**RAILGUN EXPERIMENTS AT THE UNIVERSITY OF TEXAS,
CENTER FOR ELECTROMECHANICS**

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Abstract

The Center for Electromechanics at the University of Texas at Austin (CEM-UT) presently has five experimental electromagnetic (EM) launchers or railguns in operation. An additional ten fully operational railguns are presently decommissioned and five new launchers are being fabricated. Several different parallel rail configurations and geometries are being studied as well as augmented rails and coaxial launchers. Recent tests utilizing the magnetic flux generated in a coil have produced promising results for work with coilgun launchers. Electromagnetic launchers at CEM-UT have been used in a wide variety of experiments. Particles of 50 to 500 μm in diameter have been accelerated up to 11 km/s to determine the effects of micrometeorite impacts on materials used in space applications and 2.5-kg packages have been launched to 2.6 km/s (8.1 MJ muzzle energy) in ballistic tests. Paper studies on launching 100-kg payloads at 10 km/s have also been conducted to determine the feasibility of launching satellites with EM launchers.

Introduction

CEM-UT was started in 1975 with the primary goal of studying the generation of and applications for pulsed power. Development of EM launchers or railguns

began in 1979 after a visit to the railgun facility at the Australian National University.(1) The first launchers built were low energy capacitor powered models with parallel copper rails and G-10 insulators. While the size and performance of similar launchers today has increased, the fundamental principles which govern performance have remained the same and are illustrated in figure 1. Now in addition to simple square bore, parallel plate launchers, a wide variety of other geometries and concepts are being tested at CEM-UT (table 1) and other launcher facilities. These include round bore, coaxial, distributed energy store (DES), augmented, and induction launchers or coilguns. The uses for these are as wide in scope as the launcher systems themselves.

Table 1. Some of the twenty launchers currently available or in fabrication at CEM-UT.

Program and Power Supply	Launcher Length x Bore Dimension	Armature Type and Mass	Package Mass Total (g)	Velocity (m/s)
Micrometeoroid Square Bore & 1 MJ Capacitor Bank	1 m x 12.7 mm Square Bore	Al. Plasma NA	NA	6,000-11,000
GEDI Hypervelocity Launcher & 10 MJ HPG & Capacitor Bank	2 m x 12.7 mm Square Bore	Al. Plasma 0.06 g	2	6,200
Small Caliber Rep-ratable Gun & 9 MJ Air Core Compulsator	1.6 m x 15 mm Round Bore	Solid Al. 22 g	32	1,725
Coaxial Induction Accelerator & Actively Switched Capacitors	*10 m x 45 mm Round Bore	Multiturn Coil 225 g	225	*2,000
9 MJ Single Shot Gun (SSG) & 60 MJ Homopolar Power Supply	10 m x 90 mm Round Bore	Solid Al. 1,100 g	2,440	2,600
9 MJ Field Based Rep-ratable Gun & 200 MJ Compulsator	7 m x 90 mm Round Bore	Solid Al. *800 g	*2,000	*3,000

* Values marked by an asterisk are predicted, all other values are actuals

Micrometeoroid Launchers

Under contracts from Lockheed's Palo Alto Research Laboratory and Martin Marietta Corporation, CEM-UT has carried out 78 hypervelocity micrometeoroid impact simulations using EM launchers. The purpose of the program is to

determine the effects of fine particles colliding with structures in space. Using 1 m long, square-bore launchers with molybdenum rails and either glass-filled polycarbonate or black-granite sidewalls, 40 to 550 μm diameter glass beads were accelerated to velocities between 6 and 11 km/s.(2) The beads were fired using plasma armatures at targets of aluminum, quartz, silicon, and other proprietary materials. The tests were designed to determine the feasibility of using EM launchers to accelerate particles with masses of 10^{-4} to 10^{-7} g. These sizes of particles are less than that launched effectively by light gas guns and above the range of electrostatic accelerators.

