C180. Shen Shou Max Chung, "Kinetics of Railgun Simulated with FEM"

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Kinetics of Railgun Simulated with FEM

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Abstract

Railgun propels projectile with Lorentz force, and in principle there is no speed limit but in reality for sizable payload like 20Kg, the attainable speed nowadays is around 2.5km/s, and the energy efficiency is around or below 30%. What happens is when the projectile is accelerated between the rails; the temperature on the interface between the metal armature and the rails quickly rises due to friction and joule heating, so the resistance increases and this causes the current then to wane down. Sometimes arc discharge occurs between the surfaces. We simulate the kinetics of railgun with the FEM code COMSOL, and model the physics on the contact with a function that represents the resistance. Through the code a description of the railgun's kinetics like position, velocity, current, and Lorentz force changes in time are obtained, which can be used to simulate the behavior of railgun and serves as a diagnostic tool.

1. INTRODUCTION

The principle of railgun is illustrated in fig. 1. The picture of prototype railgun is in fig.2. Typical firing characteristics is in fig. 3.

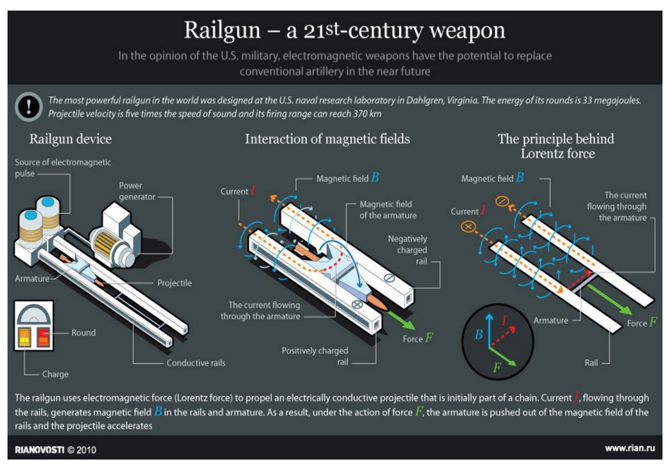


Fig. 1 Principle of railgun. (http://en.ria.ru/infographics/20101216/161806525.html)

Fig. 2. US Navy test of General Atomics railgun. (http://www.naval-technology.com/features/featureoctober-stories-railgun-prototypes-submarine-designs/featureoctober-stories-railgun-prototypes-submarine-designs-1.html)

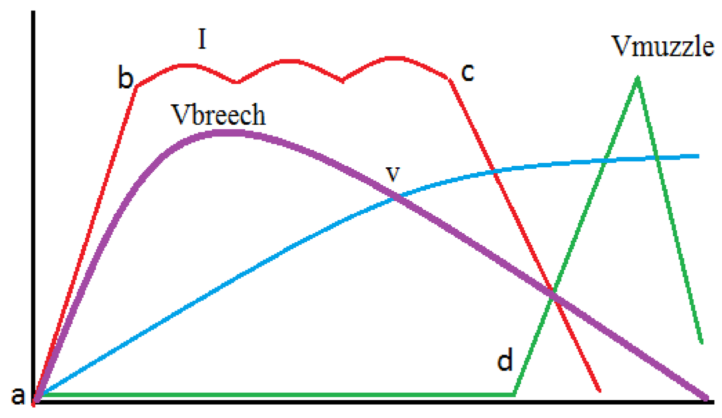


Fig. 3. Typical firing characteristics.

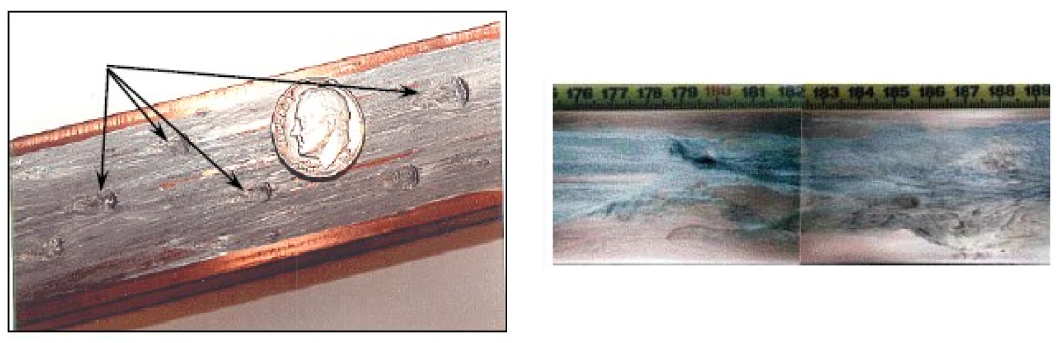


Fig. 4. Gauging and arc transition marks on the rail surface. (Dr. Harry Fair, IAT, U of Texas, Austin)

