A REVIEW ON ADVANCEMENTS IN ELECTROMAGNETIC COIL GUN MECHANISM

Parshuram Omble
Department of Mechanical Engineering,
Saraswati College of Engineering,
Email - ombleparshuram@gmail.com

Shubham Madhavi
Department of Mechanical Engineering,
Saraswati College of Engineering,
Email - shubhammadhavi@gmail.com

Sagar Howal
Department of Mechanical Engineering,
Saraswati College of Engineering
Email - sagarhowal1@gmail.com

Shubham Gupta
Department of Mechanical Engineering,
Saraswati College of Engineering
Email - iamshubhamgupta@gmail.com

Prof. Nilesh Chanewar
Department of Mechanical Engineering,
Saraswati College of Engineering
Email – nilesh.chanewar@rediffmail.com

A ground based electrically powered launcher could appreciably reduce the complication and cost of space launches for moderate weight payloads. This paper presents results of a study to calculate the required specifications. This study is based on electromagnetic gun technology which is constrained to a coaxial geometry to take advantage of the efficiency of closely coupled coils. Each coil is fired one after the other as the projectile moves down. A hybrid power electronic system has been used for firing of a projectile with no chemical substances, no loud noise or fire. With this in mind, this paper presents the electronic weaponry, which brings a great revolution in the field of advanced weaponry systems in our country and makes us proud.

Keywords— coilgun, projectile, propulsion, electromagnetism

I. INTRODUCTION

A gauss gun or coil gun is a type of projectile accelerator consisting of one or more coils used as electromagnets in the configuration of a linear motor that accelerate a ferromagnetic or conducting projectile to high speed. Mostly in coil gun configurations, the coils and the gun barrel are arranged in a line. It is not a rifle as the barrel is not rifled. The name "GAUSS" is in reference to Carl Friedrich Gauss, who made a mathematical description of the magnetic effect used by magnetic accelerators.

The fabrication of coil gun having projectiles ranging from 10 g to 5 kg and speeds up to 1 km/s. Research has been undergone to increase the speed and its constructional features. It is suitable for army purpose and has a future in next generation advance weaponry.

Coil guns are electromagnetic guns that use the Lorentz force [1] to speed up a projectile with a conducting projectile. It consists of coils arranged along a barrel, so the path of the accelerating projectile lies in line of the coils. The coils are switched on and off in a small timed sequence, causing the projectile to be speed up quickly along the barrel because of magnetic forces. When it is fired, an alternating current flows through the coil creating an alternating magnetic field. The field magnetizes the iron, which induces a circumferential alternating current in the ring. This current is repelled by the magnetic field, making the ring jump from the core at a distance of a few meters.

As the magnetic flux changes, the current is induced in the ring, resulting in a strong force. In 1933, Texan inventor Virgil Rigsby developed a stationary coil gun that was fabricated as a machine gun. It was powered by a generator and a large electrical motor. Similar principle is used in numerous areas such as linear motors, Maglev Trains, Roller coasters, etc. Coil gun use electromagnetism to propel the projectile rather than using an explosive charge or gun powder.

Hence it is also called as fireless gun or a silent machine gun. Coil gun requires high voltage, high

amperage, and high speed electrical switches. We can have a higher max projectile velocity. Powerful switches alternate the electromagnetic poles in the drive coils as the projectile passes through the coils. Many firearms operate by expanding gasses which forces a projectile out of a barrel at high speed. The propulsion for these systems is detonation of gunpowder that causes an explosion behind a projectile positioned in a tube. Systems that operate on gunpowder are very loud and leave residue in the barrel making them prone to malfunction which requires cleaning for continued use. With new research and innovation in electronics weapons systems, gunpowder may soon become a thing of the past. In this report we come across the Construction, Design Aspects, Working and Application of the Gauss rifle.

II. CONSTRUCTION AND WORKING

A coil gun consists of a coil of wire, an electromagnet, and a ferromagnetic projectile [2] placed at either ends. This type of coil gun is formed similar to the solenoid used in an electromechanical relay [3], i.e. a current carrying coil which will draw a ferromagnetic object through the middle. A large current is pulsated through the coil of wire and a strong magnetic field is formed, pulling the projectile to the center of the coil. When the projectile nears this point the electromagnet must be switched off in order to prevent the projectile from being stuck at the center of the electromagnet. Pphoto-sensitive sensors [4] or infrared sensors [5] are used for this part. These sensors are linked to the circuit. As soon as the projectile is pulled, the sensor senses the projectile and the circuit is switched-off.

