By Harry Fair,
University of Texas at Austin

The Electromagnetic Launch Technology Revolution

The ability to use electromagnetic energy to controllably propel objects to extremely high speeds has broad and important consequences for many elements of our society, including transportation, communications, energy, national defense and space, and it may even provide insight into the origins of the earth and solar system. Magnetically levitated trains and hybrid electric automobiles have been discussed in previous editions of this journal, and their role and importance in efficient transportation and energy conservation is well known. But the technology for using electromagnetic energy pulses to accelerate materials to extremely high speeds is only now sufficiently advanced that it is being exploited to evaluate the survivability of space structures and the survivability and lethality of military weapons systems. In fact, electromagnetic launchers are now capable of accelerating objects to such high speeds that projectiles are able to travel many hundreds of kilometers or penetrate the most advanced modern armors, and electromagnetic launchers have even reached sufficiently high speeds to put objects in orbit around the earth.

Electromagnetic launchers can propel objects to these high speeds because they provide all of the accelerating force by the interaction of electromagnetic fields and strong electric currents. Conventional guns or rockets accelerate materials by the combustion of chemical propellants. The propellant combustion gases provide high temperatures and pressures (conventional guns) or high combustion gas exhaust speeds (conventional rockets) to create the propulsion force. The speeds obtainable by the combustion of propellants depends on the size of the molecules in the combustion gases. Practically, this limiting speed is approximately 2 km/sec (4,500 miles per hour) for high-performance guns (1.5 km/sec is the speed of the Army's 120-mm tank gun). In contrast, electromagnetic guns have accelerated materials in the laboratory to 6-7 km/sec (almost 16,000 miles per hour). The speed required to launch materials into low earth orbit is approximately 6.5 km/sec.

Fundamental Principles

The fundamental principle of all electric launchers derives from the basic observation by Michael Faraday and others that a conducting wire carrying an electric current $\overline{J}$ subjected to a magnetic field of strength $\overline{B}$, experiences a force called the Lorentz force:

$$\overline{F} : (\overline{J} \times \overline{B}) \qquad (1)$$

This interaction between currents and magnetic field is the fundamental relationship that governs all types of electric launchers. One of the appealing features of electric launchers is the breadth of launcher types and configurations in contrast to the piston and cylinder geometry of conventional chemical gun or missile propulsion systems.

Railguns

The simplest electric launcher configuration is called the railgun, consisting of two parallel conductors (rails) and a movable conducting element (armature). As shown in Figure 1, a current introduced at the end of the rail generates a magnetic field around the rail as the current moves along its length. The conducting armature provides a conducting path, leading the current back along the second rail. This current also generates a magnetic field that is in the same direction and is added to the field from the first rail. The interaction of the current and the magnetic field produces a force, described by Equation (1), that is directed perpendicular to the magnetic field and to the current. This force attempts to push the rails apart and the movable armature along the length of the rails.

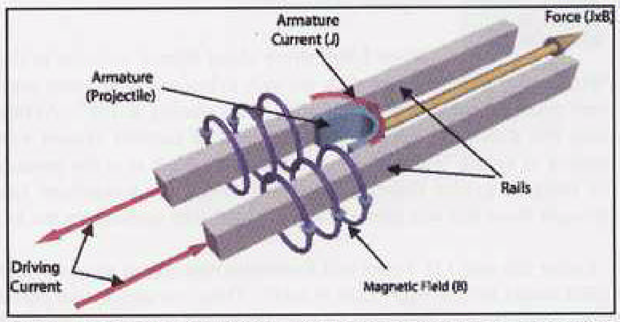

Fig 1. Basic configuration of simple railgun and projectile.

Currents of several million amperes are required to produce accelerating forces large enough to be of interest in accelerating most macroscopic objects. The technical challenge has been to understand the interaction of the rail-armature interface, at which the conducting armature is required to maintain a good electrical contact with the rail, while carrying very large currents (several million amperes) and moving at extremely high speeds.

The US Hypervelocity and Electromagnetic Launch Program

In the late 1970s, several totally independent research efforts attempted to develop practical electromagnetic launchers. A small group of physicists at the Army's Propulsion Laboratory in Dover, N.J. was asked by the office of the Secretary of Defense to develop a US national research program and take the lead in developing the technology and demonstrating the feasibility of electromagnetic launch. Previously, there had been isolated attempts to develop electric launchers, but generally, all of the earlier attempts to reach very high speeds (called hypervelocities) had been quite unsuccessful.

The remarkable exception was a successful experiment performed by Prof. Richard Marshall and Dr. John Barber at the Australian National University in Canberra in the 1970s. Using a large homopolar generator as the power source, they were able to accelerate a 3-g Lexan projectile to 5.9 km/sec in a five-meter-long railgun. This was a world-record speed for electromagnetic guns and demonstrated that electromagnetic guns could achieve hypervelocity.

At approximately the same time, Prof. Gerald O'Neill at Princeton University and Prof. Henry Kolm at MIT proposed a coaxial electromagnetic launcher, the "Mass Driver." They collaborated to build a laboratory launcher, which accelerated a relatively large mass (several kilograms) to only a modest velocity, but the experiment helped generate enthusiasm and support for electromagnetic launch research.

