بسم الله الرحم الرحيم
In the name of God, the Merciful, the Compassionate

Electric Propulsion for SAT direction and orbit correction and stabilization

Attitude and Orbit Control Systems

(AOCS)

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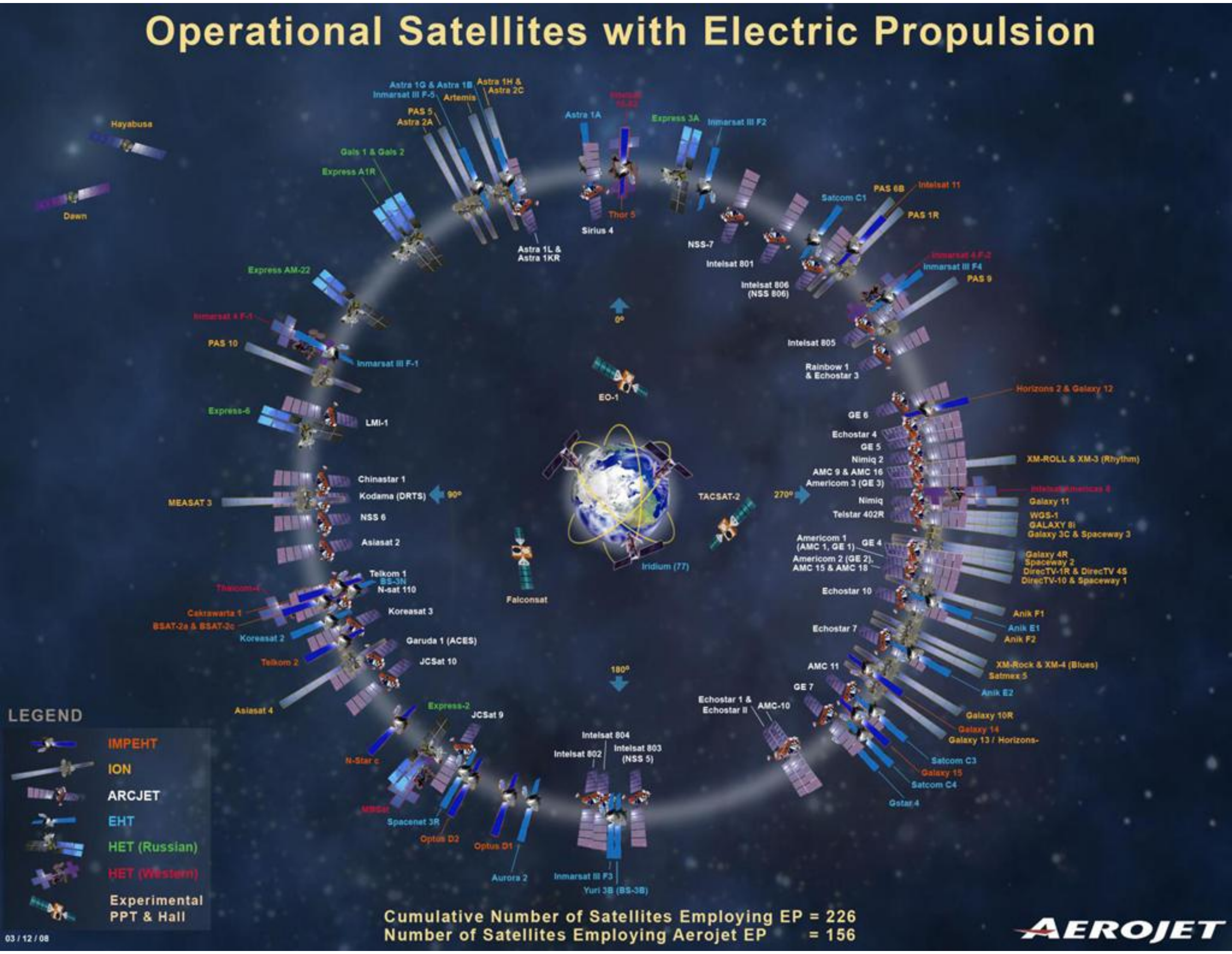


Definitions

A geostationary satellite travels from west to east over the equator. It moves in the same direction and at the same rate Earth is spinning. From Earth, a geostationary satellite looks like it is standing still since it is always above the same location.

