THE CEM-UT DISTRIBUTED ENERGY STORE RAILGUN FACILITY

L. D. Holland

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Center for Electromechanics
The University of Texas at Austin
Balcones Research Center
EME 1.100, Building 133
Austin, TX 78758-4497
(512)471-4496

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L. D. Holland
Center for Electromechanics
The University of Texas at Austin
Austin, TX 78712

Summary

The Center for Electromechanics has constructed a facility for the operation of a distributed energy store railgun consisting of separate energy storage capacitor bank modules, a 4-m railgun, and the systems required to operate and diagnose the railgun. The power supply consists of ten 53-kJ, 10-kV capacitor bank modules rated at 200 kA. Each module is triggered by signals from magnetic pickup coils located along the bore of the railgun which detect the passing of the plasma armature used to accelerate the projectiles. The railgun will accelerate 1-gm projectiles to velocities greater than 10 km/s. The railgun and the other components of the facility are designed as a testbed system for use in a wide variety of electromagnetic accelerator experiments.

DES Railgun

The distributed energy store (DES) railgun, first proposed by Marshall and Weldon in 1980, uses multiple energy storage units to power an electromagnetic railgun.[1] The energy store connection points are distributed along the bore of the railgun. Figure 1 shows a schematic of a DES railgun. The primary energy store can be capacitors, homopolar generators, or some other device. The energy is then transferred from the primary store into the inductors shown in Fig. 1 which are used to control the current in the armature of the railgun.

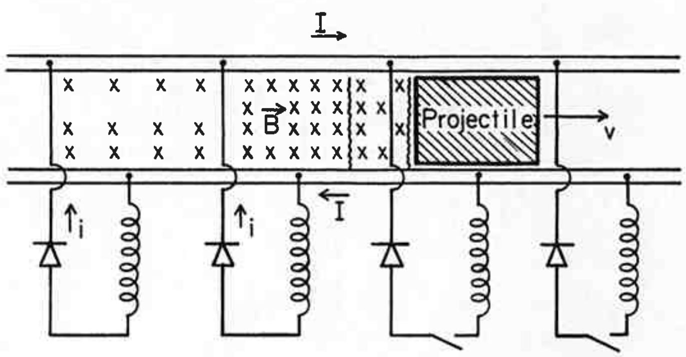

Fig. 1. Distributed store rail gun

The DES railgun overcomes several limitations of the conventional breech-fed railgun. A breech-fed railgun is limited in length by the back emf generated at the breech due to increasing rail resistance as the projectile moves down the bore. The rail resistance also reduces the efficiency of the gun. For a constant current breech-fed railgun, the stored magnetic energy in the bore of the gun is equal to the projectile kinetic energy when the projectile exists the gun. The DES railgun is not limited in length, due to the distributed current feed points. The current is present in only a portion of the rails at any instant in time, reducing energy loss due to rail resistance. The magnetic energy stored in the bore of a DES railgun is less than the projectile kinetic energy.

Development of the CEM-UT Program

In 1980, CEM-UT began a program to study the feasibility of the DES railgun concept.[2] This project was funded by the Texas Atomic Energy Research Foundation. A two-stage DES railgun was constructed and operated with a shotgun shell injector. The 1-g Lexan projectile entered the railgun at 700 m/s and was accelerated by the current from the two energy stores. Each store had a maximum current of 70 kA and able to accelerate the projectile to a terminal velocity of 900 m/sec. The TAERF railgun demonstrated the DES railgun principle and was used as the foundation for the planning of the present DES railgun facility.

Based on the experimentation with the TAERF railgun, planning for the DES railgun facility began. The major criterion for the facility was the construction of a system for reliably operating DES railgun with 0.5- to 10-g projectiles. The energy stores for this system were to have a 10-kV rating and be capable of operating with projectile speeds in excess of 10 km/s. The system was to be a testbed facility with all components interchangeable and an emphasis on flexibility. As constructed, the total current switching capability of the system is 2 MA, with complete control of the current-time profile during the operation of the railgun. The facility was also designed to be used for multiple electromagnetic propulsion experiments operating on a daily basis.