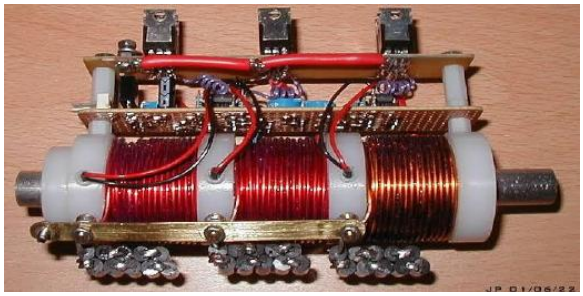

Figure 1. Diagram of Coil Gun Geometry

This way ferromagnetic projectile is projected outward. The projectile is situated at one end of the coil and is pulled to its center by magnetic induction. When the current is switched off, the projectile travels forward down the barrel, exits the gun and moves towards the intended target. The force applied to the projectile is proportional to the change in inductance of coil with respect to the change in position of the projectile and current flowing through the coil. The forces are characterized by the current and the variation in the mutual inductance between the projectile and coils. More advanced coil gun designs incorporate a number of accelerator coils switches sequence as the projectile moves down the barrel. The heart of this project is a miniature of a fire free, sound free gun.

In order to increase the speed of the projectile there are two main setups for a coil gun, Single stage and multistage. A single stage coil gun uses one electromagnet to propel a projectile. A multistage coil gun uses several electromagnets in succession to progressively increase the speed of the projectile. This increases the speed of the projectile by many folds.

III. DESIGN ASPECTS

To develop a coil gun there are some aspects which are to be kept within check. As the coil gun works on the principle of induction and repulsion. The nature of current, magnetic field, etc. are to be designed. These are the following factors which significant importance is to be given while developing an Electromagnetic Coil gun.

A. Magnetic Circuit

The current flowing in a magnetic field suffers an action of a force. Two conductors with currents flowing in the same direction are attracted to each other and two conductors with currents flowing in opposite direction are repelled from each other. The same applies to two parallel conductors with the shape of a ring. Using currents that flow in the same direction makes them attract each other. Using currents that flow in the opposite directions makes them repeal each other. This is the repulsion principle of the apparatus. The current in the coil is opposite to the induced current in the projectile, resulting in a force applied to it. But is the current from the coil really opposite to the induced current? The alternating current applied to the coil creates in the core an alternating magnetic flux that is directly proportional to the current and induces an alternating current advanced Π/4 from the source current. So, the resulting force is repulsive in half a period and attractive in the other half. If repulsive and attractive forces were of the same magnitude, the projectile would remain motionless, or oscillate around a point, due to the balanced resulting effect. A more careful analysis shows that this does not take place. The ring is actually launched, so the resulting effect cannot be

a balanced one. In fact, the repulsive forces are stronger that the attractive ones creating an overall repulsive force. Regardless the friction, the acceleration [6] of the projectile in the driven coil is:

$$Fp = ma = \frac{m(V2 - V1)}{(t2 - t1)} \dots\dots\dots (1)$$

Where,
Fp = electromagnetic force experienced by the projectile.
m = mass of the projectile (in Kg).
V 1 = velocity of the projectile at time t1.
V2 = velocity of the projectile at time t2.

B. Electric Circuit

Power is supplied to the electromagnet from some sort of fast discharge storage device, typically a battery, or high capacity high voltage capacitors (one per electromagnet), designed for fast energy discharge. A diode is used to protect polarity sensitive components (such as semiconductors or electrolytic capacitors) from damage due to inverse polarity of the voltage after turning off the coil.

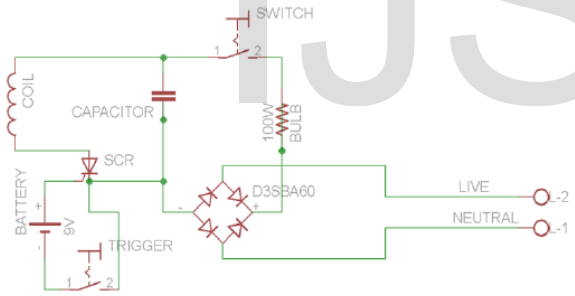

Figure.2. Circuit diagram of coil gun stage.

The coils on the coil gun have to be wired based on the schematic shown above.. An SCR (Silicon Controlled Rectifier) [6] is used to control the high voltage supplied to the coil, it acts like a switch. When a voltage is applied to its gate via a small battery, the diode is activated and the cathode and anode can be connected to the coil just like a normal diode. A switch that controls gate voltage being applied to the SCR essentially controls the current going to the coil and acts as our trigger for the coil gun. High gauge copper wires should be used while connecting the capacitors and the coils.

C. Switching Circuit

One main obstacle in coil gun design is switching the power through the coils. There are several common solutions; the simplest is the spark gap, which releases the stored energy through the coil when the voltage reaches a certain threshold.
A better option is to use solid state switches; these include IGBT's [7] or Power MOSFET's [8] and SCR's. The time of firing of individual coils in the gun is based on the position of the projectile's armature, not a pre programmed time. However, once the correct position has been sensed for a given coil, there will be a delay until current flows from that coil's capacitor bank.

