VELOCITY MEASUREMENT OF THE CEM-UT RAILGUN

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Introduction

In recent years research has been under way to develop linear macroparticle accelerators known as railguns.[1,2] A railgun uses the JxB forces in a current-carrying armature between two rails to accelerate a projectile (Fig. 1). A distributed energy store railgun that uses multiple energy storage inductors sequentially connected to the rails to drive the projectile (Fig. 2) is being constructed at the Center for Electromechanics, the University of Texas at Austin (CEM-UT). The projectile is injected into the railgun with an initial velocity of about one km/s.

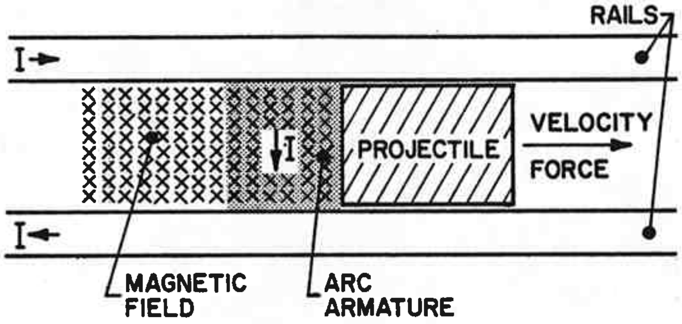

Fig. 1. Schematic of a Railgun

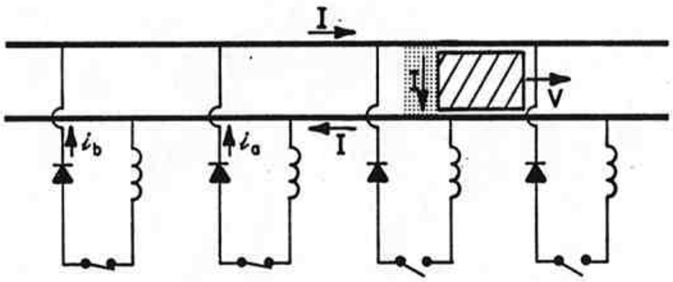

Fig. 2. Schematic of a Distributed Store Railgun

Diagnostics of such a railgun include two main types of measurements: (1) such external quantities as voltages between the rails and velocity of the projectile and (2) the internal distributions of current density, magnetic field, and the magnitude of other physical effects in the armature region. This paper discusses the external measurements of a railgun.

Selection of Diagnostics

The external parameters that characterize a railgun are acceleration and velocity of the projectile and the efficiency of electrical to kinetic energy transfer. These can be determined by measuring the voltage between the rails, V, and current, I, at the point of current injection to the rails and the velocity of the projectile. With these three measurements the velocity is measured directly while the acceleration is inferred based on the time resolution of the velocity measurement. The energy transfer efficiency can be obtained by

$$\eta = \frac{1/2\ m\ (v_1{}^2 - v_2{}^2)}{V\ I\ (t_2 - t_1)}$$

where v_1 and v_2 are the velocities of the projectile, mass, m, at times t_1 and t_2. The performance of a railgun can be specified by L'_{eff}, the calculated inductance per unit length if the rails were perfect conductors, L', times η. The force acting on the projectile is given by the equation[3]

$$F = 1/2\ L'_{eff}\ I^2.$$

The current measurements are made using Rogowski coils on each input to the rails with passive integrators for the time constants of present railguns. Voltages and these current measurements can be obtained from standard oscilloscope traces, though digital waveform analyzing systems will allow more detailed analyses. Velocity measurement devices can give either discrete or continuous velocity data. In discrete-velocimeters signal paths, such as laser beams, are broken by the projectile yielding the average velocity between two points. Continuous velocimeters could be made using lasers or microwaves in doppler shift devices or by constructing the bore of the gun as part of a microwave resonant circuit.

Laser Beam Velocimeter

The railgun under development at CEM-UT is being constructed with a laser beam discrete-velocimeter for measuring the velocities of the projectile entering and leaving the railgun (Fig. 3). Two beams are used to measure the injection velocity. This measurement is used to predict the time the projectile reaches the location in the railgun for triggering the current supplies. Preset thumbwheel inputs allow adjustment of the trigger timing about this nominal location.

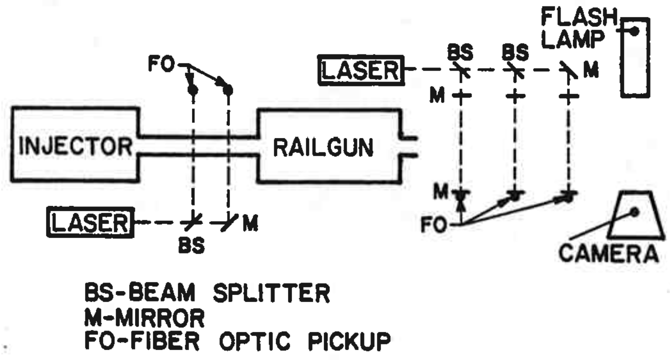

Fig. 3. Laser Velocimeter System

Redundant measurement of the terminal velocity will be accomplished with three laser fences and a photographic system. Each of the three laser beams makes multiple passes across the projectile's trajectory between mirrors to form a laser fence. From the three beams two velocity measurements will be made. Based on these velocities a flashlamp for a shadowgraph system is triggered. Included in the electronics used to trigger the flashlamp is an allowance for constant deceleration due to the frictional drag of air as determined by the difference of the two velocity measurements. The position of the projectile in the shadowgraph will then verify the velocity measurements.

