**Railgun**

From Wikipedia, the free encyclopedia



Schematic diagram of a railgun



Naval Surface Warfare Center test firing in January 2008, leaving a plume of plasma behind the projectile.

A railgun is an electrically powered electromagnetic projectile launcher based on similar principles to the homopolar motor. A railgun comprises a pair of parallel conducting rails, along which a sliding armature is accelerated by the electromagnetic effects of a current that flows down one rail, into the armature and then back along the other rail.

The armature may be an integral part of the projectile, but it may also be configured to accelerate a separate, electrically isolated or non-conducting projectile. Solid, metallic sliding conductors are often the preferred form of railgun armature but "plasma" or "hybrid" armatures can also be used. A plasma armature is formed by an arc of ionized gas that is used to push a solid, non-conducting payload in a similar manner to the propellant gas pressure in a conventional gun. A hybrid armature uses a pair of "plasma" contacts to interface a metallic armature to the gun rails. Solid armatures may also "transition" into hybrid armatures, typically after a particular velocity threshold is exceeded.

In its simplest (and most commonly used) form, the railgun differs from a traditional homopolar motor in that no use is made of additional field coils (or permanent magnets). This configuration is thus a self-excited linear homopolar motor formed by a single loop of current.

A relatively common variant of this configuration is the augmented railgun in which the driving current is channeled through additional pairs of parallel conductors, arranged to increase ("augment") the magnetic field experienced by the moving armature. In electric motor terminology, augmented railguns are usually series-wound configurations.

A railgun requires a pulsed, direct current power supply. For potential military applications, railguns are usually of interest because they can achieve much greater muzzle velocities than guns powered by conventional chemical propellants. Increased muzzle velocities can convey the benefits of increased firing ranges while, in terms of target effects, increased terminal velocities can allow the use of kinetic energy rounds as replacements for explosive shells.

Thus typical military railgun designs aim for muzzle velocities in the range of 2000 - 3500 m/s with muzzle energies of 5 - 50 MJ. For single loop railguns, these mission requirements require launch currents of a few million amperes, so a typical railgun power supply might be designed to deliver a launch current of 5 MA for a few milliseconds. As the magnetic field strengths required for such launches will typically be approximately 10 T, most contemporary railgun designs are effectively "air-cored", i.e. they do not use ferromagnetic materials such as iron to enhance the magnetic flux.

It may be noted that railgun velocities generally fall within the range of those achievable by two stage light gas guns; however, the latter are generally only considered to be suitable for laboratory use while railguns are judged to offer some potential prospects for development as military weapons. In some hypervelocity research projects, projectiles are "pre-injected" into railguns, to avoid the need for a standing start, and both two stage light gas guns and conventional powder guns have been used for this role.

In principle, if railgun power supply technology can be developed to provide compact, reliable and lightweight units, then the total system volume and mass needed to accommodate such a power supply and its primary fuel can become less than the required total volume and mass for a mission equivalent quantity of conventional propellants and explosive ammunition. Such a development would then convey a further military advantage in that the elimination of explosives from any military weapons platform will decrease its vulnerability to enemy fire.

Railguns have long existed as experimental technology but the mass, size and cost of the required power supplies have prevented railguns from becoming practical military weapons. However, in recent years, significant efforts have been made towards their development as feasible military technology. For example, in the late 2000s, the U.S. Navy tested a railgun that accelerates a 3.2 kg (7 pound) projectile to approximately 2.4 kilometers per second (5,400 mph). They gave the project the Latin motto "Velocitas Eradico," which they translate as "speed I kill". The motto is currently under debate in the railgun community and among Latin scholars.

In addition to military applications, railguns have been proposed to launch spacecraft into orbit; however, unless the launching track was particularly long, and the acceleration required spread over a much longer time, such launches would necessarily be restricted to unmanned spacecraft.

**History**



German railgun diagrams

In 1918, French inventor Louis Octave Fauchon-Villeplee invented an electric cannon which is an early form of railgun. He filed for a US patent on 1 April 1919, which was issued in July 1922 as patent no. 1,421,435 "Electric Apparatus for Propelling Projectiles". In his device, two parallel busbars are connected by the wings of a projectile, and the whole apparatus surrounded by a magnetic field. By passing current through busbars and projectile, a force is induced which propels the projectile along the bus-bars and into flight.

During World War II the idea was revived by Joachim Hänsler of Germany's Ordnance Office, and an electric anti-aircraft gun was proposed. By late 1944 enough theory had been worked out to allow the Luftwaffe's Flak Command to issue a specification, which demanded a muzzle velocity of 2,000 m/s (6,600 ft/s) and a projectile containing 0.5 kg (1.1 lb) of explosive. The guns were to be mounted in batteries of six firing twelve rounds per minute, and it was to fit existing 12.8 cm FlaK 40 mounts. It was never built. When details were discovered after the war it aroused much interest and a more detailed study was done, culminating with a 1947 report which concluded that it was theoretically feasible, but that each gun would need enough power to illuminate half of Chicago.

