Journal of Physics Special Topics
An undergraduate physics journal

P6_4 The Physics of Magneto

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November 8, 2018

Abstract

During a scene of the well-known X-men series, Magneto, capable of generating and controlling magnetic fields, stops multiple missiles mid-air before they reach him. In this paper, we investigate the characteristics of the magnetic field he would have to generate for this event to be possible. We calculated that at 100 m, a magnetic field strength of 37.5 T would be necessary for the projectile to be stopped. Although theoretically possible, to generate this field Magneto would need to produce a current of 1.9×10^{10} A.

Introduction

During the film "X-Men: First Class", Magneto is attacked by a naval fleet that fires numerous missiles at him. The mutant, Magneto, stops them before they reach him with the use of a powerful magnetic field, which he is able to create and control at will. We consider the magnitude and characteristics of the magnetic field that would make this possible. For the calculations, we use the specifications of a CTV-N-2 Gorgon IIC missile, which has a mass of 880 kg and travels at a speed of 200 m/s. It can be approximated, for simplicity, as a cuboid of 6 m in length and 0.5 m in height [1]. As a starting point, we took the braking distance to be 50 m, before the missiles freeze 100 m away from him.

Theory

For a moving projectile to be stopped, a change in momentum, equal to the momentum of the moving object, is needed. Momentum can be expressed in the two following ways:

$$p = mv \tag{1}$$

$$p = Ft \tag{2}$$

Where p stands for momentum, m for mass, v for velocity, t for time and F represents the force needed to stop the motion. Equating Eq. (1) and Eq. (2) and substituting in the equation of motion:

$$\frac{2s}{v} = t, \tag{3}$$

where s is the stopping distance and t the stopping time, we estimate the force needed to be 3.5×10^5 N.

As a conductor moves through a non-uniform magnetic field, an electric current, also known as Eddy current, will flow through the object, as can be seen in Figure 1. This current transforms the kinetic energy of the object to thermal energy by a process known as Joule heating.

Assuming the projectile behaves as a resistor made of steel, the power dissipation through it is given by:

$$P = I^2R \tag{4}$$

The resistance, R, is given by $R = \frac{\rho L}{A}$, where ρ is the resistivity, A is the area and L is the length of the wire. The currents flowing upwards and downwards each travel through half

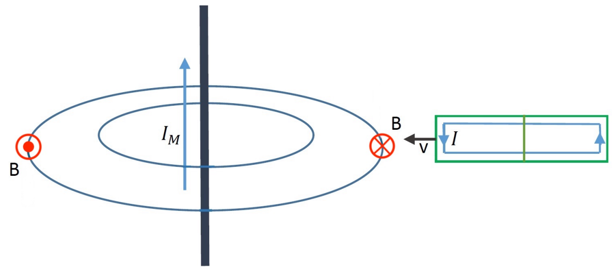

Figure 1: Magneto is idealised as an infinitely long straight wire. A projectile with velocity v approaches him and, as a consequence, an anticlockwise Eddy current is generated inside the moving object.

of the object only (see Figure 1). In this case A would be approximately 3 m^2, L is 0.5 m and ρ is $7.2 \times 10^{-7}\,\Omega$m [2], resulting in a resistance of 2.4×10^{-7} Ω.

Similarly, the power can be expressed as by Eq. (5) below. By equating Eq. (4) and Eq. (5) and solving for I, we find that the current needed to dissipate such energy in the amount of time the projectile takes to stop has a magnitude of 1.2×10^7 A.

$$P = \frac{Fs}{t} \tag{5}$$

We now move into calculating the change in magnetic flux $\Delta\Phi$ that would generate such a current through a conductor. Faraday's law states

$$\xi = IR = \frac{\Delta\Phi}{\Delta t}, \tag{6}$$

where I is the current flowing through the projectile and R is the resistance, both previously calculated. Substituting the values we have already found and solving for $\Delta\Phi$, we find the necessary change in magnetic flux to be 1.45 T/m^2. If we approximate Magneto to be an infinitely long straight wire, the field is uniform perpendicular to the direction of motion. Taking the length of the projectile to be 6 m results in a gradient in the magnetic field of 0.25 T/m along the direction of motion.

The magnetic field generated by an infinitely long straight wire has a magnitude

$$dB = -\frac{\mu_0}{2\pi}\frac{I_M}{r^2}dr \tag{7}$$

where μ_0 is the permeability of free space, r is the distance from the wire and I_M is the current Magneto would have to generate to produce such a magnetic gradient. If

$$\begin{aligned} \int_d^{d+s} dB &= -\frac{\mu_0 I_M}{2\pi}\int_d^{d+s}\frac{1}{r^2}dr \\ &= \frac{\mu_0 I_M}{2\pi}\left[\frac{1}{r}\right]_d^{d+s}, \end{aligned} \tag{8}$$

where d and s, as previously stated, are 100 m and 50 m respectively, the solution to the left hand side integral is 12.5 T. This is simply the gradient multiplied by the stopping distance. Solving the right hand side integral, yielding a result of $\frac{1}{300}$, and rearranging to find I_M, we are able to calculate a value for I_M of 1.9×10^{10} A. Using this result in Eq. (7) gives a magnetic field strength, at 100 m from him, of 37.5 T.

Conclusion

We found that although theoretically possible to stop a missile with a non-uniform magnetic field, it would require a remarkably large electric current (a few tens of billions of Amps) to generate it. This is approximately a million times greater than the current of an average lightning flash [3], and not feasible at the current technological stage.

References

[1] https://en.wikipedia.org/w/index.php?title=CTV-N-2_Gorgon_IIC&oldid=819399368 [Accessed 2 October 2018]

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[3] https://hypertextbook.com/facts/1997/BrookeHaramija.shtml [Accessed 2 October 2018]