

Comparison of Multiphysics 3-D Transient and Quasistatic Models for Railgun Simulations

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A novel 3-D multiphysics Finite Element Method (FEM) electromagnetic simulation model for railguns was developed, effectively handling moving components through a deformed geometry approach. Results show a 2.5 % deviation in armature speed compared to those obtained with a quasistatic model. The presented model facilitates potential detailed railgun studies, such as thermal analysis.

Index Terms—Railgun, electro-mechanics, mesh deformation and current distribution.

I. INTRODUCTION

IN ELECTROMAGNETIC modeling, handling moving domains typically involves a moving mesh where moving regions slide over stationary ones. This approach encounters significant challenges when solving the magnetic vector potential with Curl elements, which is the case of 3-D electromagnetic simulations. To address these challenges, analytical models or quasistatic studies are commonly employed [?], [?], [?]. In [?] an alternative approach for conducting transient simulations is presented. However, this approach requires a highly refined mesh in the region between the rails to accurately capture temporal dynamics, resulting in substantial computational costs.

To overcome these limitations, a novel modeling method is proposed using a deformed geometry approach. This technique deforms the mesh domains as the armature moves. The geometry is periodically remeshed to maintain an acceptable mesh quality. The proposed method minimizes the need for fine mesh elements. To assess the accuracy, the results are compared with those from the quasistatic approach [?].

II. METHODOLOGY

The problem is defined under quasi magneto static conditions and motional effects are handled in the electric constitutive equation:

$$\mathbf{J} = \sigma \mathbf{E} + \sigma \mathbf{v} \times \mathbf{B} + \mathbf{J}_e. \quad (1)$$

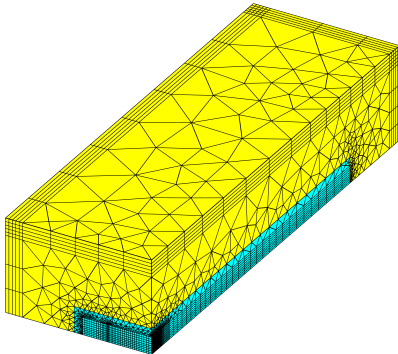


Fig. 1: Mesh.

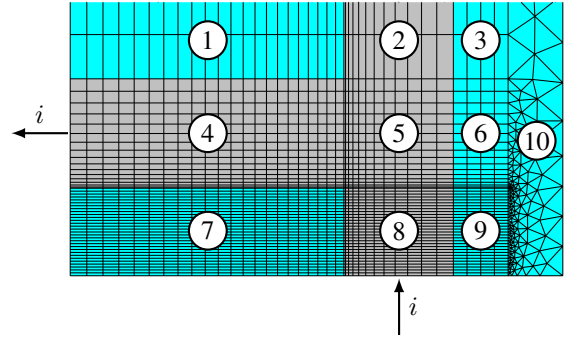


Fig. 2: Mesh zoom (Bottom view).

The armature is free to move along the y -direction, and its position is determined by applying Newton's Law and solving the second-order kinematic differential equations, with the forcing term $\mathbf{F}$ and an initial condition of zero velocity.

Figure ?? shows the simulation mesh, representing one-quarter of the geometry to reduce computation time.

The blue domains shown in Fig. ?? represent the deformed geometry. As the armature moves, the mesh elements within these domains will deform or displace accordingly. In contrast, the yellow domains will remain static and will not undergo any deformation. As shown in Fig. ??, domains 1–3 will contract, domains 4–6 will displace, domains 7–9 will expand, and domain 10 will be stuck to the adjacent domains. To keep an acceptable mesh quality, the geometry is remeshed every $1 \mu\text{s}$. The maximum simulation time step is 100 ns .

It has been verified that the mapped mesh offers greater stability after remeshing compared to the free tetrahedral mesh.

It is important to note that this simulation does not include thermal effects, contact resistance, or friction.

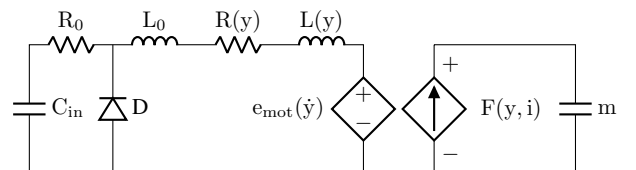


Fig. 3: Electro-mechanical railgun equivalent circuit.