In the early 1960s, the railgun was investigated by NASA as a potential means for studying hypervelocity impact physics. The NASA work also provided the inspiration for the work that was subsequently carried out in Australia.

During 1950, Sir Mark Oliphant, an Australian physicist and first director of the Research School of Physical Sciences at the new Australian National University, initiated the design and construction of the world's largest (500 megajoule) homopolar generator. This machine was operational from 1962 and was later used to power a large-scale railgun that was used as a scientific experiment.

**Railgun design**

**Theory**

A railgun consists of two parallel metal rails (hence the name) connected to an electrical power supply. When a conductive projectile is inserted between the rails (at the end connected to the power supply), it completes the circuit. Electrons flow from the negative terminal of the power supply up the negative rail, across the projectile, and down the positive rail, back to the power supply.

This current makes the railgun behave as an electromagnet, creating a magnetic field inside the loop formed by the length of the rails up to the position of the armature. In accordance with the right-hand rule, the magnetic field circulates around each conductor. Since the current is in the opposite direction along each rail, the net magnetic field between the rails (**B**) is directed at right angles to the plane formed by the central axes of the rails and the armature. In combination with the current (**I**) in the armature, this produces a Lorentz force which accelerates the projectile along the rails, away from the power supply. There are also Lorenz forces acting on the rails and attempting to push them apart, but since the rails are mounted firmly, they cannot move.

It may be recalled that, by definition, if a current of one ampere flows in a pair of infinitely long parallel conductors that are separated by a distance of one meter, then the magnitude of the force on each meter of those conductors will be exactly 0.2 micro-newtons. Furthermore, in general, the force will be proportional to the square of the magnitude of the current and inversely proportional to the distance between the conductors. It also follows that, for railguns with projectile masses of a few kg and barrel lengths of a few m, very large currents will be required to accelerate projectiles to velocities of the order of 1000 m/s.

A very large power supply, providing on the order of one million amperes of current, will create a tremendous force on the projectile, accelerating it to a speed of many kilometers per second (km/s). 20 km/s has been achieved with small projectiles explosively injected into the railgun. Although these speeds are possible, the heat generated from the propulsion of the object is enough to erode the rails rapidly. Under high-use conditions, current railguns would require frequent replacement of the rails, or to use a heat resistant material that would be conductive enough to produce the same effect.

**Mathematical formula**

In railgun physics, the magnitude of the force vector can be determined from a form of the Biot–Savart law and a result of the Lorentz force. It can be derived mathematically in terms of the permeability constant (), the radius of the rails (which are assumed to be circular in cross section) (), the distance between the center points of the rails () and the current in amps through the system () as follows:

It can be shown from the Biot-Savart law that the magnetic field at a given distance () from an infinite current-carrying wire is given by:



So, in the space between two infinite wires separated by a distance, , the magnitude of the field is:



To obtain an approximate expression for the average magnetic field on a railgun armature, we assume that the rail radius is small compared with the rail separation and, by assuming that the railgun rails can be modelled as a pair of semi-infinite conductors, we compute the following integral:



By the Lorentz force law, the magnetic force on a current-carrying wire is given by , so since the width of the conductive projectile is , we have



The formula is based on the assumption that the distance () between the point where the force () is measured and the beginning of the rails is greater than the separation of the rails () by a factor of about 3 or 4 (). Some other simplifying assumptions have also been made; to describe the force more accurately, the geometry of the rails and the projectile must be considered.

Since it is not easy to produce an electromagnetic expression for the railgun force that is both simple and reasonably accurate, most simple railgun analyses actually used a lumped circuit model to describe the relationship between the driving current and the railgun force.

**Considerations**

The power supply must be able to deliver large currents, sustained and controlled over a useful amount of time. The most important gauge of power supply effectiveness is the energy it can deliver. As of December 2010, the greatest known energy used to propel a projectile from a railgun was 33 megajoules. The most common forms of power supplies used in railguns are capacitors and compulsators which are slowly charged from other continuous energy sources.

The rails need to withstand enormous repulsive forces during shooting, and these forces will tend to push them apart and away from the projectile. As rail/projectile clearances increase, arcing develops, which causes rapid vaporization and extensive damage to the rail surfaces and the insulator surfaces. This limited some early research railguns to one shot per service interval.

The inductance and resistance of the rails and power supply limit the efficiency of a railgun design. Currently different rail shapes and railgun configurations are being tested, most notably by the United States Navy, the Institute for Advanced Technology, and BAE Systems.