Polar-orbiting satellites travel in a north-south direction from pole to pole. As Earth spins underneath, these satellites can scan the entire globe, one strip at a time.

Miniaturized Satellites

Miniaturized satellites are small satellites usually of low mass and a weight lighter than 1100 lb.

Miniature satellites are also known as "smallsats" or "small satellites". The primary objective of creating miniature satellites is to reduce the costs, as bigger satellites require huge rockets with greater thrust and are expensive to maintain. Tiny satellites are lighter because of their size, and several of them can be launched.

space engineering & technology

WHAT IS ELECTRIC PROPULSION?

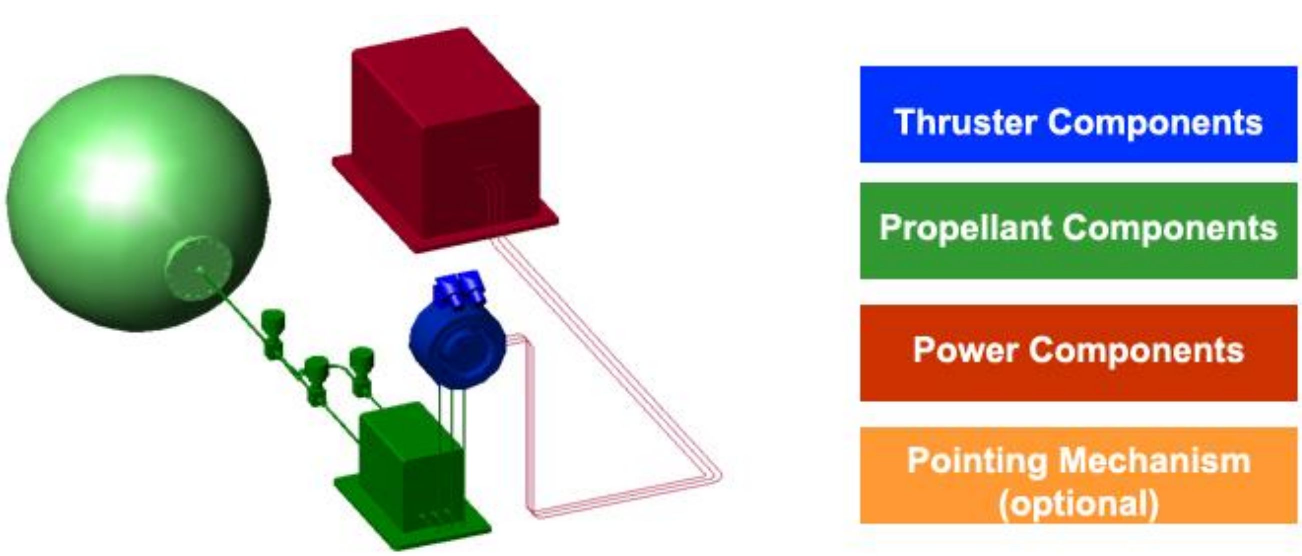
Electric Propulsion (EP) is a class of space propulsion which makes use of electrical power to accelerate a propellant by different possible electrical and/or magnetic means. The use of electrical power enhances the propulsive performances of the EP thrusters compared with conventional chemical thrusters. Unlike chemical systems, electric propulsion requires very little mass to accelerate a spacecraft. The propellant is ejected up to twenty times faster than from a classical chemical thruster and therefore the overall system is many times more mass efficient.

Electric Propulsion, when compared with chemical propulsion, is not limited in energy, but is only limited by the available electrical power on-board the spacecraft. Therefore EP is suitable for low-thrust (micro and milli-newton levels) long-duration applications on board spacecrafts. The propellant used in EP systems varies with the type of thruster and can be a rare gas (i.e. xenon or argon), a liquid metal or, in some cases, a conventional propellant.

Electric Propulsion System components

An Electric Propulsion System is composed by four different building blocks:

- The thruster components,
- The propellant components or fluidic management system,
- The power components, which includes the PPU,
- The pointing mechanisms (optional),



EPS Main building blocksACCESS THE IMAGE

Specifically, the all-electric propulsion system uses electron bombardment to create xenon ions, which are then expelled by the spacecraft, producing thrust in the opposite direction.

