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P2_3 Electric Armour

M. Phillips, K. Herlingshaw, D. Vasudevan, T. Griffiths

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

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Abstract

The validity of using a highly charged capacitor as ‘electric armour’ on light tanks is investigated. The capacitor discharges a large amount of energy into the incoming projectile, causing it to vaporise. It is found that a potential difference of 252MV is required to charge the capacitor to the desirable electric potential energy to vaporise the projectile. Materials with higher dielectric breakdown strengths are desirable for realistic plate separations for the capacitor.

Introduction

A new type of reactive armour has been reported to have been developed for light tanks and armoured personnel carriers [1]. Two or more conductive plates are attached to the exterior of the tank and are separated by an insulating material. These plates are then charged to form a highly charged capacitor. The RPG (Rocket Propelled Grenade) is a common weapon used to attempt to destroy light tanks and armoured personnel carriers. Upon impact, the grenade fires a jet of hot molten copper into the target tank at around 1000mph [1]. If the target is equipped with electric armour, the molten copper will penetrate both plates of the highly charged capacitor on the outer hull. This will mean a circuit is formed between the plates of the capacitor and the copper. The capacitor will then discharge a large amount energy vaporising the copper. This study will attempt to evaluate the core physics behind this idea.

Theory

All capacitors are characterised by the ratio of the charge $\pm Q$ on each of the plates to the voltage V between them. This is known as the capacitance

$$C = \frac{Q}{V}. \quad (1)$$

We model the capacitor on the tank as a parallel plate capacitor. Let each plate have an area A and the separation between the plates be d . The electric field between the plates is uniform and has a magnitude $E = \rho/\epsilon$ where ρ is the charge density on the plates and ϵ is the permittivity of the dielectric medium. Since the electric field is uniform the potential difference between the plates can be written as

$$V = Ed = \frac{\rho}{\epsilon}d = \frac{Qd}{\epsilon A}. \quad (2)$$

Therefore it can be seen using equation (1) that the capacitance of a parallel plate capacitor is

$$C = \frac{\epsilon A}{d} = \frac{k\epsilon_0 A}{d}, \quad (3)$$

where k is the dielectric constant of the material and ϵ_0 is the permittivity of free space. The electric potential energy of the capacitor is stored in the electric field between the plates. It can be calculated as the work done W in moving a charge from one plate to the other.

$$W = \int_0^Q V dq = \int_0^Q \frac{q}{C} dq = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2} CV^2. \quad (4)$$

We must also consider the energy required to vaporise a material. The energy ΔQ required to raise the temperature of a substance of mass m by ΔT is given by

$$\Delta Q = mc\Delta T, \quad (5)$$

where c is the specific heat of the substance. When the substance undergoes a phase change, the energy added to the material does not raise its temperature. Instead, the energy raises the potential energy between the molecules causing the material to go from solid to liquid or liquid to gas. The

energy Q_v required to change a substance of mass m from its liquid state to its gaseous state is given by

$$Q_v = mL_v, \quad (6)$$

where L_v is the latent heat of vaporisation of the substance.

Results and Conclusions

First, the energy required to vaporise molten copper was calculated. The mass of the RPG was found to be $7kg$ [2], and it was assumed that 50% of this mass contributed to the molten copper warhead. The specific heat of copper is $0.386kJ/kg^{-1}K^{-1}$ [3]. It was assumed that the hot copper was at least at its melting point of $1356K$ [4] and we needed to raise its temperature to its boiling point of $2835K$ [4]. The energy required to do this was found by substituting these numbers into equation (5), which gave a value of $2MJ$. The latent heat of vaporisation of copper is $4730kJ/kg^{-1}$ [4]. Therefore the energy required to turn copper into a gas is found by using equation (6) and calculated to be $17MJ$, causing the total energy required in this process to be $19MJ$. This is the energy that the capacitor will have to discharge to vaporise the copper.

The tank was assumed to be the size of a challenger 2 tank with a length l of $8.3m$ and a height h of $2.49m$ [6] giving the area of the side of the tank (and therefore the size of the conducting plates) as $A = l \times h = 20.67m^2$. The distance between the plates d was assumed to be one foot since this is typically the distance that an RPG can penetrate into solid steel armour [1]. The dielectric medium used was air which has a dielectric constant of $k = 1.00058986$ [5]. Substituting equation (3) into equation (4) and rearranging for the voltage, we can use these numbers to calculate the voltage. The voltage needed to generate the required potential energy to vaporise the copper i.e. $19MJ$. It was found that the voltage needed to generate this energy was approximately $252MV$.

Using the relation $E = V/d$ the electric field E between the plates can be found to be $77 \times 10^6Vm^{-1}$. This exceeds the dielectric breakdown strength of air which is $3 \times 10^6Vm^{-1}$. This is the minimum electric field strength that can be applied without the insulating properties of air breaking down. Substituting equation (3) into equation (4), using the relation $V = Ed$ and rearranging for the plate separation d we can obtain the equation

$$d = \frac{2W}{k\epsilon_0AE^2}. \quad (7)$$

Using equation (7) the plate separation for the capacitor to not experience dielectric breakdown can be found. Using the breakdown strength for air, $E = 3 \times 10^6Vm^{-1}$, in equation (7) the plate separation is found to be $23km$. This is clearly an unrealistic plate separation for the tank. Since the plate separation is proportional to $k^{-1}E^{-2}$ using a dielectric material with a higher dielectric constant and a higher breakdown strength could yield a more feasible plate separation. Diamond has one of the highest known dielectric breakdown strengths at $2000 \times 10^6 V/m$ and a dielectric constant of 5.7 [8]. Using these values in equation (7) the minimum separation between the plates using diamond as a dielectric medium can be found to be $9mm$. In conclusion, dielectric materials with higher dielectric constants and breakdown strengths are desirable to produce realistic plate separations, when creating enough electrical potential energy to vaporise the copper.

References

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