Plans for the DES facility were completed and construction began in early 1982. After the completion of a prototype energy storage module and a 33-in. railgun, work began on construction of the other systems needed for operation of the DES railguns. CEM-UT then began construction of the remaining components of the facility as part of a joint program with the Vought Corporation under the sponsorship of the U. S. Army Armament Research and Development Command and the Defense Advanced Research Projects Agency. Under this program, CEM-UT is building a system for experimentation of DES railgun. Based on this work the Vought Corporation is constructing a DES railgun for ballistics studies of projectiles at velocities greater than 3 km/s.

Major Components of the Facility

The DES railgun facility can be broken down into five major components. These are the energy storage modules, the railgun bed, the trigger system, the diagnostic system, and lab utilities. A brief description of each of these components is given below.

Energy Storage Modules

The energy storage modules are independent capacitor banks. Each module is a complete bank with four high energy density capacitors, an ignitron switch to initiate current, an automatic crowbar consisting of an ignitron triggered by a diode, an inductor to limit the current delivered to the load, and auxiliary circuits for connecting to power supplies and dump circuits. A circuit diagram of an energy store is shown in Fig. 2. The modules are mounted on wheels to allow configuring of the laboratory for different experiments, and each module can be triggered either by timing circuits or from signals generated by the load. Eleven energy stores have been constructed and operated. Two of the energy stores have over one-hundred shots with peak current greater than 100 kA. Maintenance requirements for the stores has been minimal.

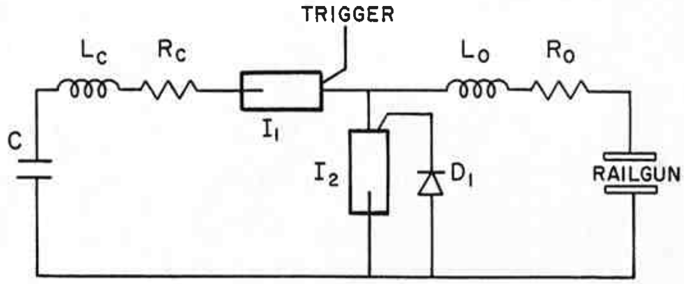

Fig. 2. Energy store circuit

Gun Bed

The gun bed is the second major component of the railgun system. The gun bed consists of two DES railguns that are operated at different times. The first gun constructed was a four-stage, 33-in railgun. This short gun was used for system tests on the triggering and diagnostic systems. It has also been used to verify the design current level of the 12-ft railgun presently under construction. The short gun has clearly demonstrated the DES principle and will be used in the future in material studies under high-current operation -- that is, at current densities greater than 500 kA/cm height of the bore. The 12-ft gun has current connection points for all the energy stores and will be used to achieve velocities in excess of 10 km/sec in the first series of test to be conducted this summer. Both of the guns use a symmetric coaxial current feed connection scheme to reduce interference of the magnetic field in the bore by the current feeds. Also, the guns have a flexible bore geometry. In Fig. 3 a cross section of the guns is shown. Multiple layers of G10 are used to clamp the bore. The spacers adjacent to the bore are replaceable and various materials will be tested as side walls for the bore. By changing these spacers and the rails, the bore size can be varied from 0.6 cm to 2.5 cm on a side.