The US Army and the Defense Advanced Research Projects Agency (DARPA) joined forces to demonstrate that larger masses could be accelerated to high speeds. They funded a Westinghouse team led by Dr. Ian McNab to build a laboratory system to launch a projectile weighing a third of a kilogram to 3 km/sec. In these early experiments, an upper bound of approximately 3 km/sec was chosen to eliminate complexities from aerothermodynamic heating of the projectiles. Later, under the joint DARPA/Army program, two large (90-mm) railgun facilities, one at The University of Texas Center for Electromechanics (CEM) using homopolar generators as the power source, and one at Green Farm in California using capacitors as the energy source, were constructed and were capable of accelerating several kilogram projectiles to 2 to 2.5 km/sec.

It is significant that all of these large electromagnetic launchers provided initial important results but are no longer in operation. They clearly demonstrated the feasibility of accelerating large (several kilogram) masses to hypervelocity, but they also helped identify numerous critical fundamental issues that needed to be resolved before continuing with further large and expensive demonstration experiments.

Institute for Advanced Technology (IAT) Created

The US electric launch efforts prior to 1990 were directed toward resolving technological issues but with heavy emphasis on building hardware and large facilities to demonstrate feasibility. However, it was determined from these experiments that there were still serious, fundamental physics issues that had to be resolved and were serious impediments to further implementation of the technology.

In 1990, the Institute for Advanced Technology (IAT) was created at The University of Texas. The purpose was to create a research organization dedicated to developing the fundamental physical principles, computational tools, and experimental research capability to provide the scientific underpinning for hypervelocity electric launchers and hypervelocity impact physics.

In just a relatively short time, an impressive list of issues previously regarded as "show stoppers" or major technical hurdles have yielded to the combination of theoretical analyses, computations, and novel experiments, and electromagnetic launchers are now being developed for a broad range of applications.

Applications

The US Army has been the most consistent supporter of the technology. Its primary interest is in a future hypervelocity electromagnetic gun capable of overwhelming the most advanced and sophisticated armor.

Compact energy storage and power conditioning is the pacing technology. The U.S. program has focused on energy storage by inertial high-speed rotors, integrated into some form of electrical pulse generator. To minimize size and weight, these devices require extremely high rotational speeds, which require the use of high-strength carbon fiber composites to contain the embedded metallic current carrying conductors (see Figure 2).

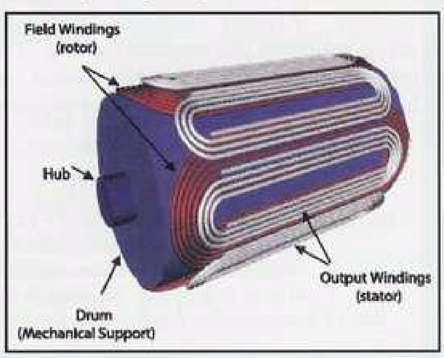

Fig 2. Rotating Shell Pulsed Alternator

The critical challenge is to reduce the size and weight of these pulsed alternators so they are compatible with lightweight, highly mobile combat vehicles. An artist's concept is shown in Figure 3.

Fig 3. Railgun-armed combat vehicle.

The US Navy is currently evaluating two competitive electromagnetic aircraft launch systems as an electrical alternative to steam catapults. The major challenges appear to be engineering issues with extremely high requirements on control, reliability, and robustness in a relatively hostile physical environment. But the application that will provide a technical revolution for the Navy is the potential to launch guided hypervelocity projectiles from a ship-based electromagnetic gun at speeds in excess of 2 to 2.5 km/sec. These hypervelocity projectiles will have most of their ballistic flight in space and will descend with incredibly high speed on targets at ranges of 400 km.

Launching material directly to space with an electromagnetic launcher is an intriguing goal as a means of reducing the cost of supplying water and other vital materials to stations in space. Projected savings by factors of 300 to 1,000 times appear possible, but it is clearly the most stressing of the possible applications. It may well be that the low-cost access and commercialization of space will be enabled by hypervelocity electromagnetic launch.

The ability to use electromagnetic energy to launch materials controllably to hypervelocity has been advanced significantly in recent years. Much additional research is needed, but several important applications now appear to be possible that are not achievable by any other means. The development and exploitation of electromagnetic launch science and technology will be as revolutionary as the early employment of steam or jet engines or chemical explosions or propellants.

Dr. Fair is an experienced laboratory director, program manager, and physicist who has created, directed, and managed complex multi-disciplinary, technical efforts of national importance. To focus the research and development of the enabling technologies for the next generation of hypervelocity weapons, he established and is the Director of the Institute for Advanced Technology at The University of Texas at Austin, the Army's University Research Center in hypervelocity physics and electrodynamics. He received a B.S. in Physics from Indiana University, an M.S. in Chemical Physics from the University of Delaware, and a Ph.D. in Solid State Physics from the University of Delaware. He can be reached at Harry_Fair@iat.utexas.edu.