Ultrahigh-Velocity Railgun

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Railguns have the theoretical potential to provide compact, repeatable acceleration of gram-sized projectiles to velocities significantly in excess of 10 km/s. However, the results from numerous experiments over the past 40 years show a perceived "velocity barrier" of 6 to 8 km/s.

This project aims to understand the physics behind this limitation using a combination of simulation and experiment, with the ultimate goal of proposing a concept that might overcome this barrier.

Project Goals

The project aimed to modify the 3-D coupled-physics code ALE3D such that it could model plasma and hybrid (solid/plasma) armature railguns, and use this tool to understand the physics. As a step in this direction, we constructed the Fixed Hybrid Armature experimental apparatus, comparing simulations to experiments in a sub-scale device. Finally, the project aimed to design and test a railgun with the potential to overcome the 8 km/s velocity limitation.

Relevance to LLNL Mission

A means to reliably launch gram-sized projectiles to velocities significantly in excess of 10 km/s is of great interest to the Laboratory for equation-of-state research. There remains a "gap" between high-energy states accessible primarily by lasers such as NIF, and lower energy states accessible via gas guns (currently limited to ~8 km/s). In addition, there is continued interest from NASA and the DoD for such a device as a kinetic energy weapon, for simulating asteroid impacts on space vehicles, and space launch.

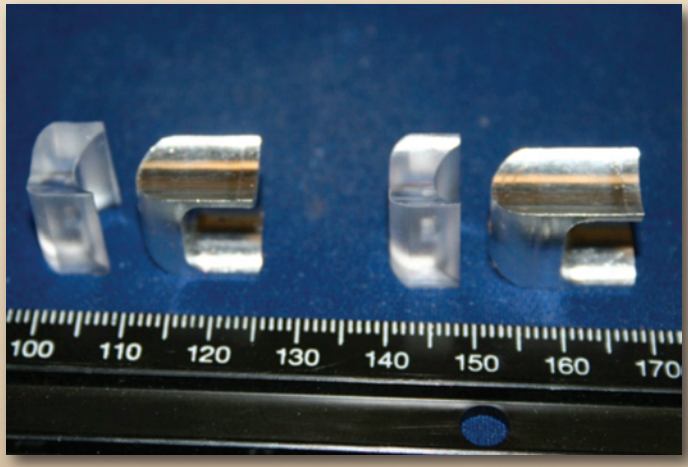

Figure 1. Launch package designs for novel ultrahigh-velocity railgun.

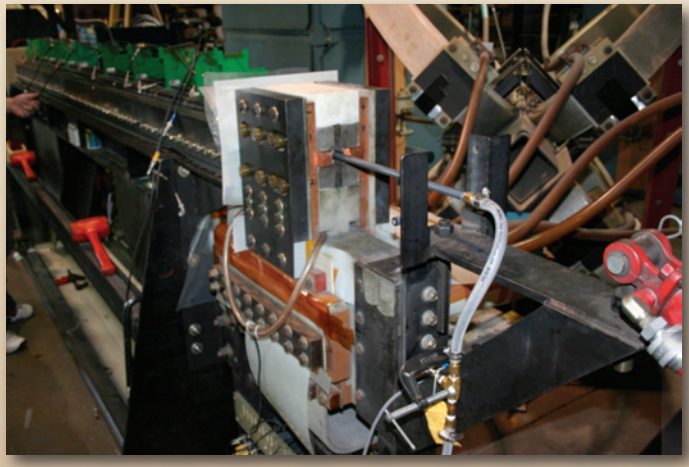

Figure 2. Novel ultrahigh-velocity railgun ready to fire. The hose connection provides the vacuum to the breech end of the internal railgun structure.

FY2009 Accomplishments and Results

Over the course of three years we modified ALE3D to include significant plasma physics and electromagnetics, including radiation heat transfer. These capabilities have been demonstrated on simulations of both the Fixed Hybrid Armature and full 3-D plasma-armature railguns. We have identified the remaining primary deficiency as radiation heat transfer in nearly transparent regions, which is being remedied through a related project. Through a combination of simulation and theory we identified a concept for a railgun using a hybrid armature (solid body with plasma brushes) that could overcome the velocity barrier, and built and tested a prototype. Unlike its predecessors, this railgun was designed to operate in hybrid mode throughout the launch process, using the concept of a barrel without sidewalls to eliminate insulator ablation. The accelerating armature was designed to lose significant mass throughout the acceleration process as a result of plasma-arc induced erosion, while maintaining acceleration.