While electric propulsion isn't as powerful as chemical propellants when it comes to producing raw thrust, it can be up to 1,000 times more efficient than chemical propellant, which is why it's suitable for long-range or long-duration space missions. Due to its high efficiency, with enough time, a constant emission of ions will also enable spacecraft to reach higher speeds than a chemical propellant.

As a largely stationary satellite, the ABS–3A won't need to be heading anywhere in a particular hurry, although its use of the propulsion system will enable it to adjust its altitude and position in orbit.

Boeing says the satellite contains a sufficient quantity of the inert, non-hazardous element xenon to power the craft's propulsion needs for its operational lifetime. The ABS–3A has an expected lifespan of 15 years, after which time it presumably becomes space junk, floating around in orbit and causing general mayhem.

While the ABS–3A is the world's first satellite to make use of a fully electric propulsion system, it's certainly not the first spacecraft to incorporate electric propulsion. Vessels using different kinds of electric propulsion have been in existence since the 1960s.

Electrically powered spacecraft propulsion

Types

Ion and plasma drives

Main article: Ion thruster

This type of rocket-like reaction engine uses electric energy to obtain thrust from propellant carried with the vehicle. Unlike rocket engines, these kinds of engines do not necessarily have rocket nozzles, and thus many types are not considered true rockets.

Electric propulsion thrusters for spacecraft may be grouped in three families based on the type of force used to accelerate the ions of the plasma:

Electrostatic

If the acceleration is caused mainly by the Coulomb force (i.e. application of a static electric field in the direction of the acceleration) the device is considered electrostatic.

- Gridded ion thruster
- NASA Solar Technology Application Readiness (NSTAR)
- HiPEP
- Radiofrequency ion thruster
- Hall effect thruster
- SPT – Stationary Plasma Thruster
- TAL – Thruster with Anode Layer
- Colloid ion thruster
- Field Emission Electric Propulsion
- Nano-particle field extraction thruster

Electrothermal

The electrothermal category groups the devices where electromagnetic fields are used to generate a plasma to increase the temperature of the bulk propellant. The thermal energy imparted to the propellant gas is then converted into kinetic energy by a nozzle of either solid material or magnetic fields. Low molecular weight gases (e.g. hydrogen, helium, ammonia) are preferred propellants for this kind of system.

An electrothermal engine uses a nozzle to convert the heat of a gas into the linear motion of its molecules so it is a true rocket even though the energy producing the heat comes from an external source.

Performance of electrothermal systems in terms of specific impulse (Isp) is somewhat modest (500 to ~1000 seconds), but exceeds that of cold gas thrusters, monopropellant rockets, and even most bipropellant rockets. In the USSR, electrothermal engines were used since 1971; the Soviet "Meteor-3", "Meteor-Priroda", "Resurs-O" satellite series and the Russian "Elektro" satellite are equipped with them.[18] Electrothermal systems by Aerojet (MR-510) are currently used on Lockheed Martin A2100 satellites using hydrazine as a propellant.

- Arcjet
- Microwave arcjet
- Resistojet

Electromagnetic

Main article: Plasma propulsion engine

If ions are accelerated either by the Lorentz force or by the effect of an electromagnetic fields where the electric field is not in the direction of the acceleration, the device is considered electromagnetic.

- Electrodeless plasma thruster
- MPD thruster

- Pulsed inductive thruster
- Pulsed plasma thruster
- Helicon Double Layer Thruster
- Variable specific impulse magnetoplasma rocket (VASIMR)

Non-ion drives

Photonic

Photonic drive does not expel matter for reaction thrust, only photons. See Laser propulsion, Photonic Laser Thruster,Photon rocket.

Electrodynamic tether

Main article: electrodynamic tether

Electrodynamic tethers are long conducting wires, such as one deployed from a tether satellite, which can operate on electromagnetic principles as generators, by converting their kinetic energy to electric energy, or as motors, converting electric energy to kinetic energy.[19] Electric potential is generated across a conductive tether by its motion through the Earth's magnetic field. The choice of the metal conductor to be used in an electrodynamic tether is determined by a variety of factors. Primary factors usually include high electrical conductivity, and low density. Secondary factors, depending on the application, include cost, strength, and melting point.

