DESIGN AND IMPLEMENTATION OF AN ELECTROMAGNETIC PROPULSION SYSTEM

O.M.Butt, A.Raza

Department of Electrical Engineering
University of the Punjab, Lahore, Pakistan

Abstract:

Enhancement in technology is the need of the day for all nations in the world. Development in the defense field has been increased tremendously and today's war is utterly dependent on technology. Hence rapid advancement in technology is desirable in order to lead the world. Wars and defense techniques have been changed with the passage of time. In present era survival is only reliant on the most effective, advance and purposeful techniques. Therefore, to meet this prerequisite, development of a new concept which is different from the conventional war techniques has been discussed in the present work.

Keywords: Electromagnet, Coil, Rectifier, Inductance, Circular mills, Flux, Acceleration

1. Introduction:

Propulsion is the basic criterion of warfare. Here, the technique is focused to change this conventional procedure according to requirement. The techniques discussed in this work is not only limited for war purposes but could also be useful for civilian use like firing rockets in space for astronomical purposes etc. Conventional propulsion mechanism is based on some firing technique in which some kind of detonation is involved in which a fuel or gun powder is detonated to create propulsion to the object which is to be fired. Thus the main focus is to create high speed propulsion without detonation.

The main principle of this technique is based on the phenomena of electromagnetism which will explain how the magnetic propulsion is more beneficial than the conventional one.

The main feature of magnetic technique is:

- Propulsion can be created without fuel.
- It is cost effective and can deliver more quantity of package as deliver with the same size of rocket or bullet
- Its velocity is easy to modify and adjustable

2. Working:

A 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 velocity. In coil gun configurations, the coils and the gun barrel are arranged on a common axis. [1],[2] The coils are switched on and off in a precisely timed sequence, causing the projectile to be accelerated quickly along the barrel via magnetic forces.

.Each stage acts on similar principles to those of a solenoid. Current loops induce magnetic flux through their center. When the conductive projectile approaches the air-core current loops, two phenomenons occur i.e as the loop inductance increases,the projectile become magnetized. Secondly this magnetized projectile is then attracted to the loop magnetic field.

2.1 *Experiment:*

Keeping in view the above phenomena, a prototype of three stage coil gun is successfully completed and fruitful results have been obtained. A fully insulated and a non-magnet material are used as a barrel for firing.

2.1.1 *Mechanism*

This prototype consists of 4 parts.

1. Coils 2. Controller (heart of the system) 3. High power rectifier 4. IGBT switches

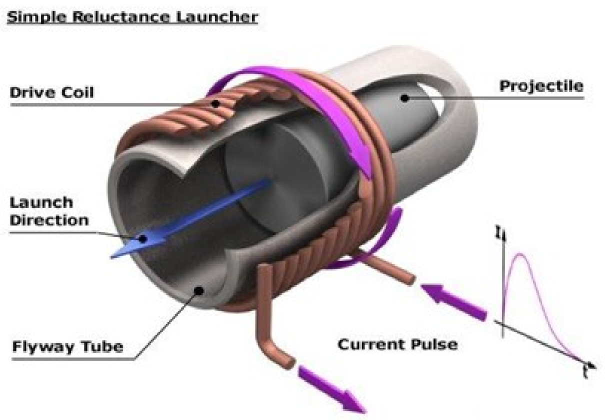


Figure 1 [3]

