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P4_6 Super MAC Cannons

Y. Abbas, G. Thomas, D. King, R. Williams

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

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Abstract

In this article the physics of a super MAC (magnetic accelerator cannon) in the Halo universe is investigated. This weapon creates powerful magnetic fields using multiple superconducting solenoids. The force due to the magnetic fields created by these solenoids accelerates a 3000 tonne Ferric-Tungsten slug round to a velocity of 0.04c. It is assumed that a super MAC cannon uses 5 solenoids with about 500 turns each. Each solenoid must do 4.32×10^{19} J of work to accelerate the round. It was found that a current of 468 MA must flow through each solenoid to do this work.

Introduction

Halo is a game set 500 years into the future where the human race is at war with a group called the "Covenant". One weapon used by the humans in this war is a super MAC. A super MAC fires a 3000 tonne Ferric-Tungsten slug round at a speed of 0.04c by using the magnetic force of multiple superconducting solenoids to accelerate the slug [1]. The solenoids are placed next to each other in series in a 802 m long barrel that the slug passes through when being launched [1]. The slug is accelerated through this barrel by activating the solenoids one after the other. The first solenoid accelerates the slug to a fraction of the final velocity then is quickly deactivated [1]. This process is repeated for each solenoid after the first.

Theory

Since the slug is a Ferric-Tungsten slug it is assumed that the round consists of 70% Tungsten and 30% Iron similar to the Ferrotungsten alloy [2]. The density of Tungsten is 19.4 gcm^{-3} and the density of Iron is 7.87 gcm^{-3} [3] therefore the average density of the round is about $\rho = 15.9$ gcm^{-3}. From this we can determine the length of the round using the equation:

$$l = \frac{m}{\rho \pi R^2} \tag{1}$$

if we assume that it is perfectly cylindrical and has a radius of $R = 2.00$ m. We already know the mass of the round is $m = 3000$ tonnes. All this gives us a value of $l = 15.0$ m.

The magnetic field of a solenoid is given by the equation:

$$B = \frac{\mu \mu_0 N I}{l} \tag{2}$$

where N is the number of turns, I is the current passing through the solenoid, μ_0 is the permeability of free space and μ is the relative permeability (a dimensionless quantity). From this equation we can determine the energy density of the solenoid. The energy density is given by the equation:

$$u_B = \frac{B^2}{2\mu\mu_0} = \frac{1}{2} \frac{\mu \mu_0 N^2 I^2}{l^2} \tag{3}$$

The energy stored in a solenoid is then given by:

$$U = u_B V = \frac{1}{2} \frac{\mu\mu_0 N^2 I^2 \pi R^2}{l} \tag{4}$$

where V is the volume. If a material fills the space in between the coils of a solenoid then the permeability of that material must be used [4]. When this happens the change in energy is given by:

$$\Delta U = U_{filled} - U_{empty} \tag{5}$$

U_{filled} is the energy stored in the solenoid when filled by a material and U_{empty} is the energy stored in the solenoid when empty [4]. For the U_{filled} term $\mu_{filled} = 1500$ and for the U_{empty} term $\mu_{empty} = 0$ (as the solenoids are superconductors) [5] so:

$$\Delta U = \frac{1}{2} \frac{\mu_0 N^2 I^2 \pi R^2}{l} \ (\mu_{filled}) \tag{6}$$

Making I the subject gives:

$$I = \Big(\frac{2l\Delta U}{\mu_0 N^2 \pi R^2 (\mu_{filled})} \Big)^{1/2} \tag{7}$$

The value of $\mu_{filled} = 1500$ is derived from the the fact that the relative permeability for Iron is about 5000 [5] and 7.80×10^{-5} for Tungsten [6]. The Iron and Tungsten ratio is 3:7 so the average permeability is $\mu_{filled} = 1500$.

Results

The following assumptions have been made about the solenoids based on what they appear to be in the game [7]:

- Number of turns $N = 500$.
- Length of the solenoid $l = 100$ m
- 5 solenoids are used to accelerate the round.
- Each solenoid provides the same acceleration and hence causes the same increase in kinetic energy.

The change in energy ΔU can be determined by considering the kinetic energy of the round after it has left the barrel. The kinetic energy can be calculated using the equation:

$$E_k = \frac{1}{2} m v^2 \tag{8}$$

where E_k is the kinetic energy and v is the velocity of the slug. The kinetic energy is found to be $E_k = 2.16 \times 10^{20}$ J. Each solenoid must do 4.32×10^{19} J of work for the round to achieve this kinetic energy. Therefore, $\Delta U = 4.32 \times 10^{19}$ J. Using equation (7) the current passing through each solenoid is found to be 468 MA

Conclusion

The kinetic energy of the MAC round when it leaves the barrel is 2.16×10^{20} J. Which is about 3.43 million times the output energy of the bomb dropped on Hiroshima. This is equivalent to about 15.0 kilotons of TNT [8].

References

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