Unconventional[

The principle of action of these theoretical devices is not well explained by the currently-understood laws of physics.[20]

- Quantum Vacuum Plasma Thruster
- EM Drive or Cannae Drive

A number of different Electric Propulsion Systems (EPS) exist, based on the following thrusters, (non-exhaustively):

Gridded Ion Engine (GIE)

Hall Effect Thruster (HET)

High Efficiency Multistage Plasma Thruster (HEMPT)

Pulsed Plasma Thruster (PPT)

Magneto Plasma Dynamic (MPD) thruster

Quad Confinement Thruster (QCT)

Resistojet

Arcjet

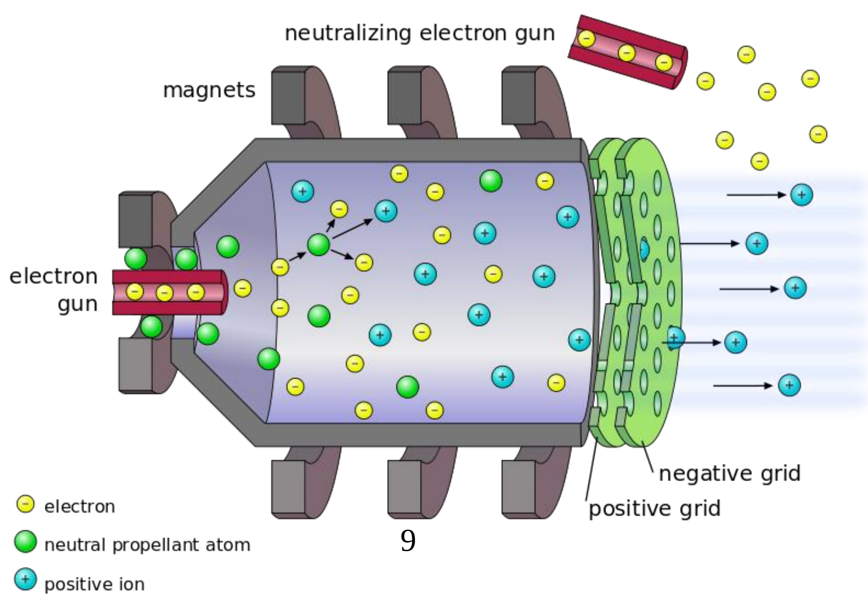
Field Emission Electric Propulsion (FEEP) thruster

Colloid and electrospray thrusters

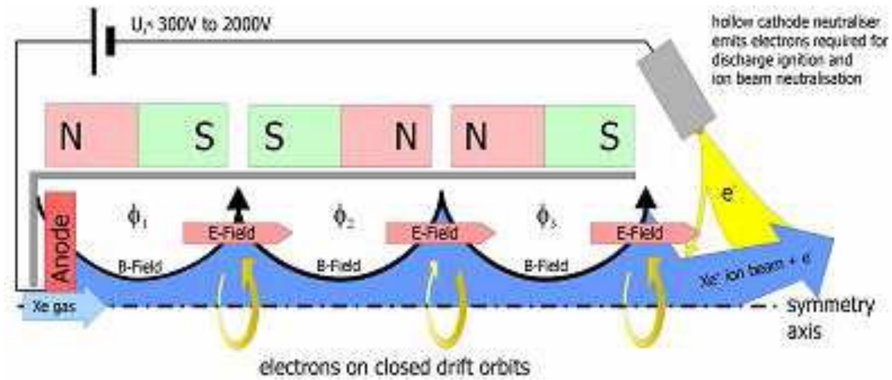
Electrode-less thrusters

Hollow cathode and neutralisers

Gridded Ion Engine (GIE)



High Efficiency Multistage Plasma Thruster (HEMPT)



Pulsed Plasma Thruster (PPT)

A pulsed plasma thruster (PPT) is a type of electromagnetic propulsion system , with a high specific impulse and low power and fuel requirements, that has been used on a number of satellites for station-keeping maneuvers.

A PPT works by ablating and ionizing material from a fuel bar (typically consisting of a chlorofluorocarbon such as Teflon) with the current from a discharging capacitor. The positive ions released are then accelerated between two flat-plate electrodes – one positive, the other negative – arranged in the form of two long parallel rails which are connected across the capacitor. Escaping from the spacecraft, the accelerated ions produce a thrust of some several hundred newtons. The capacitor is then charged up again from a power supply and the pulse cycle repeated.