2.1.2 *Coils:*

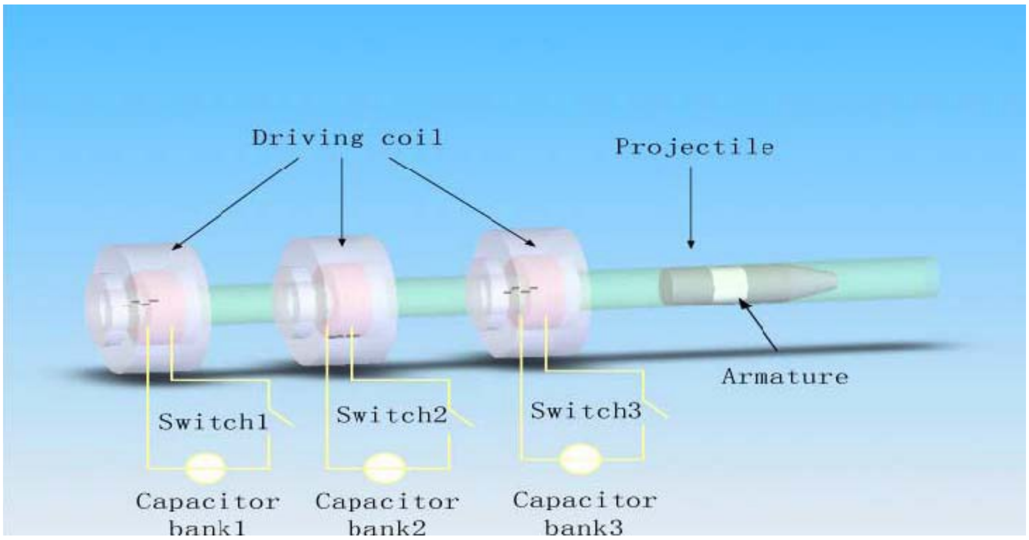


Figure 2 [1]

Three coils were wrapped on to the barrel cascadely. Following is the data for the design of coils

Length of coil = 72mm

Diameter = 70mm

For the bullet, mild steel (0.17% carbons) was used as it is one of the best ferromagnetic material. The data for bullet is as under:

Mass = 80 gm

Length = 76 mm

Diameter = 15 mm

Controller:

To control the various functions of the gun, AVR microcontroller model name ATMEGA 8 is used. There are two switches attached to the controller while three outputs are used to control signals for the IGBT.

All input and outputs are buffered and protected by 4N25 opt-coupler. First switch is for the fire mechanism. When the button is pressed, the controller automatically generates the specific timing signals to fire the IGBTS. While second one is used for safety purpose i.e in case of any malfunction in the system, this will cut off the power from the system.

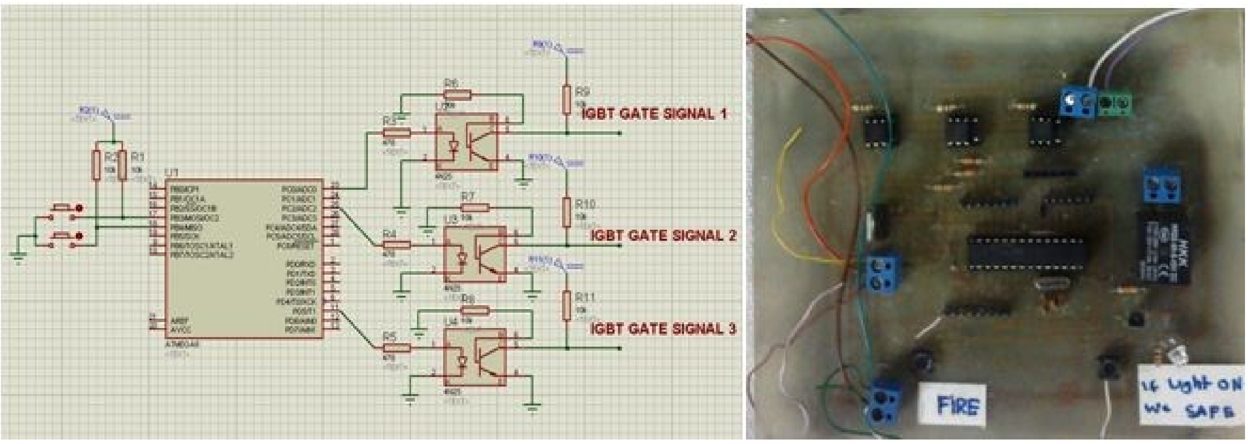


Figure 3

2.1.3 *Rectifier:*

Single phase, 220 volts AC supply is used for this prototype which is when rectified by high power diodes resultant in 300 Volt DC. Large bank of capacitors are required to make a smooth DC voltage [1]. For this purpose 3300uf /350volts capacitor is used for each stage. Each stage (coil) has its own rectifier and capacitor bank.

