Ballistic Testing

Capacitor Driven Electromagnetic Railgun

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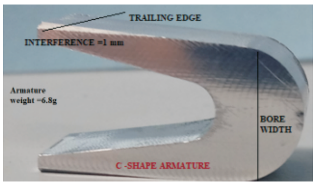

C-shaped armature

ABSTRACT

The article presents the experimental results of developed electromagnetic railgun including its design parameters. The 1.2 meter long rectangular bore railgun launches 6.8g aluminum armature at an exit velocity of 525ms^{-1}. The interference fit between rail and armature interface is selected 1mm. Further the impact of amor piercing shape projectile to defeat stainless steel plate is investigated by electromagnetic railgun system.

KEYWORDS: *PFBR, Fuel Pin, End Plug, Electromagnetic Welding, Automation.*

Introduction

Electromagnetic (EM) railgun is a device designed to launch a projectile with hypervelocity. Railgun is powered by some electrical energy source e.g. a capacitor bank. When the high current (100's kA) with a typical millisecond duration pulse is discharged into parallel conductor of rails, a magnetic field is established surrounding the rails. A conductive armature with a projectile allocated in front of it is placed between two rails. The projectile accelerates forward with JXB electromagnetic force acting on armature.

System Description

The capacitor bank consists of ten capacitors[1]. Each capacitor is rated for 178uF, 15kV DC are further connected in parallel configuration to increase the effective bank capacitance to 1.78mF. The 200kJ, 1.78mF capacitor bank is connected with high coulomb transfer Ignitron switch. The conventional railgun consists of two copper rails. The copper rails are inserted in the G-10/FR4 containment structure to provide the rail insulation. The spacing between the rails is defined as rail bore. Fig.1 represents the 14 x 13mm rectangular bore EM Railgun[2]. The muzzle velocity of projectile depends upon the initial velocity, mass, inductance gradient, current, pulse duration[3,4]. The design parameter of the developed railgun is tabulated in Table 1.

Table: 1

	Electromagnetic Railgun type	Conventional Railgun
1	Bore shape, Bore dimension	Rectangular bore, 14mm x 13mm
2	Railgun length, Inductance gradient (L')	1.2m, 0.3μH/m
3	Rail thickness, material	16 mm, Copper
4	Rail cross sectional area, insulator material	400 sq mm, Garolite (G-10) FR-4
5	Armature shape, material, weight	C-shape, Al 7075, 6.8 gm
6	Total weight of railgun	20 kg
7	Rail armature contact in rails	Metal armature contact

Fig.1: Electromagnetic railgun.

The contact of the armature placed between rails play a significant role in rail lifetime and railgun efficiency[5]. Armature contacts with rail interface is improved by providing armature interference fit in the rail barrel[6,7]. The armature utilized in railgun experiment employing interference of 1mm from each side is shown in Fig.2.

Fig.3 shows the photographs of rails after shot utilizing 1mm interference fit armature. White aluminum deposit from the start point to muzzle end of rail signify that armature has moved in railbarrel with good contact. Erosion damage of rails is least when interference fit armatures are utilized. Fig.4 shows the oscilloscope trace of capacitor discharge current in rails.

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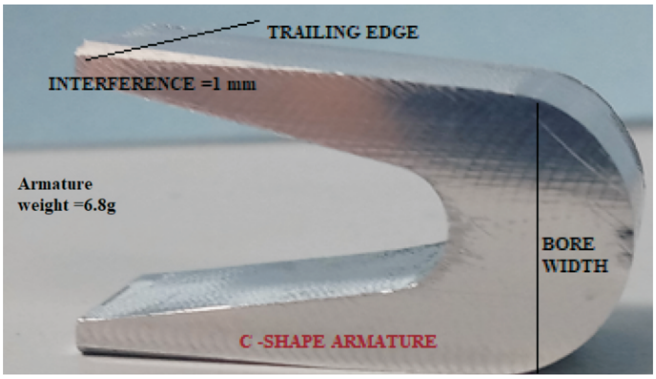

Fig.2:C-shaped armature.

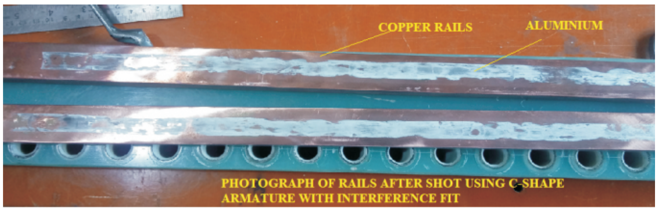

Fig.3: Copper rails after shot.

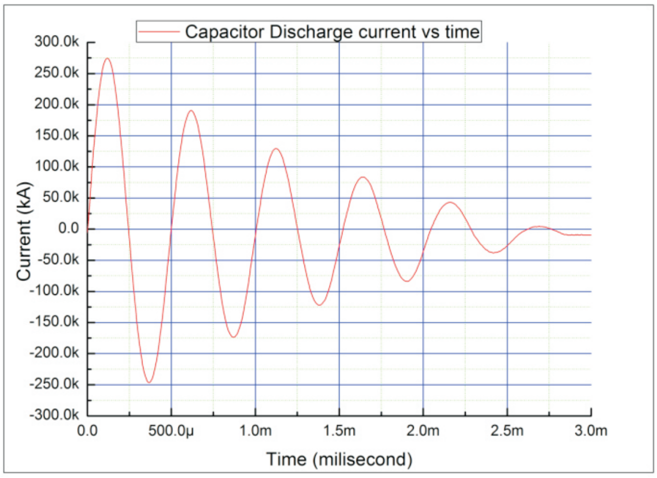

Fig.4: Capacitor discharge current with time.