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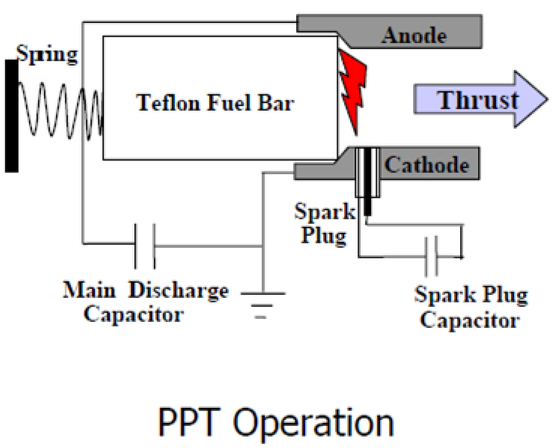

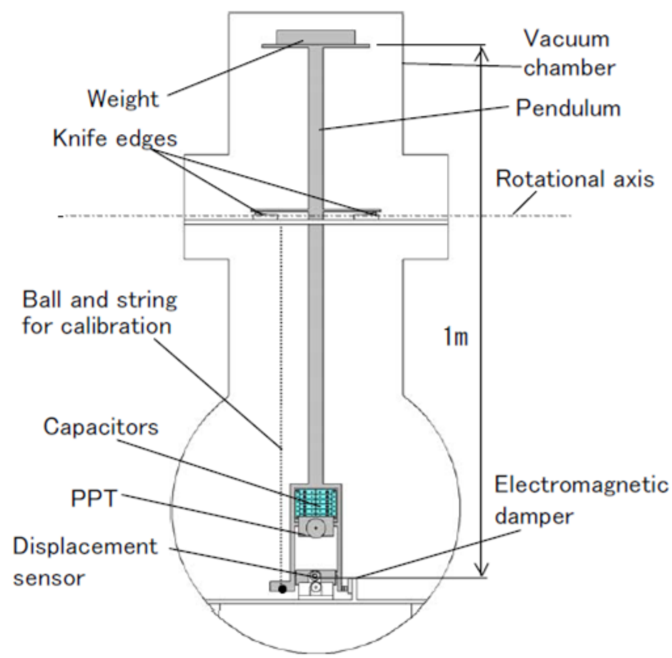

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Multiple thrusters can be driven by a common capacitor.

Summary / Conclusion

 Benefits of PPT Technology
– Micro impulse capability for precision pointing/positioning
– Unique high Isp, low power attributes well suited to small spacecraft
– Eliminates distributed, toxic propellant systems
– Low mass / power / volume alternative for mission in which both
conventional ACS and delta-V systems can be replaced.
 Applications
– Formation flying/precision pointing (Starlight,SAR, TPF, Maxium)
– Propulsive attitude and drag free control (Future GRACE/GPS missons,
GEO solar disturbances)
– Micro/small satellite propulsion (Dawgstar, Techsat 21)
 EO-1 Flight Validation
– EO-1 PPT experiment will validate the capability of a new generation of
PPTs to perform spacecraft attitude control
– Ground validation tests indicate adequate PPT performance

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Hall thrusters

The SEP project also will use electrostatic **Hall thrusters** with advanced magnetic shielding instead of a rocket engine with conventional chemical propellant. With SEP, large solar cell arrays convert collected sunlight energy to electrical power. That energy is fed into exceptionally fuel-efficient thrusters that provide gentle but nonstop thrust throughout the mission.

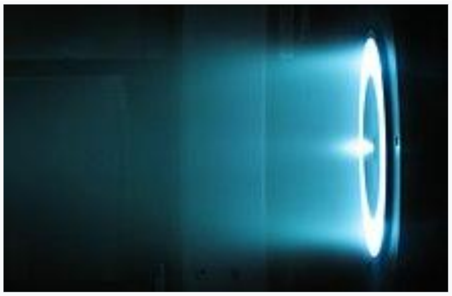
The thruster traps electrons in a magnetic field and uses them to ionize the onboard propellant -- in this case, the inert gas xenon -- into an exhaust plume of plasma that accelerates the spacecraft forward. Several Hall thrusters can be combined to increase the power of an SEP spacecraft. Such a system can be used to accelerate xenon ions to more than 65,000 mph and will provide enough force over a period of time to move cargo and perform orbital transfers.