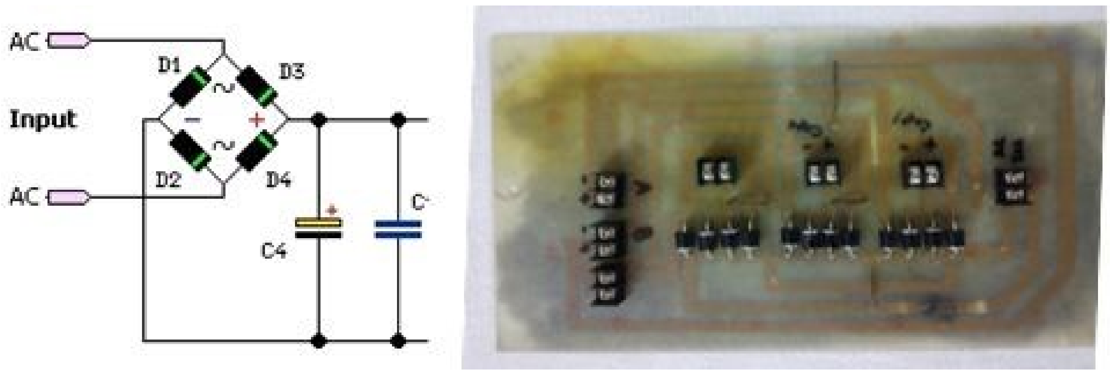


Figure 4

2.1.4 *Insulated Gate Bipolar Transistor IGBT:*

IGBT are most sensitive part of the system. A 500volts/100Amps (2 in one module so combined current is 100 amps, 50 amps each) rating IGBT is used for the experiment. Snubbers and 300 volts zener diodes are used to protect these IGBTs from damaging. In real time there is always a mismatching in IGBTs. This mismatch causes problem for IGBTS even in the single module, as they do not turn on exactly at the same time. One of them turn "on" earlier, even both gate pulses reaches the gate at the same time. Therefore, to make them active at the same time a cross coupled inductor of wire gauge 17Awg with turn ratio of 1:1 is used [4].