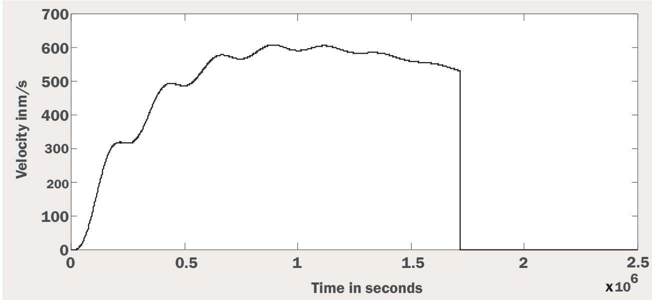

Fig.5:Profile of armature velocity.

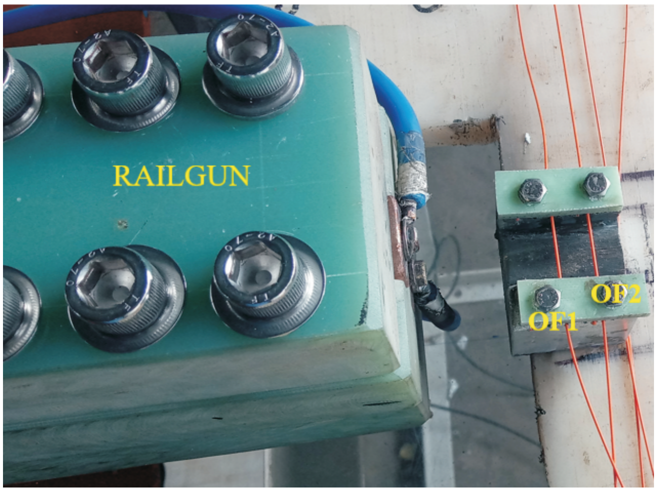

Fig.6: Muzzle velocity measurement setup.

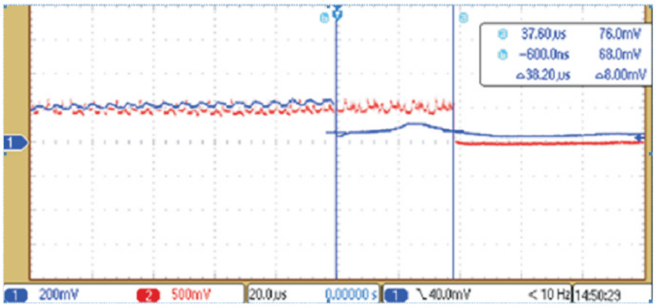

Fig.7: Optical fiber cut signal.

Simulation

The interpretation of armature velocity profile of mass 6.8g for discharge current illustrated in Fig.4 is analysed. The plot shows an estimated armature exit velocity 580m/s when it is placed at 850mm from muzzle end shown in Fig.5. The generalized equations for determining armature velocity is as follows.

$$Facc(t) = \frac{1}{2} * L' * i(t)^2 \quad (1)$$

$$F(a_{fric}(t)) = \frac{2vA}{t} * vel(t) \quad (2)$$

$$Fnet(t) = F(acc)(t) - F(a_{fric}(t)) - F(ra_{fric}(t)) \quad (3)$$

$$Fnet = m * \frac{dVel}{dt} \quad (4)$$

$$Vel(t) = \frac{1}{m} * \int Fnet.dt \quad (5)$$

where *Facc*, F(a_{fric}), F($ra_{friction}$), *Fnet*, *Vel* represents the electromagnetic force, friction force due to air coloumn inside rail bore, friction force due to rail armature interface, net force exerted on armature, armature velocity respectively. Friction drag due to rail armature contact, skin depth factors is not incorporated in this simulation. The oscillatory signature at each time interval of 0.25ms in the velocity profile implies that armature experiences pulsating acceleration. At such interval, the current remains zero. Decrement in armature velocity after 1ms, possibly due to larger frictional drag.

Experimental Results

Solid armature mass 6.8gm is accelerated at an velocity of 525m/s. The armature location prior shot is 850mm from muzzle end. The detailed experiment results is tabulated in Table 2. The muzzle velocity of armature during shot is measured by velocity measurement arrangement shown in Fig.6. Optical fiber F_o1 and F_o2 are positioned at 2cm apart at muzzle end of railgun. Laser light is transmitted through fiber F_o1 and F_o2. When armature hits the fiber, laser light is interrupted. The interruption timing of laser light results in information about exit velocity of projectile[8].

Table: 2

	Railgun detail	14x13 mm Rectangular bore, 1.2 m long
1	Capacitor bank detail	1.78mF, 200kJ
2	Peak Current, Energy, Total time period	275kA, 175kJ, 2.5ms
3	Armature weight, Muzzle Velocity	6.8gm, 525m/s
4	Diagnostic used for velocity measurement	Optical fiber cut

Fig.8: Projectile 316 SS with 7075 Al armature.

Fig.9: Impact on 304 SS plate.

The oscilloscope trace shows the time information of fiber cut and it is measured 38µs shown in Fig.7. In another shot, the impact of armor piercing shape projectile (Φ7.6mm-7.8mm) on 2mm thick 304 SS target is experimented. Projectile is made with 316 SS material weighing 5g. The combined weight of armature with projectile ~10g is used in this experiment, shown in Fig.8. The 2 mm thick 304 SS target is placed 0.5m away from the rail muzzle end to investigate the penetration information by projectile. The observed results of Fig.9 show that projectile is able to perforate the target by rail peak current 300kA, 2.5 millisecond duration, impact velocity 450-500m/s. This estimation is based on B-dot signals obtained inside the rail-barrel.

Conclusion

The results show that electromagnetic railgun could be used as a feasible driver to accelerate armour piercing shape projectile by non-explosive source in ballistic testing application.

Acknowledgements

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