Launching a nonconductive material such as glass requires the use of a separate armature. Thin strips of aluminum foil 0.254 to 0.0254 mm thick were bonded to an insulating plug at the breech of the gun. The glass microspheres were secured to the plug either electrostatically or with a spray adhesive. Typically, two capacitor modules charged to 7 kV (54 kJ) were discharged simultaneously into the gun. The fuse would vaporize into a plasma and be accelerated through the launcher, carrying the entrained microspheres to the target. The fact that both the plasma and the beads were accelerated required that particular attention be paid to differentiating the effects of the microspheres from those of the plasma. While the impact craters on the targets made by the beads were clearly different from any plasma effects, the velocities were assumed to be the same. Several methods to strip the plasma from the beads prior to target impact met with limited success but alternative methods and further testing have been proposed.

Small Caliber Repeated Launcher

Under a contract supported by the Joint Services Small Arms Program a repeatable, skid mounted, 0.60 caliber 1.6 m long EM launcher and power supply is in

fabrication at CEM-UT.(3) The skid, which will weigh less than 1,100 kg, includes the launcher and autoloader, the compulsator power supply, an SCR switch and the torque management system to compensate for the torque developed when the compulsator discharges. The only additional components required for firing the system in the field are the hydraulic motors, bearing sumps, and nitrogen and vacuum supplies.

The launcher incorporates primary rails of molybdenum to reduce the bore damage normally associated with solid or plasma armature launchers. Copper secondary rails running parallel to the primaries and carrying current in the same direction are used to augment the primary rails. The augmentation increases the L' of the launcher to $1.25 \mu\text{H/m}$ vs. $0.37 \mu\text{H/m}$ for the same geometry without augmentation. Rail insulators are fabricated by potting polyurethane in place around the rails after they are inserted into the gun support structure.

This gun is designed to fire a three shot salvo of solid aluminum armatures and projectile packages with masses of 32 g at velocities up to 2,000 m/s. The objective of the solid armature design is to provide an adequate contact surface with good mechanical compliance while maintaining sufficient current-carrying capability. This is accomplished by machining a 30' taper into the 12.7 mm long contact surface, which results in a 0.23 mm interference fit on the diameter at the rear of the contact and a line-to-line fit at the front. This assures that the contacts are adequately loaded against the rails for the initial surge of current which starts the armature moving from its static position. Because the armature is designed with compliance in mind, as it moves down the bore and the contacts are worn away, the magnetic pressure continues to force additional contact material against the rails.

While other programs have produced higher muzzle energies this compact power supply will operate at higher energy and power densities than any system previously tested at CEM-UT. This is accomplished primarily by using a compensated pulsed alternator (compulsator), invented by CEM-UT engineers in 1978 (4) as the prime railgun power and power conditioner. Energy density in the compulsator running at 25,200 rpm will be 12 kJ/kg vs. 2.7 kJ/kg for capacitors, and 4 kJ/kg for homopolar generators (HPG's).(5)

Coaxial Induction Launcher

Another type of launcher being tested at CEM-UT uses a series of coils to propel a multiturn armature by inducing a current as illustrated in figure 2. The goal of this program, funded by the U.S. Army Armament Research, Development, and Engineering Center (ARDEC) and the Defense Advanced Research Projects Agency (DARPA), is to launch a 225-g armature, 45 mm in diameter at 2,000 m/s.(6) Because the current in the armature is induced, no physical contact between the armature and launcher is required. This eliminates the type of bore damage seen in both plasma and solid armature launchers. Another feature of the induction launcher design is its modular nature. When completed, it will consist of 47 separate stages. Each stage includes a stator coil driven by a dedicated capacitor bank and ignitron switch. Fiber-optic sensors in each coil detect the position of the armature as it passes. A common controller determines velocity and the optimum time to fire the following stage. This sequence is repeated with each succeeding stage. At present, five stages have been completed and tests with two active stages have been conducted. Over 100 low energy launches have been completed and a monolithic armature with a mass of 96 g has been launched at 165 m/s.