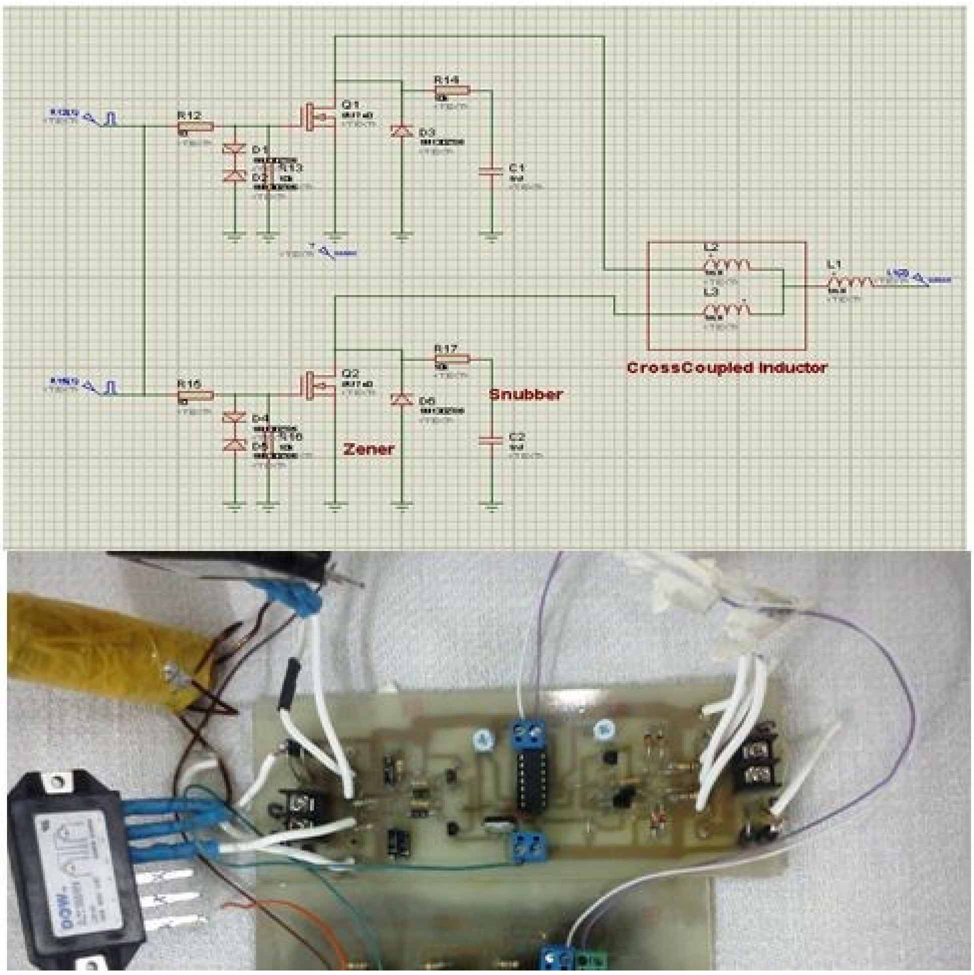


Figure 5

2.1.5 *Block Diagram*

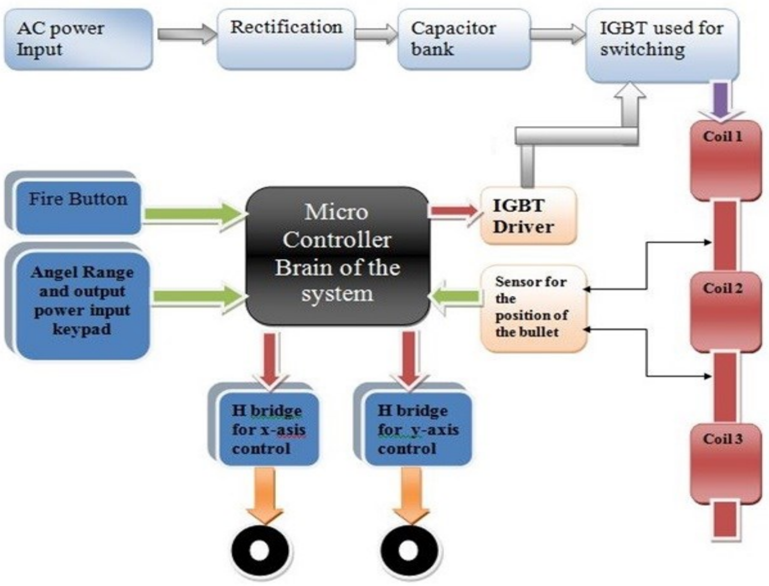


Figure 6

Calculations:

Length of coil = 72mm

Diameter = 70mm

Weight of bullet = 80gm

$F = mg$

$F = 0.08 \text{ x } 9.8 = 0.784 \text{ N}$

If extension factor is 5

Then

$$F = 0.784 \text{ X } 5 = 3.92 \text{ N}$$ [5]

$$A = \frac{(3.14)(0.035)^2}{4}$$

$A = 9.62 \text{ x } 10^{-4} \text{ m}^2$ (Pole face area)

