Optimal Utilization of Railgun

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Abstract

Railgun is an electrically-powered gun that accelerates a conductive projectile along magnetic metal rails. Various factors affect the projectile velocity and the longevity of the gun decreases as they get damaged after few uses due to the extreme working conditions. Some of the common problems are discussed and solutions are addressed with the final goal of finding the optimal operation solution for the gun. The analysis is done on COMSOL Multiphysics using Magnetic Field physics and the model is studied by Frequency Domain analysis at 50Hz. As seen in Figure 1, it comprises of two parallel copper rails placed on a rectangular Aluminium oxide base. A current density of desired value is passed through a copper contact at the base of the rails and the armature slides between the rails.

1. Limitation on current density: We establish a theoretical limitation on the maximum current that could be passed through the rails based on melting points of the armature and rails.The relation between current density and temperature change is as shown in Figure 2:
2. Magnetic levitation: To reduce the frictional force between armature and the base, we propose the addition of another external magnetic field in the direction of the motion of the armature. This adds an upward Lorentz force on the armature making it levitate during motion.
3. Velocity skin effect: The non-uniform current at the edges (as in Figure 3) results in current density spikes that increase the temperature at the armature-rail interface. These results in structural failure of the setup called as Velocity Skin effect. Also molten armature is released in the rear of the armature on the guns damaging them and making reuse difficult. To overcome this problem we introduce an additional high resistive layer between the rails and armature. It is observed that the current density spike at the interface reduces as the resistivity of the introduced additional layer increases. This can be used to overcome the issue of Velocity Skin Effect.
4. Magnetic Wrap: To reduce the effect of the gun's field on the surrounding circuits we suggest the addition of a wrap around the gun as shown in Figure 4. The wrap restricts the magnetic field within itself and so the surroundings remain unaffected by the field of the gun. The material chosen should have low skin depth value.

The optimal operation point of a rail gun depends on projectile velocity and on the factors that could damage the rail gun. There exists a tradeoff between these two factors. One has to choose the rail gun operation according the application by addressing the discussed factors.

Reference

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Figures used in the abstract

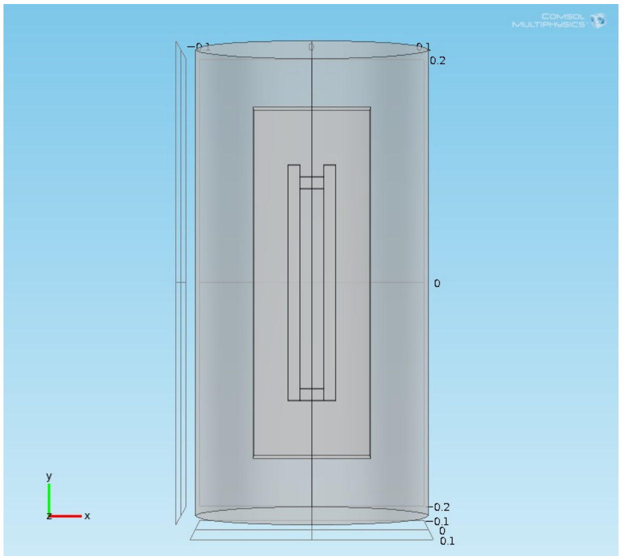

Figure 1: COMSOL Multiphysics model of Railgun.

$$J = \frac{i}{A} = \left[\frac{\sqrt{2Ba}\,(2m_r s_r + m_0 s_a)\delta\theta}{\sqrt{Am_0}\,(\frac{4}{3}\rho_r L^{3/2} + 2\rho_a a L^{1/2})} \right]^{2/3}$$

A=Area of Rails
B=Magnetic Field in Rail gun
a=Length of armature
m_0=Mass of armature
m_r=Mass of each rail.

L=Length of Rails
s_r =Specific heat capacity of Rails
s_a =Specific heat capacity of Rails
$\delta\theta$ =Difference between melting point of copper and room temperature

Figure 2: Relation between current density and temperature change.

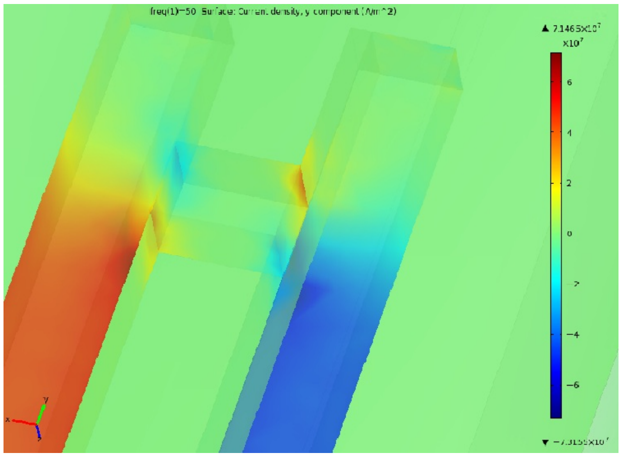

Figure 3: Result depicting the Velocity Skin Effect.

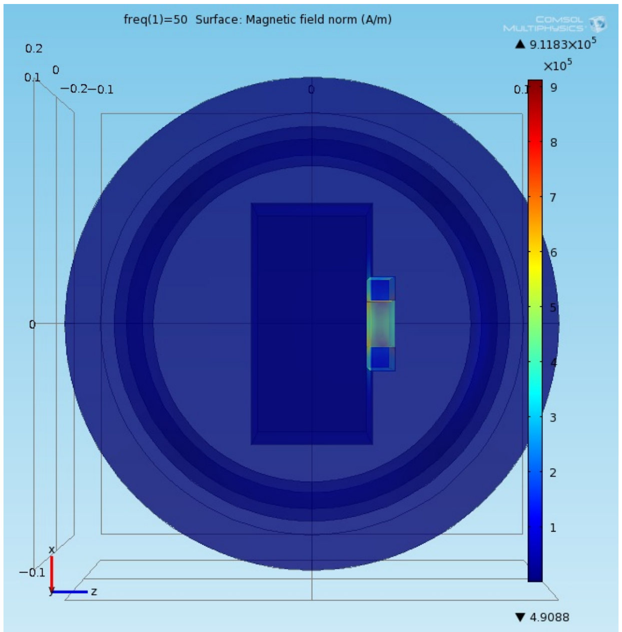

Figure 4: Variation of Magnetic Field with the wrap.