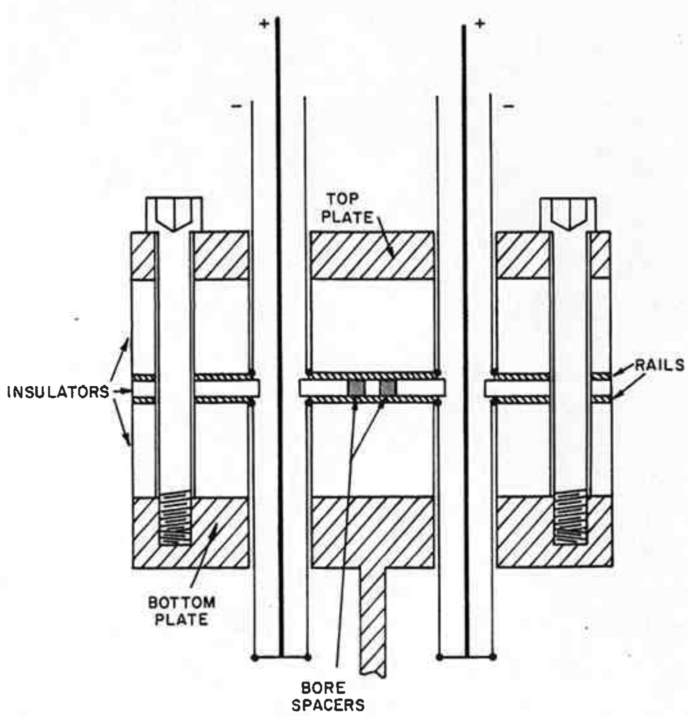

Fig. 3. Cross section of DES railgun

Rail Gun

The railgun bed also contains a catch tank and diagnostic equipment. The catch tank is a 2-m steel structure for the containment of the projectile. The side walls are 1-in. thick mild steel plate and all sections of the tank are accessible through hinged top plates. Contained in the tank are a closing switch velocimeter and material to catch the projectile. At present, multiple layers of cardboard are used to slow the Lexan projectile. The main diagnostic equipment on the railgun bed at this time is the breaking laser beam velocimeter. This system has redundant velocity measurements and a photographic verification system. Details of this system were reported previously.[3]

Triggering System

The triggering system for the DES railgun facility is used to time the initiation of current from the individual energy stores. The triggering system uses a combination of magnetic pick-up coils, which sense the position of the armature in the bore of the railgun, and time delay circuits to send trigger pulses to the energy stores. This system must prevent improperly timed triggering of the stores, either by electromagnetic noise generated during a railgun shot or by free-running arcs in the bore of the gun traveling ahead of the projectile. If an energy store is triggered before the armature passes the current connection point for that store, the current from that store will slow the acceleration of the armature and result in a lower exit velocity or, if the armature is stalled by the current, in melting of the rails. Over thirty shots with the four-stage railgun have been performed to date. The triggering system has used both the timing delay technique and a magnetic pick-up coil. In these tests, only one failure of the triggering system has occurred, due to a faulty circuit which has been replaced.

Diagnostic System

The diagnostic system is used to monitor the current from each of the energy stores, to record the velocity of the projectile, to investigate the plasma armature of the railgun, and to obtain information for use in modeling the DES railgun system. Current measurements are made using Rogowski coils on the coaxial leads that connect the energy stores to the railguns. The velocity measurements inside the gun are made using magnetic pick-up coils. For terminal velocity measurements, both the laser beam velocimeter and a closing switch velocimeter, which measures the time of flight between the closing of two switches by the projectile, are used. The plasma armature is investigated using signals from magnetic pick-up coils oriented both along and facing the bore of the gun. Voltage measurements at the breech and muzzle are made to complete the information needed to model the railgun system.

DES Railgun Facility

The DES railgun facility is designed to be a laboratory test bed system. As such, the high voltage distribution, trigger systems and diagnostic systems were constructed so that the high current power supply could be tailored to a wide variety of loads. The energy store can be moved about the lab and fired in any desired time sequence.

Operating Experience

The short gun was first operated as a single-stage gun. During the summer of 1982, 1.0-cm cubes of Lexan were accelerated from zero velocity by a 32-kJ energy store. The exit velocities were typically 650 m/s. In the fall of 1982, the short gun was operated as a two-stage DES railgun. This allowed tests of the electromagnetic noise immunity of the trigger system to be conducted. This was also the second successful DES railgun to be operated by CEM. In February of 1982, the 33-in. railgun was first operated as a four-stage railgun. The February test demonstrated triggering the energy stores using magnetic pick-up coils near the bore of the railgun. High current test firings were performed to test the gun design before construction of the 12-ft gun began. Peak armature currents of 550 kA with a 1-cm bore were achieved on six successive shots. Part of one of the fiberglass-epoxy spacers was damaged by these shots. The rails were pitted in the region where the projectile started, but remained usable.

Based on the February test on the four-stage railgun, the design of the 12-ft railgun was finalized and construction began in March. The gun, which is similar in design to the four-stage gun, has connection points for all the energy store. Construction of the gun was completed in May, and firings will begin in June. The eleven energy stores, which have contained 240 kJ at 10 kV, are being upgraded to 580 kJ at 10 kV for operation of the large gun.

Future Work

The next major effort for the DES railgun facility will be the operation of the 12-ft railgun with the upgraded energy store system. The plans call for the operation of the gun with 1-g Lexan cubes to speeds in excess of 10 km/s. The diagnostic system of the facility will then be upgraded to prepare for future electromagnetic propulsion experiments. For such experiments, the facility contains 580 kJ of capacitor energy with a switching capability of 2 MA. These capabilities combined with the DES railguns comprise a powerful tool for the study of hypervelocity projectiles and their accelerators.

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