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P3_2 Railguns! Miniaturised?

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Abstract

Rail-guns (RG) are advanced ordnance, with the ability to propel projectiles at large velocities in excess of $\sim 2kms^{-1}$, using no chemical propellant [1]. We are investigating, and expanding on the current literature in this journal, whether this technology can be miniaturised into infantry equipment. Contrasting to previous research we are discussing the current required to fire the weapon [2]. We find that these weapons could be miniaturised to $\sim 700mm$ barrel length, however there is currently no power source small and powerful enough to be deployed in this manner.

Introduction

Rail-guns (RG) take advantage of the Lorentz force; providing an effective way to fire propellant free munitions [1]. They are particularly intriguing to the Navy for an upgrade onboard their vessels opposed to the standard artillery; due to the high velocity nature of RGs they are effectively an *instant* hit of any target within sight. Currently RGs are only in prototype scenarios due to their complexity, barrel length is usually in the order of metres, and power supply in the region of several tonnes. We discuss the feasibility of such arms in a miniaturised format, comparing the relative current required to fire.

Method

We are basing the feasibility of such designs only on the current required to fire. To be viable we must improve on contemporary weapon systems. We have decided to select some characteristics: Barrel length $L = 700mm = 0.7m$, Muzzle velocity $v = 1500ms^{-1}$, Bullet mass $m = 100g$ ($\sim 1.0cal$) as a large bullet with higher mass will have more momentum and hence less detrimental aerodynamic effects with, and Rail-gap width $R = 10cm = 0.1m$ [3]. We have simplified the systems taking place within the RG; approximating the acceleration to constant, for simplification, allowing the use of the SUVAT equations. Equations for these calculations: final velocity Eq.(1), combining the Biot-Savart law and Lorentz force leads to total force Eq.(2)

$$v_1^2 = v_0^2 + 2as \quad (1)$$

$$F = \frac{\mu_0 I^2 L}{4\pi R^2} \quad (2)$$

Where v_0 & v_1 are initial and final velocity respectively, s & L is the length of the barrel, a the acceleration of the bullet, F force, μ_0 vacuum permeability, I current and R is half the distance between the rails. Figure(1) below is useful for visualising the Lorentz force in relation to the rails.

Results & Discussions

Using the expressions stated, the characteristics desired and Newton's second law: $F = ma$,

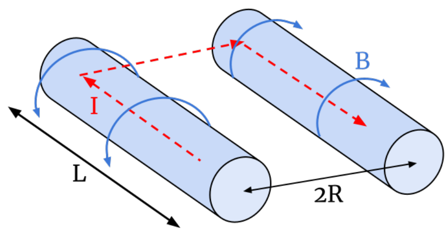

Figure 1: Rail-gun cross section diagram

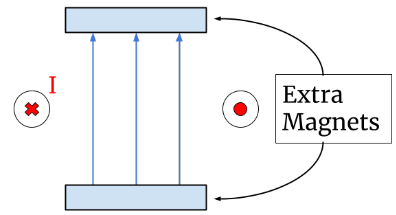

Figure 2: Rail-gun cross section diagram, with external magnetic field

current (I) required to fire the system can be calculated. We first determine the acceleration of the bullet and hence the Lorentz force. Using Eq.(1) we determine an acceleration $a \sim 1.6 \times 10^6 ms^{-2}$. The Lorentz force is equal to the force accelerating the $0.1kg$ bullet; $F_L \sim 1.6 \times 10^5 N$. Using this the current required to produce this force, with no external magnetic field, is $\sim 75kA$.

There are methods of reducing the current required to produce the Lorentz force calculated; adding an external magnetic field to strengthen the field induced by the current carrying rails. This system can be seen in the figure(2) external magnets are added above and below the rails, the current can then be calculated including an external field in Eq. (3) where all symbols retain their meaning and B magnetic field strength.

$$F = \left[\frac{\mu_0 I}{4\pi R^2} + B\right] IL \tag{3}$$

Exploiting an external magnetic field allows for lower values of current producing same force, in this case we have decided to use neodymium magnets for their mass-to-field ratio over the more conventional ferromagnetic counterparts [4]. Laying these magnets along the length will create a stronger magnetic field. Using force calculated before, $F_L \sim 1.6 \times 10^5 N$, the quadratic formula and equation Eq. (3) we attain a value of $\sim 60kA$, a reduction of 20%. This is still too large and not viable for a portable format.

Conclusion

With the current technology available to us, producing and releasing a current of such vast quantity of current in either situation is entirely unavailable in a portable format, even with the use of quality capacitors [2]. In this numerical viability check we have neglected to consider any heating that the rails would occur, nor have we involved any potential degradation of such rails. For further research we would consider heating and potential use of superconducting materials.

References

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