$$F = \frac{B^2 A}{2\mu_0}$$

$$B^2 A = 9.8 \text{ x } 2 \text{ x } 4\pi \text{ x } 10^{-7}$$

$$B^2 = 0.010241$$

$$B = 0.1011 \text{ wb/m}^2$$

$$\text{Core Area} = 2\pi r l + 2\pi r^2$$

$$\text{Core Area} = 2\pi((0.035)(72 \text{ x } 10^{-3}) + (0.035)^2)$$

$$\text{Core Area} = 23 \text{ x } 10^{-3} \text{ m}^2$$

$$\phi = 23 \text{ x } 10^{-3} \text{ x B} \qquad (\phi = \text{Flux})$$

$$\phi = 2.325 \text{ x } 10^{-3}$$

$$H = \frac{B}{\mu_{\circ}}$$

$$H = \frac{0.1011}{4\pi \text{ x } 10^{-7}} = 80452.8 \text{ AT/m}$$

Extension Factors / Parameters	5	30	50
F	3.92	23.52	39.2
B	0.1011	0.2478	0.3614
ϕ	$2.325 \text{ x } 10^{-3}$	$5.699 \text{ x } 10^{-3}$	$22.045 \text{ x } 10^{-3}$
H	80452.8	197192.9	287592.9

Table 1

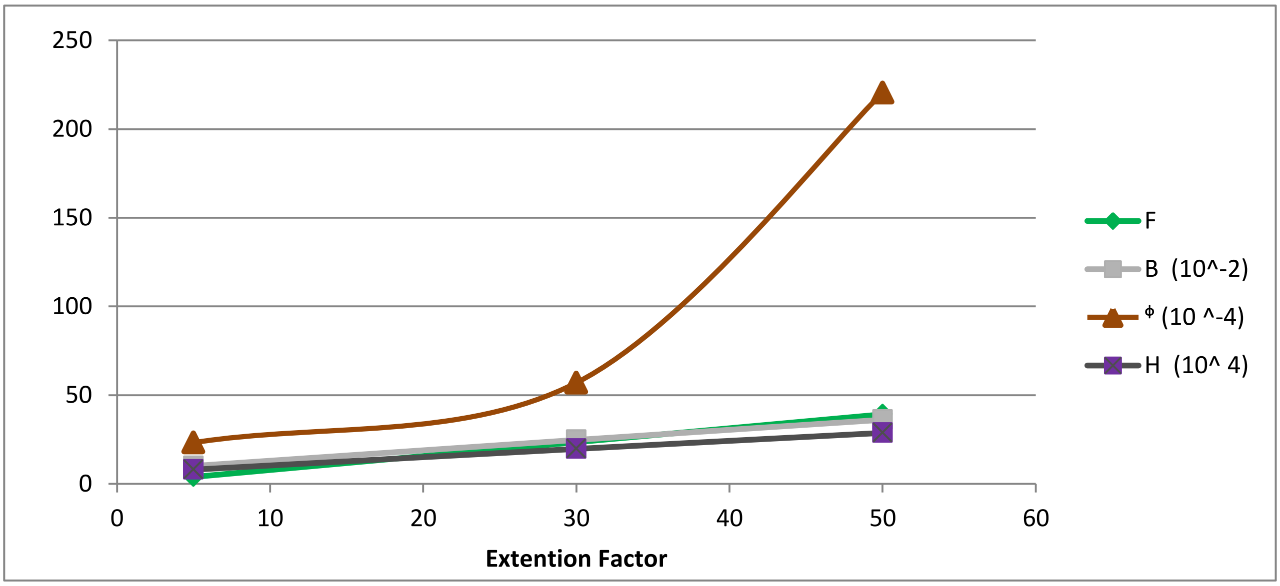


Figure 7

If gap between coil and bullet is = 10mm

$$\mathrm{H\,x\,L} = 0.1011 \mathrm{\,x\,} 0.01 = 804.528 \mathrm{\,AT}$$

If we have 600 turns with diameter of coil 69mm and length 72mm

Then,

$$\mathrm{Current} = \mathrm{I} = 804.528/600$$

$$\mathrm{I} = 1.34 \mathrm{\ ampere}$$

2.3.1 *For wire selection:*

Different current density standards i.e 700, 1000, 1500, 2000 amp/m^2 [5] are available. But for this prototype a density of “1000” have been used.’.

