

I. ELECTRIC ROCKET PROPULSION

Rockets with which thrust is produced by employing electrical energy are called electrical rockets. In nuclear electric rocket engines nuclear energy is converted into electrical energy. In the solar electric rockets engines nuclear energy is converted into electrical energy. In the Solar electric type rocket electrical energy is obtained from the solar radiation. The attractiveness of electrical propulsion is that propellant mass consumption can be greatly reduced because, in principle any amount of electrical energy can be added to a given quantity of mass. Electric propulsion engines generate exhaust velocities from about 4 to more than 100 times those of chemical rocket engines, and thus they have considerable potential for space propulsion.

Electrical rocket propulsion devices use electrical energy from a separate energy source for ejecting propellants. In all electric propulsion the source of electric power (nuclear, solar radiation receivers or batteries) is physically separate from the mechanism that produces the thrust. This type of propulsion has been handicapped by heavy and inefficient power sources. The thrust usually is low, typically 0.005 to 1N. In order to allow a significant increase in the vehicle velocity, it is necessary to apply the low thrust and thus a small acceleration for a long time (weeks or months).

The basic sub systems of a typical electrical propulsion system are

- a) A power source (usually solar, nuclear or chemical) with its auxiliaries such as pumps, panels, radiators and controls
- b) A conversion device to convert this energy into electrical energy at the proper voltage, frequency and current suitable for electric propulsion.
- c) A propellant feed system for storing, metering and delivering the Propellant
- d) One or more thrusters to convert the electrical energy into kinetic energy of exhaust gases.

There are three fundamental types.

1. **Electrothermal:** Here the propellant is a fluid heated either by an electrical arc discharge the fluid [arc jet (i.e. Arc Heating)] or by electrical heating through a wall [resistojet (i.e. Electrical Resistance Heating)] i.e. the propellant is heated electrically and it is thermodynamically expanded and the heated gas is accelerated to supersonic speeds through nozzle as in a chemical rocket. These electro thermal units typically have thrust ranges of 0.01 to 0.5N, with exhaust velocities of 1000 to 5000 m/sec, and ammonium, hydrogen, nitrogen or hydrazine decomposition product gases have been used as propellants.

Arc heating

The arc or plasma jet utilizes the very high temperatures in arcs to heat the propellant. The latter becomes partly ionized, but remains neutral overall, hence the term plasma, and the operation is not "electric" in the sense that the propellant is accelerated by an electric field but by expansion.

Gaseous discharges between electrodes take many forms but here we are concerned with what might be called the "fully developed" discharge when the cathode becomes sufficiently hot to emit electrons by thermionic means, photo voltaic means (from the intense light of the gas) and by field emission (electrons emitted by virtue of the ambient electric field). Typically, an arcs has a relatively low voltage and a high current.

The potential across the electrodes is divided up into a cathode fall region of the order of 10-20 V, an anode fall region of variable amount but generally of the order of the cathode fall, with the remainder of the potential being across positive or arc column. The linear dimensions of the cathode and anode fall regions are small, with the positive column being the predominating feature and the region where the propellant gas is heated.

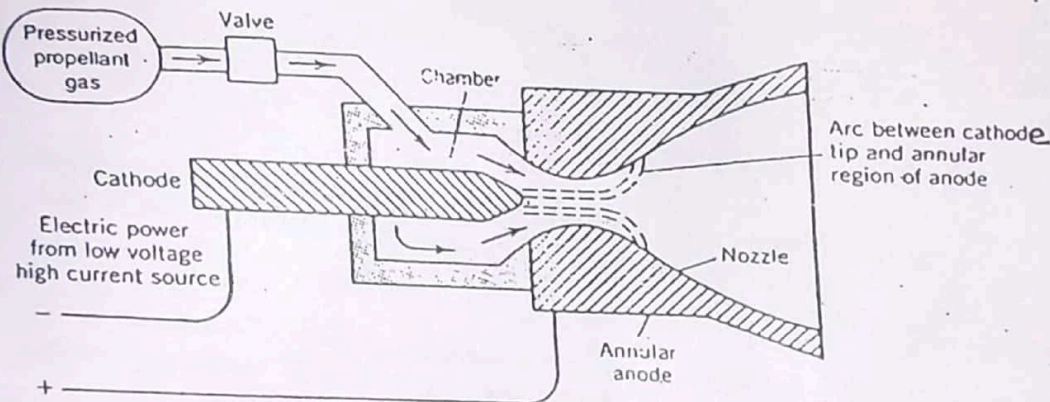


FIGURE 1-8. Simplified schematic diagram of arc-heating electric rocket propulsion system. The arc plasma temperature is very high (perhaps 15,000 K) and the anode, cathode, and chamber will get hot (1000 K) due to heat transfer.