In fiscal year 2015, researchers successfully tested a new 12.5-kilowatt Hall thruster that employs magnetic shielding, enabling it to operate continuously for years -- a capacity important to deep-space exploration missions.

The Solar Electric Propulsion project will demonstrate the key technologies necessary for robotic and human exploration-class SEP transportation systems as well as highly efficient orbit transfer capabilities for commercial space operations and science missions. This effort will benefit not only NASA missions-such as the **Asteroid Redirect Robotic Mission** (ARRM), new highly capable science missions and human missions to Mars -- but can provide more affordable primary power and more efficient orbital maneuvering and station-keeping capabilities for commercial communications satellites. ARRM, the project's planned flight demonstration, will employ a number of Hall thruster strings operating at a total power of 40 kW with a set of solar array wings supplying 50 kW overall.

Hall-effect thruster

In spacecraft propulsion, a **Hall-effect thruster** (**HET**) is a type of ion thruster in which the propellant is accelerated by an electric field. Hall-effect thrusters trap electrons in a magnetic field and then use the electrons to ionize propellant, efficiently accelerate the ions to produce thrust, and neutralize the ions in the plume. Hall-effect thrusters (based on the discovery by Edwin Hall) are sometimes referred to as **Hall thrusters** or **Hall-current thrusters**. Hall thrusters are often regarded as a moderate specific impulse (1,600 s) space propulsion technology. The Hall-effect thruster has benefited from considerable theoretical and experimental research since the 1960s.[1]



6-kW Hall thruster in operation at the NASA Jet Propulsion Laboratory.

Hall thrusters operate on a variety of propellants, the most common being xenon. Other propellants of interest include krypton, argon, bismuth, iodine, magnesium, and zinc.

Hall thrusters are able to accelerate their exhaust to speeds between 10 and 80 km/s (1,000–8,000 s specific impulse), with most models operating between 15 and 30 km/s (1,500–3,000 s specific impulse).

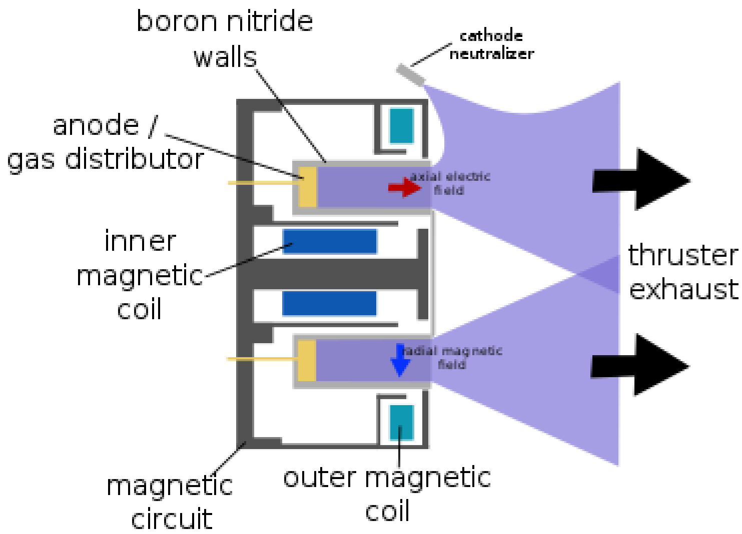
The thrust produced by a Hall thruster varies depending on the power level. Devices operating at 1.35 kW produce about 83 mN of thrust. High-power models have demonstrated up to 5.4 N in the laboratory.[2] Power levels up to 100 kW have been demonstrated by xenon Hall thrusters.

As of 2009, Hall-effect thrusters ranged in input power levels from 1.35 to 10 kilowatts and had exhaust velocities of 10–50 kilometers per second, with thrustof 40–600 millinewtons and efficiency in the range of 45–60 percent.[3]

The applications of Hall-effect thrusters include control of the orientation and position of orbiting satellites and use as a main propulsion engine for medium-size robotic space vehicles.