Cir mills = 1000 x 1.34 = 1340

As extention factor and air gap can be increased to achieve maximum efficiency. From above calculations 18 AWG copper wire for coil winding was used as evident from the table (2).

Circular mills	**American Wire Gage**
2050	17
1620	18
1290	19

Gauge standards [5]

Table 2

2.3.2 *Inductance of wire:*

$$\mathrm{Inductance} = \frac{\mathrm{n}\phi}{\mathrm{I}}$$

$$\mathrm{Inductance} = \frac{600(3.13 \mathrm{\,x\,} 10^{-3})}{1.34}$$

$$\mathrm{Inductance} = 1.41 \mathrm{\ henery}$$

2.3.2 *Switching time of IGBT:*

Inductance = 1.41 H

Mass = 80 gm

Current (according to graph) = 31 amp

Volt = 200 volt

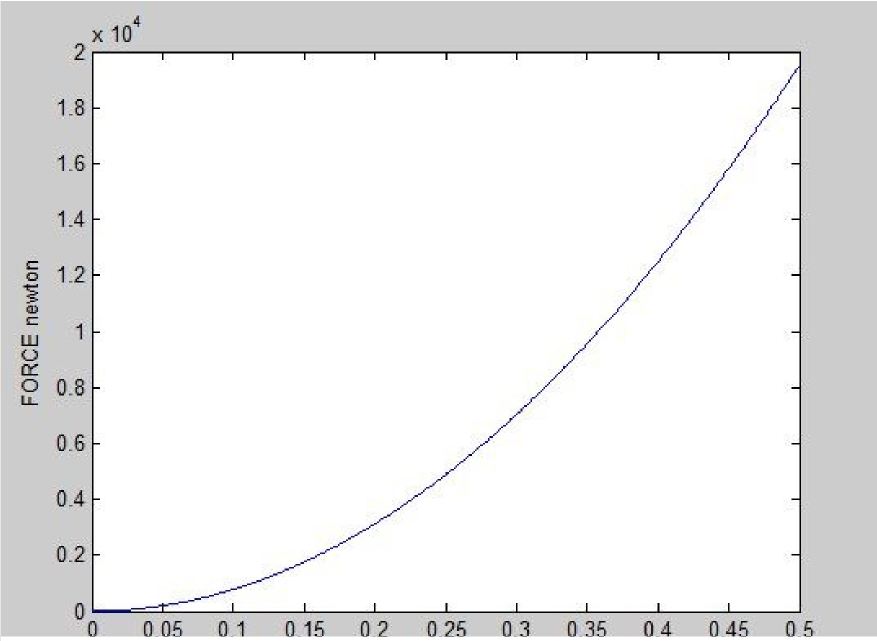
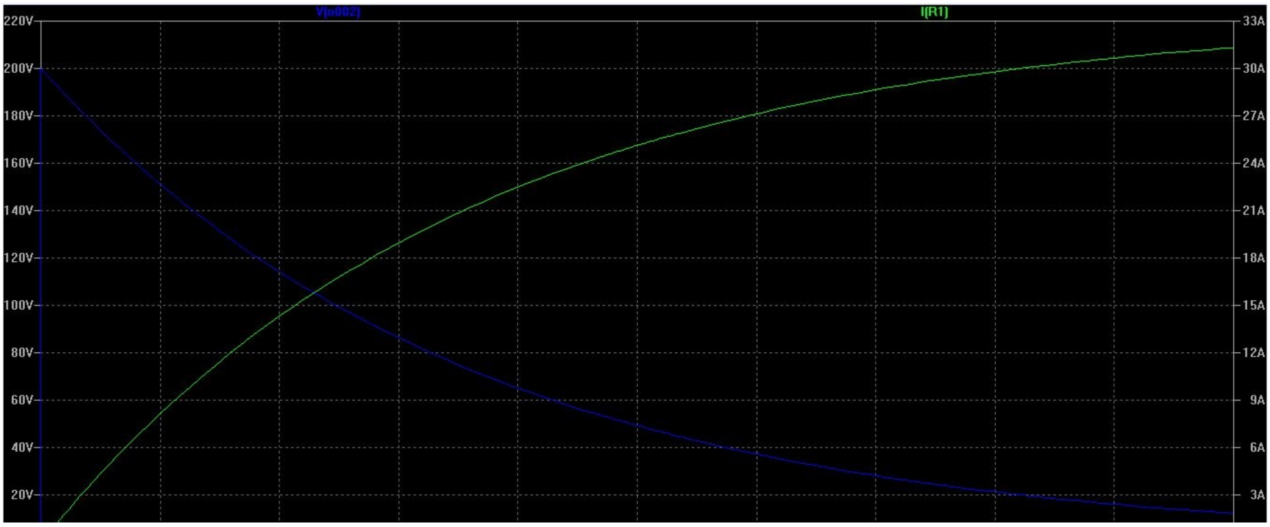


