo-gate registers that it is inside. It is possible for the projectile to have moved slightly into the gate in-between the collection of samples. However, assuming that the projectile is moving on the order of 20 m/s, the change of position in 1/500k of a second is very small and therefore is a very small contribution to the error. Another issue is the “beam” of infrared photons between the LED and the photodiode isn’t perfectly collimated, and therefore it is difficult to determine how far into the gate the projectile has to be in order for the photodiode to register a voltage drop.

**Data:**

**Analysis:**

**Conclusions:**

1. http://www.ni.com/labview/whatis/ [↑](#endnote-ref-1)