The results of these experiments indicate that the projectile was able to operate in hybrid-mode past 4 km/s, even though more than 50% of the armature mass had been lost. Again in agreement with the design intent, the armature was able to operate at more than twice the theoretical "gouging velocity" without gouging the rails. The existing railgun facilities used for the test (IAP Research, Dayton OH) were not capable of operating at pressure levels less than 1 Torr without additional hardware, which was beyond the scope of the initial investigation. Larger sustained levels of breech voltage (and hence higher velocities) were found to be obtainable at higher pressures (lower levels of vacuum), indicating that for operation at pressures on the lower side of the Paschen minimum (70 mTorr or less) the inter-rail standoff voltage can be increased to levels that could sustain significantly greater velocities. The ultimate goal is to augment the magnetic field with an external circuit, thus reducing the required armature current and standoff voltage, and allowing for pure hybrid-mode to be sustained to velocities > 10 km/s.

Figures 1 through 4 illustrate our system and results.

Related References

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5. Tang, V., J. M. Solberg, T. J. Ferriera, *et al.*, "Compact Collimated Fiber Optic Array Diagnostic for Railgun Plasma," *Review of Scientific Instruments*, **80**, 1, January 2009.

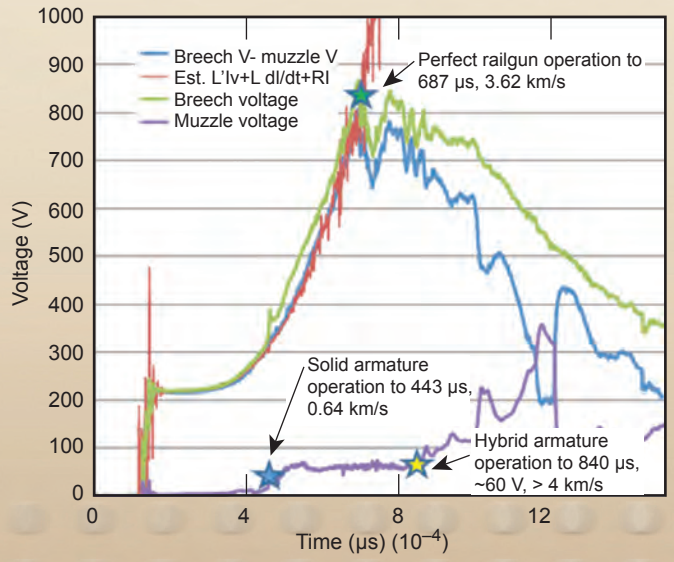

Figure 3. Plot illustrating hybrid mode operation past 4 km/s with low value of muzzle voltage and perfect railgun operation even with significant mass lost from the armature.

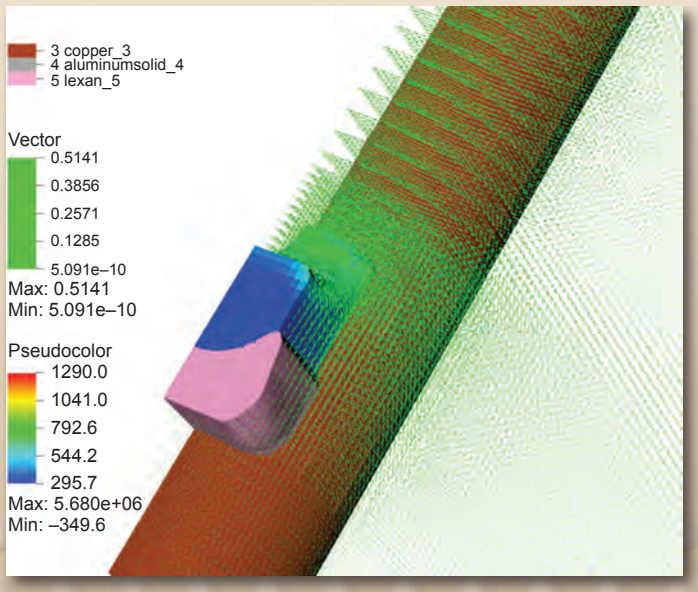

Figure 4. Novel ultrahigh-velocity railgun modeled by ALE3D. Solid armature mode before transition; armature beginning to melt near the trailing edge.