2. COMSOL MODEL OF RAILGUN

Due to the challenges arises with a moving mesh in FEM, the original COMSOL model of the railgun was constructed with a fictional armature. Depicted in fig. 4 is the railgun model. The 5m long railgun is composed of two rails enclosed in an insulation surrounding. The armature is 4x4cm^2, and the rails are made of cupper. The armature is not actually drawn, instead it is a fictional armature driven by the Lorentz force, which is calculated by the surface integral of the current density and the magnetic field, and then Newton's equations are used to propel the armature. The phenomena occurring in the interface between the rails and the armature is represented by the resistance term that determines the current *I*, and thus the Lorentz force *FX*.

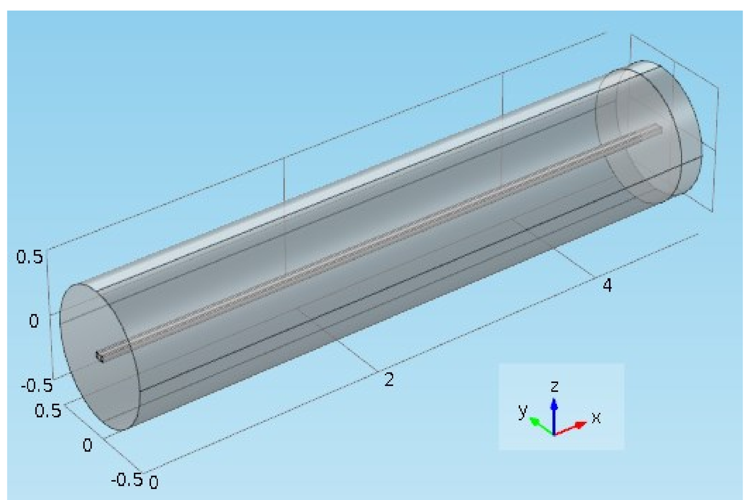


Fig. 4. COMSOL model of railgun.

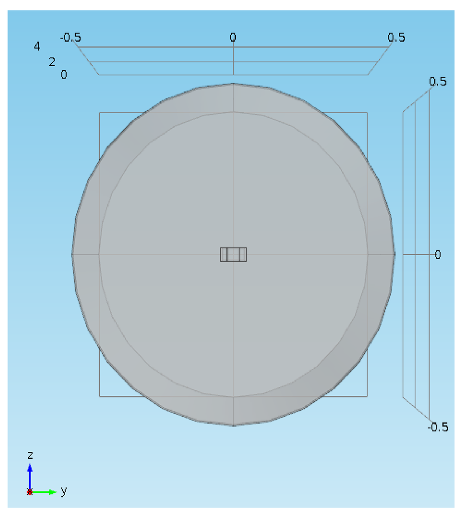


Fig. 5. The Y-Z cross section of the railgun model.

Name	Expression	Value	Description
V	0.04^3[m^3]	6.4000E-5 m³	Armature volume
rho_Al	2700[kg/m^3]	2700 kg/m³	Armature density
M	rho_Al*V	0.1728 kg	Armature mass
w	0.04[m]	0.04 m	Armature length
k	100	100	Constant in exponential...
sigma_Al	1/2.65e-8[ohm*m]	3.7736E7 S/m	Armature conductivity
V0	1000[V]	1000 V	Applied voltage

$$\sigma\frac{\partial \mathbf{A}}{\partial t} + \nabla\times(\mu_0^{-1}\mu_r^{-1}\mathbf{B}) - \sigma\mathbf{v}\times\mathbf{B} = \mathbf{J}_e$$

$$\mathbf{B} = \nabla\times\mathbf{A}$$

$$\mathbf{n}\times\mathbf{A} = 0$$

External current density:

