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A5_1 Field Shield: Fact or Fiction?

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Abstract

In this paper we calculate an estimate for the magnetic field strength required to stop a 9 mm bullet via the mechanism of eddy current drag. We found that a lower bound for the magnetic field strength, B, required to stop a bullet was 10.81 T.

Introduction

There are several forms of ballistic protection available globally today, ranging from Kevlar to composite armours. In many sci-fi scenarios, protection from weaponry is accomplished with a force field. As a field cannot be made up of "force", we considered a more realistic alternative. A shield composed of a magnetic field capable of stopping a bullet, a Field Shield. This paper aims to calculate an estimate for the magnetic field strength required to stop a 9 mm bullet via the drag forces produced by induced eddy currents as the bullet enters a magnetic Field Shield.

Method

To go about calculating the required magnetic field, we established a model of the bullet's interaction with the field and the eddy currents induced within the bullet. An eddy current is a circulation of charged particles within an electrical conductor, induced by the conductor experiencing a change in magnetic field. Our model involved the following assumptions: The bullet can be modelled as a square-based prism, the bullet is entirely made of elemental Lead, zero air resistance, the bullet enters a uniform magnetic field, perpendicular to the field direction, the force applied to the bullet is a constant over the time taken to enter the field and the eddy currents induced do not heat the bullet, via the mechanism of Joule heating.

Once the model was established, we set about finding the length of the bullet, x. To find x, we used Equation 1.

$$x = \frac{m}{\rho A} \tag{1}$$

Where m is the mass of the bullet, ρ is the density of Lead and A is the cross-sectional area of the bullet. We then calculated the time taken for the bullet to enter the field, t, using Equation 2,

$$t = \frac{x}{v} \tag{2}$$

where v is the bullet velocity. Upon entering the field, eddy currents are generated in the bullet which induce a drag force, F_d, opposing the bullet's motion. An equation for F_d can be derived using the integral form of Faraday's Law, the equation for electrical power and the differential form of Ohm's Law, a method for which can be found online [1]. The derivation gives

$$F_d = \sigma B^2 v x A \tag{3}$$

where σ is the electric conductivity, B is the magnetic field strength, xA is the bullet's total volume. To isolate B, we equate the impulse on the bullet by F_d to the change in momentum of the bullet required to stop it as it enters the field. This is dictated by Equation 4, the equation for impulse, as outlined below.

$$F_d t = mv - mv_2 \tag{4}$$

Where v_2 is the final velocity of the bullet after the deceleration, which in this case is 0, leading to the further simplification to

$$F_d = \frac{mv}{t} \tag{5}$$

Using Equations 3 and 5, and rearranging for B, gives Equation 6.

$$B = \sqrt{\frac{m}{\sigma x A t}} \tag{6}$$

This allows us to calculate the value of B necessary to stop a bullet entering the field.

Results

For the calculation of x, we took $A = 81 \times 10^{-6}$ m^2, based off of a 9 mm bullet [2]. The bullet mass was taken as $m = 115$ grains $= 7.45 \times 10^{-3}$ kg [2] and the density was taken to be $\rho = 11,343$ kgm^{-3} [3]. This produced the value $x = 8.11$ mm.

Next we calculated $t = 21.34$ μs using $v = 380$ ms^{-1} [2]. Finally, we used Equation 6 along with $\sigma = 4.55 \times 10^6$ Sm^{-1} [4] to calculate a final value of $B = 10.81$ T.

Conclusion

This is a particularly large B value and is stronger than the magnetic fields used in the Large Hadron Collider ($B = 8.36$ T) [5]. The effects of such a field on the human body have not been explored, for obvious ethical reasons. However, the field would likely interfere with bodily functions such as stimulating nerve signals.

In addition to these effects on the human body, any magnetic metals would likely be attracted to the field generator with a significant force. The metals would also be subject to Joule heating, which would cause most metals to rapidly melt with fields of this strength.

Although our B value is large, it is lower than the likely true value due to the assumptions we made. The presence of a copper jacket and the non-cuboidal shape of the bullet would reduce the volume of the bullet the eddy currents can be induced in, causing F_d to be weaker, therefore the value of B required to stop the bullet would need to increase.

Conversely, the lack of air resistance results in a higher v value than the likely true value. Accounting for air resistance would provide a smaller v value, leading to a decrease in B value required.

Though the assumption of no Joule heating does not directly affect our B value, melting due to this heating would cause deformities in the bullet shape, along with a significant decrease in σ. These potential changes would cause further increases in the realistic B value.

In conclusion, the B value calculated in this paper is likely a lower bound of the true B value required to stop a 9 mm bullet. This would mean using a Field Shield would require extremely large field strengths, upwards of 10 T, making them an unfeasible form of ballistic protection, especially compared to current solutions.

References

[1] `https://tinyurl.com/yyeb2jvq` [Accessed 13th October 2020]

[2] `https://www.gd-otscanada.com/product/9mm-x-19-ammunition/` [Accessed 13th October 2020]

[3] `https://theengineeringmindset.com/density-of-metals/` [Accessed 13 October 2020]

[4] `https://tinyurl.com/l72m86d` [Accessed 13th October 2020]

[5] `https://tinyurl.com/y2prmp2y` [Accessed 18th October 2020]