IV. FACTORS AFFECTING THE PERFORMANCE OF COIL GUN.

A. Efficiency

The overall energy conversion efficiency is determined by the ratio of Kinetic energy [9] increment and the original electric power energy in the capacitors. The equation is

$$\eta = \frac{Wm}{Wc} = \frac{\frac{1}{2}m(v_2^2 - v_1^2)}{\frac{1}{2}CV^2} \dots\dots\dots (2)$$

Where,
Wm = Kinetic energy increment,
Wc = Original Electric energy stored in the Capacitors.
m = Mass of the projectile (in Kg).

B. Temperature rise of the coil

The temperature raise of any coil can be calculated with the following equation (3).

$$\Delta T = \frac{R}{C_v m_c} \int I^2 \, dt \dots\dots\dots (3)$$

Where,
Temperature raise in degree Celsius.
R = Resistance of the coil.
= Specific heat capacity of the coil material.
= Mass of the coil.

Both the heat capacity and resistivity [10] is temperature dependant, which may need to be accounted for when a large amount of heating in unavoidable, otherwise they can be assumed to be constant.

Generally speaking,

$$B^2 \text{ is proportional to } (NI)^2$$
$$I^2 \propto \frac{B^2}{N^2} \ldots\ldots\ldots (4)$$

Where,
I = Current in the coil.
N = Number of turns of the coil.
B = Magnetic flux density in the coil.

This means that for a given acceleration [11], the temperature rise is only dependent on the coil geometry and input energy, not the number of turns. Discharge times are typically too fast to extract heat during the discharge. Forced cooling using air, water or oil can only be utilized to extract heat between shots.

V. ADVANTAGES AND DISADVANTAGES

The electromagnetic coil systems are silent when projectiles are fired at high velocities as compared to the speed of sound and are low maintenance. These coil guns are highly versatile in nature where it can adapt to many different areas of applications. This concept of coil gun has a number of areas for implementation which can also be launch of satellites and missiles. Explosive gun powder can become redundant.
There is also the peak power issue, combustibles [12] can give out high amounts of energy in short time, and to do that with electricity need of good capacitors, since a battery or generator won't be able to put out enough instantaneous power. User is prone to electrocution. Proper insulating safeties have to be taken in count before dealing with voltage of higher ratings. Shots taken after the first short might be affected by heat building up on the rails and making the metal more malleable, potentially causing error margins to increase when the fire mission demands accuracy.

VI. APPLICATIONS OR POTENTIAL USES

- Much higher efficiency and energy can be obtained with designs of greater expense and sophistication. In 1978, Bondaletov in the USSR achieved record acceleration with a single stage by sending a 2 gram ring to 5000 m/s in 1cm of length, but the most efficient modern designs tend to involve many stages.
- Electromagnetic aircraft catapults are planned, including on board future U.S. Gerald R. Ford class aircraft carriers. An experimental induction coil gun version of an Electromagnetic Missile Launcher (EMML) has been tested for launching tomahawk Missiles.
- A coil gun based active defense system for tanks is under fabrication at HIT in China.
- NASA is planning to create a coil gun based launcher to launch small satellite.

VII. CONCLUSION

Coil gun is a simple application of Lorentz Law[13]. Is a type of projectile accelerator consisting of one or more coils used as electromagnets in the configuration of a linear motor that accelerate a ferromagnetic or conducting projectile to high velocity. The physical principles that rule its operation were briefly introduced. Also, some construction details have been given.

REFERENCES

[1] Lorentz Force: The force exerted on a charged particle moving with velocity through an electric and magnetic field. The entire electromagnetic force on the charged materials (iron) form permanent magnets.

[2] Ferromagnetic Projectile: A material (iron) which can be easily magnetized by applying current to it.

[3] Electromechanical Relay: It is an electromechanical switch used to control, protect, and operate various circuits or system.

[4] Photo Sensitive Sensor: It is the most sensitive for the environmental light intensity and it is generally used for detecting the ambient brightness and intensity.

[5] Infrared Sensor: It is used to sense certain characteristics of its surroundings by either emitting or detecting infrared radiation.

[6] Silicon Controlled Rectifier (SCR): A semiconductor device that functions as an electrically controlled switch.

[7] IGBT: An insulated gate bipolar transistor -3 terminal power semiconductor device primarily used as an electronic switch.
[8] Power MOSFET: It is a specific type of metal oxide semiconductor field –effect transistor designed to handle significant power levels.

[9] Kinetic Energy: It is the work needed to accelerate a body of a given mass from rest to its stated velocity.

[10] Resistivity: Fundamental property that quantifies how strongly a given material opposes the flow of electric current.

[11] Acceleration: Rate of change of velocity of an object with respect to time.

[12] Combustibles: Capable of catching fire and burning; inflammable; Gasoline. Highly combustible.