**Materials used**

The rails and projectiles must be built from strong conductive materials; the rails need to survive the violence of an accelerating projectile, and heating due to the large currents and friction involved. The recoil force exerted on the rails is equal and opposite to the force propelling the projectile. The seat of the recoil force is still debated. The traditional equations predict that the recoil force acts on the breech of the railgun. Another school of thought invokes Ampère's force law and asserts that it acts along the length of the rails (which is their strongest axis). The rails also repel themselves via a sideways force caused by the rails being pushed by the magnetic field, just as the projectile is. The rails need to survive this without bending and must be very securely mounted.

**Heat dissipation**

Massive amounts of heat are created by the electricity flowing through the rails, as well as by the friction of the projectile leaving the device. The heat created by this friction itself can cause thermal expansion of the rails and projectile, further increasing the frictional heat. This causes three main problems: melting of equipment, decreased safety of personnel, and detection by enemy forces. As briefly discussed above, the stresses involved in firing this sort of device require an extremely heat-resistant material. Otherwise the rails, barrel, and all equipment attached would melt or be irreparably damaged.

In practice the rails are, with most designs of railgun, subject to erosion due to each launch; and projectiles can be subject to some degree of ablation also, and this can limit railgun life, in some cases severely.

**Applications**

Railguns have a number of potential practical applications, primarily for the military. However, there are other theoretical applications currently being researched.

**Launch or launch assist of spacecraft**

Main article: Mass driver

See also: Space gun

Electrodynamic assistance to launch rockets has been studied. Space applications of this technology would likely involve specially formed electromagnetic coils and superconducting magnets. Composite materials would likely be used for this application.

For space launches from Earth, relatively short acceleration distances (less than a few km) would require very strong acceleration forces, higher than humans can tolerate. Other designs include a longer helical (spiral) track, or a large ring design whereby a space vehicle would circle the ring numerous times, gradually gaining speed, before being released into a launch corridor leading skyward.

|  |  |  |
| --- | --- | --- |
| **Key Parameters** | **Value** | **Units** |
| Muzzle Velocity | 7500 | m/s |
| Muzzle Energy | 35 | GJ |
| Launcher length | 1600 | m |
| Maximum acceleration | 19500 | m/s^2 |
| Maximum acceleration | 1988 | g's |
| Launch time | 0.43 | s |
| Current density | 6.8 | MA/m |

In 2003, Ian McNab outlined a plan to turn this idea into a realized technology. The accelerations involved are significantly stronger than human beings can handle. This system would only be used to launch sturdy materials, such as food, water, and fuel. Note that escape velocity under ideal circumstances (equator, mountain, heading east) is 10.735 km/s. The system would cost $528/kg, compared with $20,000/kg on the space shuttle (see Non-rocket space launch). The railgun system McNab suggested would launch 500 tons per year, spread over approximately 2000 launches per year. Because the launch track would be 1.6 km, power will be supplied by a distributed network of 100 rotating machines (compulsator) spread along the track. Each machine would have a 3.3 ton carbon fiber rotor spinning at high speeds. A machine can recharge in a matter of hours using 10 MW. This machine could be supplied by a dedicated generator. The total launch package would weigh almost 1.4 tons. Payload per launch in these conditions is over 400 kg. There would be a peak operating magnetic field of 5T -- Half of this coming from the rails, and the other half from augmenting magnets. This halves the required current through the rails, which reduces the power fourfold.

**As weapons**



Drawings of electric gun projectiles

Railguns are being researched as weapons with projectiles that do not contain explosives, but are given extremely high velocities: 3,500 m/s (11,500 ft/s, approximately Mach 10 at sea level) or more (for comparison, the M16 rifle has a muzzle speed of 930 m/s, or 3,050 ft/s), which would make their kinetic energy equal or superior to the energy yield of an explosive-filled shell of greater mass. This would decrease ammunition size and weight, allowing more ammunition to be carried and eliminating the hazards of carrying explosives in a tank or naval weapons platform. Also, by firing at greater velocities, railguns have greater range, less bullet drop, faster time on target and less wind drift, bypassing the physical limitations of conventional firearms, "*the limits of gas expansion prohibit launching an unassisted projectile to velocities greater than about 1.5 km/s and ranges of more than 50 miles [80 km] from a practical conventional gun system.*"

The increased launch velocities of railguns would also allow greater capability for both offensive and defensive applications as compared to traditional weapons. The greater kinetic energy and decreased time on target associated with increased launch velocities, when coupled with non-traditional rounds, allow a single railgun to effectively attack both airborne and land or sea based targets.

If it were possible to apply the technology as a rapid-fire automatic weapon, a railgun would have further advantages of increased rate of fire. The feed mechanisms of a conventional firearm must move to accommodate the propellant charge as well as the ammunition round, while a railgun would only need to accommodate the projectile. Furthermore, a railgun would not have to extract a spent cartridge case from the breech, meaning that a fresh round could be cycled almost immediately after the previous round has been shot.