$\mathbf{J}_e$: emdc.Jx (x), emdc.Jy (y), emdc.Jz (z) A/m^2

Electrical conductivity:

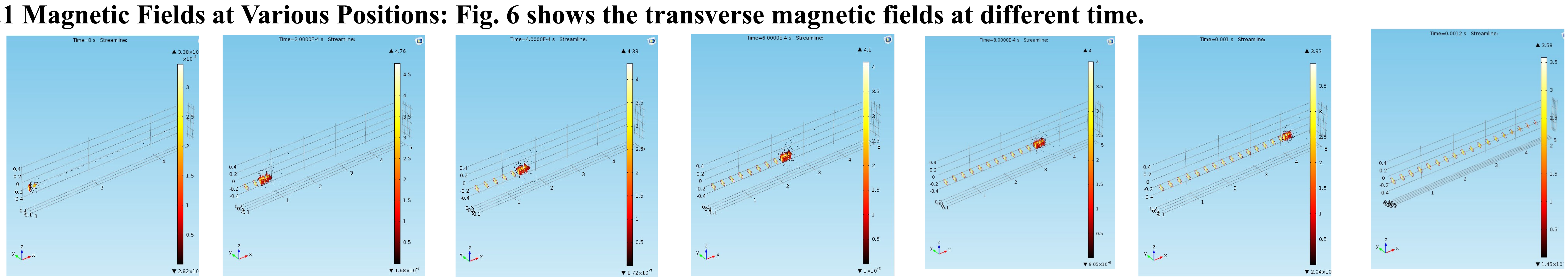
σ: User defined

1+sigma_Al*exp(-k*(abs(x-x0)>(w/2))*(abs(x-x0)-(w/2))) S/m

Table 1. Constants defined in the simulation, and the equations used.

3. SIMULATION RESULTS

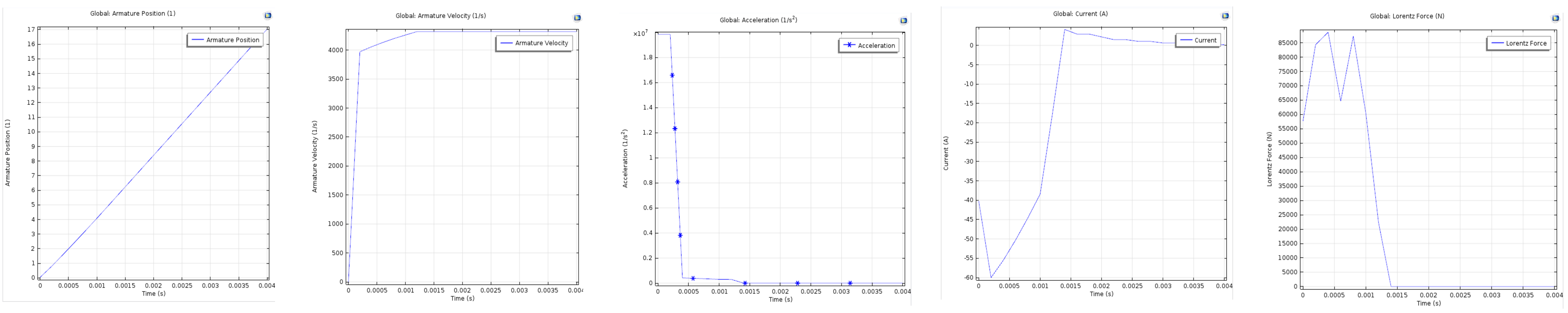
3.1 Magnetic Fields at Various Positions: Fig. 6 shows the transverse magnetic fields at different time.



t=0ms t=0.2ms t=0.4ms t=0.6ms t=0.8ms t=1ms t=1.2ms

4. RAILGUN CHARACTERISTICS FROM SIMULATION

Shown here are the position(X0), velocity(X0t), Acceleration (X0tt), Current (I), and Lorentz Force (FX) of a typical run.



Although the railgun characteristics from simulation are not similar to typical experimental results, but they are adjustable from the resistance expression, therefore, such simulation can explain the physics.

5. SUMMARY

This model shows the capability of COMSOL to simulate the characteristics of railgun, and its ability to serve as a diagnostic tool for real experiment. If the equations generate similar firing characteristics, then scaling relation is possible to derive.

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