Operation

The essential working principle of the Hall thruster is that it uses an electrostatic potential to accelerate ions up to high speeds. In a Hall thruster, the attractive negative charge is provided by an electron plasma at the open end of the thruster instead of a grid. A radial magnetic field of about 100–300 G (0.01–0.03 T) is used to confine the electrons, where the combination of the radial magnetic field and axial electric field cause the electrons to drift in azimuth thus forming the Hall current from which the device gets its name.



Hall thruster. Hall thrusters are largely axially symmetric. This is a cross-section containing that axis.

A schematic of a Hall thruster is shown in the adjacent image. An electric potential between 150 and 800 volts is applied between the anode andcathode.

The central spike forms one pole of anelectromagnet and is surrounded by an annular space, and around that is the other pole of the electromagnet, with a radial magnetic field in between.

The propellant, such as xenon gas, is fed through the anode, which has numerous small holes in it to act as a gas distributor. Xenon propellant is used because of its high atomic weight and low ionization potential. As the neutral xenon atoms diffuse into the channel of the thruster, they are ionized by collisions with circulating high-energy electrons (typically 10–40 eV, or about 10% of the discharge voltage). Once ionized, the xenon ions typically have a charge of +1, though a small fraction (~20%) have +2.

The xenon ions are then accelerated by the electric field between the anode and the cathode. For discharge voltages of 300 V, the ions reach speeds of around 15 km/s (9.3 mps) for a specific impulse of 1,500 seconds (15 kN·s/kg). Upon exiting, however, the ions pull an equal number of electrons with them, creating a plasma plume with no net charge.

The radial magnetic field is designed to be strong enough to substantially deflect the low-mass electrons, but not the high-mass ions, which have a much larger gyroradius and are hardly impeded. The majority of electrons are thus stuck orbiting in the region of high radial magnetic field near the thruster exit plane, trapped in **E**×**B** (axial electric field and radial magnetic field). This orbital rotation of the electrons is a circulating Hall current, and it is from this that the Hall thruster gets its name. Collisions with other particles and walls, as well as plasma instabilities, allow some of the electrons to be freed from the magnetic field, and they drift towards the anode.

About 20–30% of the discharge current is an electron current, which does not produce thrust, thus limiting the energetic efficiency of the thruster; the other 70–80% of the current is in the ions. Because the majority of electrons are trapped in the Hall current, they have a long residence time inside the thruster and are able to ionize almost all of the xenon propellant, allowing mass utilizations of 90–99%. The mass utilization efficiency of the thruster is thus around 90%, while the discharge current efficiency is around 70%, for a combined thruster efficiency of around 63% (= 90% × 70%). Modern Hall thrusters have achieved efficiencies as high as 75% through advanced designs.

Compared to chemical rockets, the thrust is very small, on the order of 83 mN for a typical thruster operating at 300 V, 1.5 kW. For comparison, the weight of a coin like the U.S. quarter or a 20-cent Euro coin is approximately 60 mN. As with all forms of electrically powered spacecraft propulsion, thrust is limited by available power, efficiency, and specific impulse.

However, Hall thrusters operate at the high specific impulses that is typical for electric propulsion. One particular advantage of Hall thrusters, as compared to a gridded ion thruster, is that the generation and acceleration of the ions takes place in a quasi-neutral plasma, so there is no Child-Langmuir charge (space charge) saturated current limitation on the thrust density. This allows much smaller thrusters compared to gridded ion thrusters.

Another advantage is that these thrusters can use a wider variety of propellants supplied to the anode, even oxygen, although something easily ionized is needed at the cathode.[10]

Cylindrical Hall thrusters

Although conventional (annular) Hall thrusters are efficient in the kilowatt power regime, they become inefficient when scaled to small sizes. This is due to the difficulties associated with holding the performance scaling parameters constant while decreasing the channel size and increasing the applied magnetic field strength. This led to the design of the cylindrical Hall thruster. The cylindrical Hall thruster can be more readily scaled to smaller sizes due to its nonconventional discharge-chamber geometry and associated magnetic field profile.[11][12][13] The cylindrical Hall thruster more readily lends itself to miniaturization and low-power operation than a conventional (annular) Hall thruster. The primary reason for cylindrical Hall thrusters is that it is difficult to achieve a regular Hall thruster that operates over a broad envelope from ~1 kW down to ~100 W while maintaining an efficiency of 45-55%.[14]