Many critics of weaponized railgun systems claim running at a decent rate of speed would consume too much power, though this would likely not be a problem for nuclear-powered systems such as on large warships or submarines.

The first weaponized railgun planned for production, the General Atomics Blitzer system, began full system testing in September 2010. The weapon launches a streamlined discarding sabot round designed by Boeing's Phantom Works at 1600 m/s (approximately Mach 5) with accelerations exceeding 60,000 g's. During one of the tests, the projectile was able to travel an additional 4.3496 mi (7 km). downrange after penetrating a 1/8 inch (3 mm) thick steel plate. The company hopes to have an integrated demo of the system by 2016 followed by production by 2019, pending funding. Thus far, the project is self-funded.

**Tests**



Diagram showing the cross-section of a linear motor cannon

Full-scale models have been built and fired, including a very successful 90 mm bore, 9 MJ kinetic energy gun developed by the US DARPA. Rail and insulator wear problems still need to be solved before railguns can start to replace conventional weapons. Probably the oldest consistently successful system was built by the UK's Defense Research Agency at Dundrennan Range in Kirkcudbright, Scotland. This system has now been operational for over 10 years at an associated flight range for internal, intermediate, external and terminal ballistics, and achieved several mass and velocity records.

The Yugoslavian MTI (MTI - Military - technology institute) developed, within a project named EDO-0, a rail gun with 7 kJ kinetic energy, in 1985. In 1987 a successor was created, project EDO-1, that used projectile with a mass of 0.7 kg and achieved speeds of 3,000 m/s, and with a mass of 1.1 kg reached speeds of 2,400 m/s. It used a track length of 0.7 m. According to those working on it, with other modifications it was able to achieve a speed of 4,500 m/s. The aim was to achieve projectile speed of 7,000 m/s. At the time, it was considered a military secret.

The United States military is funding railgun experiments. At the University of Texas at Austin Centre for Electromechanics, military railguns capable of delivering tungsten armor piercing bullets with kinetic energies of nine megajoules have been developed. 9 MJ is enough energy to deliver 2 kg of projectile at 3 km/s–at that velocity a rod of tungsten or another dense metal could easily penetrate a tank, and potentially pass through it.

The United States Naval Surface Warfare Center Dahlgren Division demonstrated an 8 MJ rail gun firing 3.2 kg projectiles in October 2006 as a prototype of a 64 MJ weapon to be deployed aboard Navy warships. The main problem the U.S. Navy has had with implementing a railgun cannon system is that the guns wear out due to the immense heat produced by firing. Such weapons are expected to be powerful enough to do a little more damage than a BGM-109 Tomahawk missile at a fraction of the projectile cost. Since then, BAE Systems has delivered a 32 MJ prototype to the U.S. Navy.

On January 31, 2008 the US Navy tested a railgun that fired a shell at 10.64 MJ with a muzzle velocity of 2,520 m/s. Its expected performance is a muzzle velocity over 5,800 m/s, accurate enough to hit a 5 meter target over 200 nm. (370 km) away while firing at 10 shots per minute. The power was provided by a new 9-megajoule (MJ) prototype capacitor bank using solid-state switches and high-energy-density capacitors delivered in 2007 and an older 32-MJ pulse power system from the US Army’s Green Farm Electric Gun Research and Development Facility developed in the late 1980s that was previously refurbished by General Atomics Electromagnetic Systems (EMS) Division. It is expected to be ready between 2020 to 2025.

A test of a railgun took place on December 10, 2010, by the US Navy at the Naval Surface Warfare Center Dahlgren Division. During the test, the Office of Naval Research set a world record by conducting a 33 MJ shot from the railgun, which was built by BAE Systems.

A more recent test took place in February 2012 at the Naval Surface Warfare Center Dahlgren Division. While similar in energy to the aforementioned test, the railgun used is considerably more compact, with a more conventional looking barrel.

**Trigger for Inertial Confinement Fusion**

Railguns may also be miniaturized for inertial confinement nuclear fusion.

* Fusion is triggered by very ultra-high temperature and pressure at the core.
	+ Current technology calls for multiple lasers, usually over 100, to concurrently strike a fuel pellet, creating a symmetrical compressive pressure.
	+ Railguns may be able to trigger fusion by firing energetic plasma from multiple directions. Hyper-V Technologies is working to bring this technology to fruition. The process developed involves four key steps.
		- Plasma is pumped into a chamber.
		- When the pressure is great enough, a diaphragm will rupture, sending gas down the rail.
		- Shortly afterwards, a sufficient voltage is applied to the rails, creating a conduction path of ionized gas.
		- This plasma accelerated down the rail, eventually being ejected at a large velocity.
* The rails and dimensions are on the order of centimeters.