Parametric studies of coaxial induction launchers have shown this type of accelerator to be particularly adaptable to large-bore applications where launcher efficiencies should exceed the 38% predicted for the 45 mm bore modeled. With a sufficient number of stages a large-bore launcher of sufficient length to reach escape velocity could conceivably be fabricated and used to launch satellites at a fraction of the present cost.(7)

9 MJ Single Shot Gun

As part of a program to develop alternative tactical weapons, DARPA and ARDEC have funded the design, fabrication, and testing at CEM-UT of the highest muzzle energy railgun system in existence. It consists of a 10 m long, 90 mm round-bore launcher powered by six HPG charged inductive stores.(8) During the test program, a number of solid armatures and projectile packages are being tested in the 50 m deep vertical test range depicted in figure 3. Prior to testing, computer simulations are run to determine the preferred current profile and predict system performance. During projectile flight, high speed films, X-rays, muzzle voltage, and velocity/acceleration profiles are recorded along with power supply operating parameters. Diagnostics in the vertical range include four Scandiflash model 300 kV flash x-ray units and four high speed 16 mm Photonic, Photec IV, rotating prism cameras capable of 20,000 frame/s operation with rippleflash units for back or front lighting. Four additional x-ray units and a copper-vapor laser operating at 20,000 Hz(to provide increased lighting for filming projectiles) are also being installed. In-bore diagnostics include gun current, breech and muzzle voltage and B-dot probes.

The 10 m long gun uses a replaceable rail assembly constructed of four 90 degree sectors. The L' of the 90 mm gun has been measured at 0.37 $\mu\text{H}/\text{m}$. The gun design and rail replacement technique was initially confirmed through testing of a

half-scale, 45-mm bore gun, 3-m long which is operational but mothballed at the present time. After machining the rail/insulator package to an 18 cm outer diameter (OD) it was inserted into a rail support structure, composed of ceramic disks and a forged steel pressure vessel. The rails were then preloaded by pressurizing an annulus of hydraulic fluid to 225 MPa (32.5 kpsi). This prestressing is required to contain the bore pressure, 373 MPa (54.1 kpsi), caused by the peak gun current of 3.2 MA.

Like the small caliber launcher previously mentioned the 90 mm gun uses solid aluminum armatures as complete launch packages and to launch test packages provided by outside projectile developers. Muzzle voltage vs. velocity plots have been generated for all the 90 mm gun shots which exceeded 1,800 m/s and confirm that armature transitioning does occur between 750 and 1,100 m/s. Because solid armatures do transition to a hybrid solid/plasma armature (9), it is important to address the issues relevant to both types of armatures in the solid armature design. This becomes more critical when launching projectile packages. As an additional aid in maintaining armature contact and sealing the plasma generated after transitioning, nylon boreriders are used on the armatures.

To date the highest performance shot on the 9 MJ gun system has been an 8.1 MJ shot of a 2,440 g solid aluminum armature with integral payload at a muzzle velocity of 2,557 m/s. This is believed to be a world record for muzzle energy out of an EM launcher. A total of 25 shots have been fired with this launcher, with approximately half of those exceeding 4 MJ of muzzle energy. The 9 MJ field based rep-ratable launcher mentioned in table 1 is under construction at CEM-UT and will begin field testing with its stand-alone power supply in the summer of 1991.

Conclusions

Electromagnetic launchers can be used to accelerate a wide range of projectiles at velocities not readily achievable by conventional methods. Performance limits have not been reached and there is no limit on the variety of uses for these types of launchers. While a few of the existing programs at CEM-UT have been described, there are many other potential uses. These range from fusing metals to glass or other substrates to driving nails with a small, portable railgun/nailgun. Even the arc travelling down a launcher may have a use as a future replacement for conventional spark plugs in automobiles.

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$$F = \frac{L' I^2}{2}$$

$$P = \frac{B^2}{2\mu_0}$$

$$= \frac{F}{w h}$$

Parameter	Definition	Units
F	≡ Acceleration force on the projectile.	[N]
P	≡ Apparent magnetic pressure acting on the inner rail surfaces and on the base of the projectile.	[N/m ²]
I	≡ Electrical current flowing into the top rail, through the armature, and out the bottom rail.	[A]
B	≡ Magnetic field density.	[Wb/m ²]
L'	≡ Inductance per unit length of the railgun.	[H/m]
v	≡ Projectile velocity.	[m/s]
w, t, h,	≡ Rail and bore dimensions.	[m]

Figure 1. Parallel rail principles

$$F = I_1 I_2 \frac{\partial M_{12}}{\partial x}$$

I_1 - stator current (A)

I_2 - armature current (A)

$\frac{\partial M_{12}}{\partial x}$ - inductance gradient ($\frac{H}{m}$)

F - force on armature (N)

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Figure 2. Coaxial accelerator principles

Figure 3. Vertical test range at CEM-UT