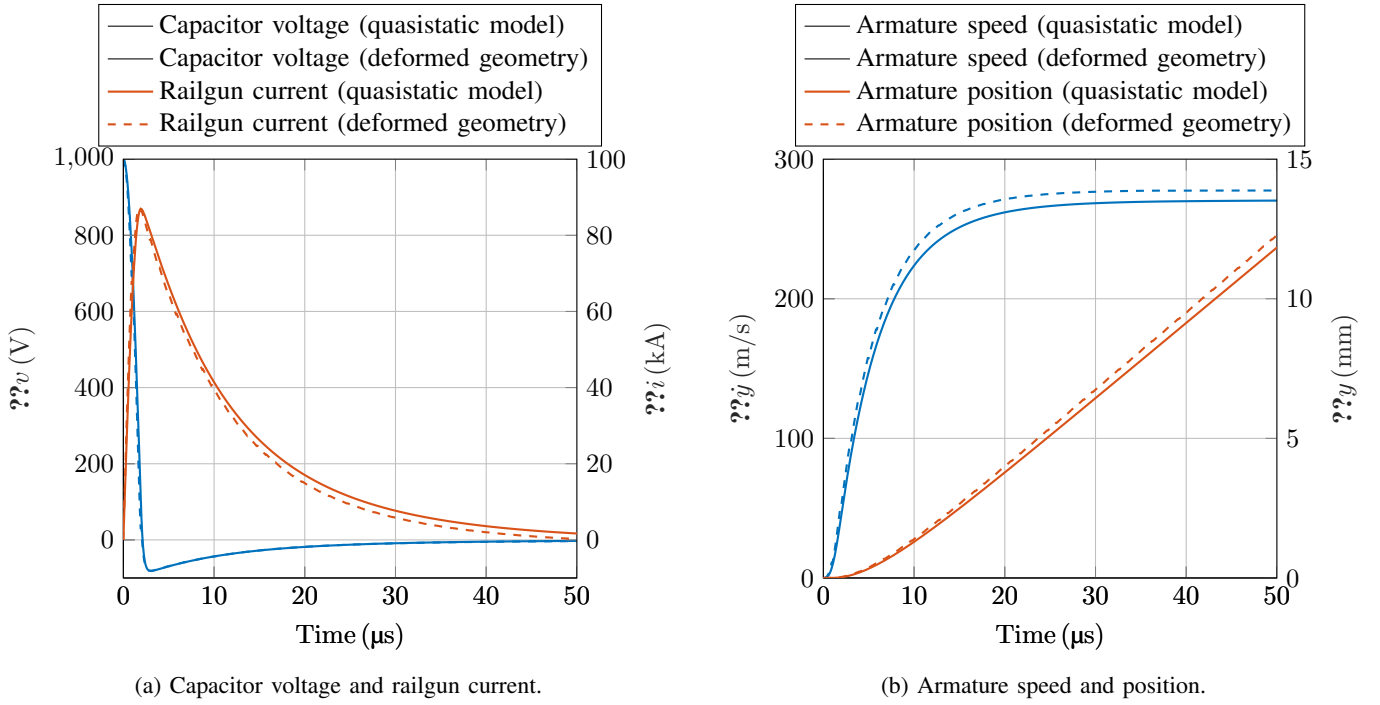


Fig. 4: Comparison of results from the quasistatic model and the deformed geometry model.

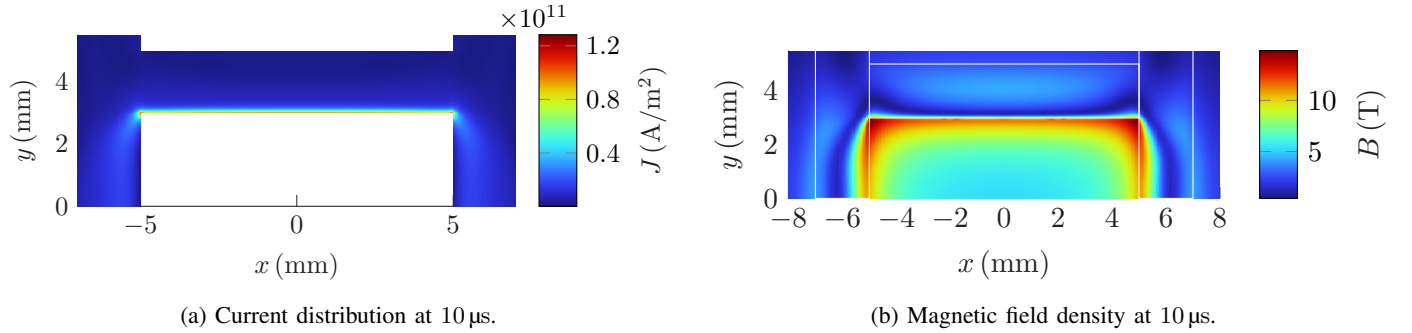


Fig. 5: Current density and magnetic field density at 10 μs .

In [?], the quasistatic study is detailed. Figure ?? shows the equivalent circuit, with $F(y, i)$, $L(y)$, and $R(y)$ derived from a 3D stationary model.

III. RESULTS

The results are compared with those in [?]. Figure ?? shows that the capacitor voltage is similar in both models. While the peak currents are comparable, the deformed geometry model exhibits a slightly faster current decay, which can be attributed to the increased resistance caused by the skin effect.

Figure ?? shows a steady-state armature speed error of only 2.5%. This minimal deviation indicates that for this system the force on the armature remains nearly constant for a given current magnitude, regardless of the current distribution.

Figure ?? demonstrates the significant influence of the velocity skin effect. Figure ?? illustrates how the magnetic field concentrates mainly along the inner edges of the railgun.

IV. CONCLUSION AND FUTURE WORK

A novel simulation model for railguns was introduced, addressing the challenge of simultaneously handling moving parts and three-dimensional electromagnetic field simulations. The quasistatic model's predictions agree closely with those of the proposed approach, confirming its accuracy and effectiveness.

REFERENCES

- [1] F. G. de León, M. Repetto, and A. Bissal, "A NOVEL RAILGUN SIMULATION MODEL BASED ON A QUASISTATIC," Portoroz, Slovenia, Jun. 2024.
- [2] H. Yongxia, L. Fuchang, D. Ling, Z. Lin, W. Lei, L. Gang, and B. Luhai, "Analysis of Electric Parameters of a PPS System and Their Influence on Muzzle Velocity in Electromagnetic Railguns," *IEEE Transactions on Magnetics*, vol. 45, no. 1, pp. 559–563, Jan. 2009.
- [3] W. Coburn and W. Williams, "Static and quasi-static models for the magnetic field of a railgun," *IEEE Transactions on Magnetics*, vol. 31, no. 1, pp. 692–697, Jan. 1995.
- [4] S. Hundertmark and M. Roch, "Transient 3-d simulation of an experimental railgun using finite element methods," in *2012 16th International Symposium on Electromagnetic Launch Technology*, May 2012, pp. 1–5.