Figure 8



Blue = Volt, Green = Current

Figure 9

Therefore,

Total distance to be travelled by bullet = Air gap + Half of the coil

Note: For bullet to be fired, the coil should be excited till the bullet move to its center and then bullet accelerate due to its inertia. If coil doesn't powered off and bullet move further from its midpoint, than bullet experience a reverse polarity force which exerts an opposite force to the direction of the bullet. As a result, bullet stops in the middle.

Therefore,

Distance = 46.5×10^{-3}m

From the figure (8),

Mean force = 9.282×10^{4}Newton

Time Difference = 0.0002 sec

$F = ma$

$\frac{F}{m} = a$

$a = \frac{9.282 \times 10^4}{0.08}$

$a = 1160250 \ m/s^2$

Time (sec)	Force $\times 10^4$(newton)
0.0108	9.112
0.0109	9.282
0.0110	9.453

Table 3

Now,

S = at^2

S = $(1160250) \times (0.0002)^2$

S = 46.2×10^{-3} m

This is approximately equal to the distance measured.

So the switching time for IGBT is less than 0.011 second.

3. Conclusion

By using the above calculations a prototype test was carried out and successful firing was achieved. Furthermore, following results have also been concluded.

- Power could be increased by increasing number of stages upon the appropriate calculations
- Timing of IGBTs switching plays a vital role in its efficiency. To work with it in an efficient way, cross coupled inductors could be used.
- Size of the capacitor and the solenoid on the barrel determine the maximum power which could be attained through it.

Moreover, it is favourable in war tanks as it can be easily operated and can be more effective for it. In future this research work may proved to be revolutionary in the field of propulsion systems.

References

[1] Zizhou S, Wei G, Bo Z, et al, "The Feasibility Study of High-velocity Multi-stage Induction Coilgun", published in Electromagnetic Launch Technology (EML), 2012 16th International Symposium on 15-19 May 2012, IEEE, Beijing

[2] Davide M, Gabriele G, Roberto P et al, "Ballistic characterization of nanocomposite materials by means of "Coil Gun" electromagnetic accelerator", XIX International Conference on Electrical Machines - ICEM 2010, Rome

[3] www.theinformationarchives.com (accessed on March 2014)

[4] Dennis B, "Unity Gain and Impedance Matching: Strange Bedfellows", RaneNote 124 written 1991; last revised 9/97, Rane Corporation

[5] Dahiru S.S and Sanusi S.A, "Design, Development and Testing of an Electromagnet for magnetic levitation system" Global journal of Engineering and Technology. Vol. 2 No. 3 pp 459-467, Sept. 2009.