The electronics system consists of an amplifier and digitizer for each of the five laser beams. The light is carried from the railgun to an avalanche photodiode by single strand fiber optic cables. Upon the first interruption of a beam an RS flip-flop is set and used to control the counters in the system. The injector stage electronics schematic is shown in Figure 4. Counter 1 is incremented by the clock during the time interval between the interruption of the first beam and the breaking of beam 2. When channel 2's flip-flop is set, counter 2 increments from its preset number from the thumbwheels until its count matches that of counter 1. Then the compare circuit triggers the railgun and stops counter 2. A similar system controls the terminal velocity measurements except the electronics add twice the time difference between the two velocity measurements to its preset thumbwheel value for triggering the flashlamp.

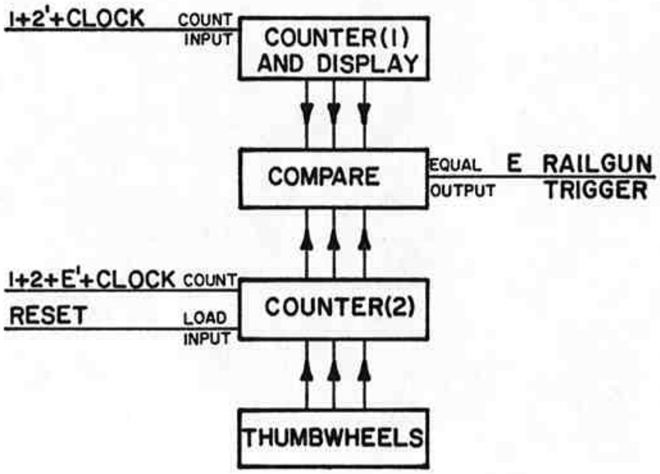

Fig. 4. Injector Stage Electronics System

The velocimeter uses two one-mW HeNe lasers as light sources. The beam steering devices are of medium grade with front silvered mirrors and dielectric beam splitters. Standard Amphenol fiber optic terminations are used as the pick up for the laser light. The other end of the fibers attach to premounted avalanche photodiodes with a response time of five-ns and sensitivity of 0.42 A/W. The one μA from the photodiode is amplified and digitizes to operate the TTL digital electronic system. The velocimeter is a three digit b.c.d. system capable of 10-MHz operation based on a maximum projectile speed of 10 km/s. The velocimeter outputs 15-V step functions to trigger the railgun and the 20-ns, 50-kW flashlamp.

At present the injector stage of the velocimeter is operating. It uses a separate one-MHz clock for better resolution of the one-km/s injection speed. Tests on the nonevacuated injector indicate that the laser beam is broken by the leading edge of the projectile's shock wave. For measurement of the projectile velocity while it is in the bore of the gun, the projectile acts like a piston to generate a shock wave that is several times the bore width in length. This long shock wave complicates the determination of the exact position of the projectile in the bore of the injector; however, the velocimeter operates as designed and will be used later this year with the railgun under vacuum.

Remarks

This velocimeter will give reliable values for the input and output velocities and trigger the first current supply of the CEM-UT railgun. Magnetic coils located near the rails will be used to trigger the subsequent current supplies. The signals from these coils will also give information on the velocity of the current center of the armature arc. Other velocimeters in the future will also yield continuous velocity information. Any continuous velocimeter will require independent verification and calibration from the discrete laser beam velocimeter which can be adapted to any railgun.

Once accurate data of the voltages, currents and velocities of a railgun is obtained, all aspects of the railgun system can be mathematically modeled except the armature. To design and optimize new railguns more diagnostic information about the plasma arc armature will be required.[4] Future diagnostic work on railguns will be directed at studying the armature system.

Acknowledgments

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References

1. R. A. Marshall, "Railgun Energy Stores and Systems," proceedings of this conference, 1981.
2. F. L. Ribe and G. C. Vlases, "Scope of Impact Fusion and Review of Macroparticle Accelerators," Proc. Impact Fusion Workshop, Los Alamos Scientific Laboratory report LA-8000-C (August 1979).
3. S. C. Rashliegh and R. A. Marshall, "Electromagnetic Acceleration of Macroparticles to High Velocities," J. Applied Phys. 49, 2540 (1978).
4. I. R. McNab, "Electromagnetic Macroparticle Acceleration by a High Pressure Plasma," J. Applied Phys. 51, 2549 (1980).