External discharge Hall thruster

Sputtering erosion of discharge channel walls and pole pieces that protect the magnetic circuit causes failure of thruster operation. Therefore, annular and cylindrical Hall thrusters have limited lifetime. Although magnetic shielding has been shown to dramatically reduce discharge channel wall erosion, pole piece erosion is still a concern.[15] As an alternative, an unconventional Hall thruster design called external discharge Hall thruster or external discharge plasma thruster (XPT) has been introduced.[16][17][18] External discharge Hall thruster does not possess any discharge channel walls or pole pieces. Plasma discharge is produced and sustained completely in open space outside the thruster structure, and thus erosion free operation is achieved.

Applications

Hall thrusters have been flying in space since December 1971 when the Soviets launched an SPT-50 on a Meteor satellite.[19] Over 240 thrusters have flown in space since that time with a 100% success rate.[20] Hall thrusters are now routinely flown on commercial GEO communications satellites where they are used for orbital insertion andstationkeeping.

The first[*not in citation given*] Hall thruster to fly on a western satellite was a Russian D-55 built by TsNIIMASH, on the NRO'sSTEX spacecraft, launched on October 3, 1998.[21]

The solar electric propulsion system of the European Space Agency's SMART-1 spacecraft used a Snecma PPS-1350-G Hall thruster.[22] SMART-1 was a technology demonstration mission that orbited the Moon. This use of the PPS-1350-G, starting on September 28, 2003, was the first use of a Hall thruster outside geosynchronous earth orbit (GEO). Unlike most Hall thruster propulsion systems used in commercial applications, the Hall thruster on SMART-1 could be throttled over a range of power, specific impulse, and thrust.[23]

- **Discharge power: 0.46–1.19 kW**
- Specific impulse: 1,100–1,600 s
- **Thrust: 30–70 mN**

Recent and Future Projects

Electric Propulsion applications and type of thrusters

The different applications which currently make or may make use of Electric Propulsion Systems in the future, are:

- LEO (e.g. Earth Observation, Earth Science, constellations)
- MEO (e.g. Navigation)
- GEO (e.g. Telecommunications)
- Space Transportation (e.g. launcher kick stages, space tugs)
- Space Science, Interplanetary, and Space exploration.

For these different types of missions and requirements, the technology is faced with operational challenges in order to be able to cope with different type of maneuvers, such as: electric transfer from GTO to GEO, station keeping, interorbital transfer, interplanetary cruise, continuous LEO operations (air-drag control), (extreme) fine and/or highly agile attitude control, Long-endurance missions, etc.

All-electric propulsion satellites

Electric satellites are simpler, lighter and safer. Without the need for heavy chemical propellant, the satellite can have a lower mass and therefore lower launch price, as such costs are in direct relation with mass. Operations are also safer at the launch site, because fuelling the satellite is unnecessary, and the mass savings can also be traded for a larger payload, thereby increasing mission capacity.

However, electric propulsion systems provide less thrust than their chemical counterparts and it takes three to six months to reach geostationary orbit, as opposed to one week using chemical propulsion. "For Eutelsat 172B it will be four months, less time than has been needed so far, because we are using a relatively higher thrust technology known as Hall Effect Thrusters," Berger adds.

With full electric propulsion, tonnes of chemical propellant are replaced by a system that requires less than a fifth of the mass, in the form of **xenon** gas. This gas is ionised and accelerated in an electric field, and it can be ejected at very high speed using only electric power supplied by solar cells. This creates the thrust that moves the spacecraft.

"We have changed the paradigm of electric propulsion systems, which were originally meant for small satellites. Using the scale effect, we are offering more payload on one satellite, equivalent to two missions. We have all the energy needed to reach orbit thanks to the satellites' large solar arrays," explains Berger.

Development of High-Power Solar Electric Propulsion

A prototype 13-kilowatt Hall thruster is tested at NASA's Glenn Research Center in Cleveland. This prototype demonstrated the technology readiness needed for industry to continue the development of high-power solar electric propulsion into a flight-qualified system.

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