Fig shows schematic diagram of an arc-heating rocket engine is shown on fig. In this type, electrical energy is transformed onto heat in an arc struck between two electrodes and thus the temp of working fluid is raised as it passes through the arc. The heated gas then expands thermodynamically through a nozzle and this is accelerated and ejected at high velocities (7500 - 20,000 m/sec)

Resistance Heating

The simplest method is to pass the propellant over an element heated to a high temperature by passing electric current through it. This type of resistance heating unit is called a resistojet and schematic arrangement is shown in fig 8.2. The heating element may be coils of wire or the duct walls themselves may be heated. Because of difficult geometries, the approach to design of heaters and minimization of radiation losses is large empirical. To considerable extent, the problem is one of materials, to withstand very high temperatures and to resist erosion. The latter point is important, because nozzle throat diameters are small and velocities very high (10- 15,000 fps for hydrogen)

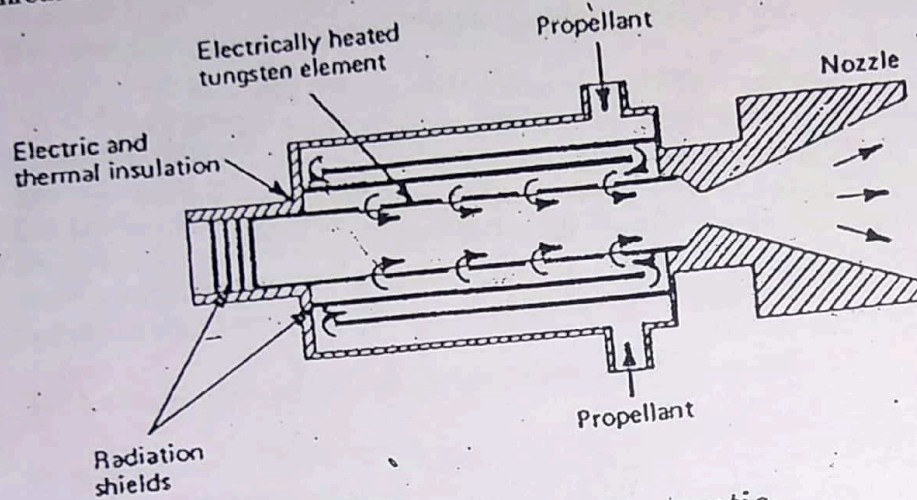


Fig. 8.2 Resistojet—diagrammatic.

Resistojets so far have been used in very small sizes with thrust starting at micro pounds and going up to a few pounds. The corresponding powers are small up to 30KW with efficiencies from 50% to 85%.

The resistojets fulfill a useful function, namely a *compact, reliable, low-thrust device* for the various auxiliary but very important jobs in connection with *satellite operation, station keeping, drag neutralization, attitude control*, and so forth.

2. Electrostatic: In this case the propellant consists of discrete charged particles. Acceleration is achieved by interaction of electrostatic fields on charged particles such as ions and colloidal.

Eg: ion rocket Engine

(A rocket engine that develops thrust by expelling ions rather than gaseous combustion products called *ion rocket*) The basis of electrostatic or ion propulsion is simply the acceleration of charged particles by an electric field. The propellant source feeds neutral atoms to an ion source and the positive ions generated are accelerated by one or more sets

of electrodes which are maintained at zero potential, the ion source being at a high potential. The negative ions or electrons have to be returned eventually to the positively charged exhaust stream to maintain a neutral beam. The propellant can in principle be any substance capable of ionization, solid, liquid or gas, and may be in atomic, molecular or particle form.

In an ion rocket a working fluid (typically, Xenon) is ionized (by stripping off electrons) and then the electrical charged ions are accelerated to very high Velocities (2000 to 60,000 m/sec) by means of electrostatic fields. The ions are subsequently neutralized; they are combined with electrons to prevent the buildup of space charge on the vehicle.

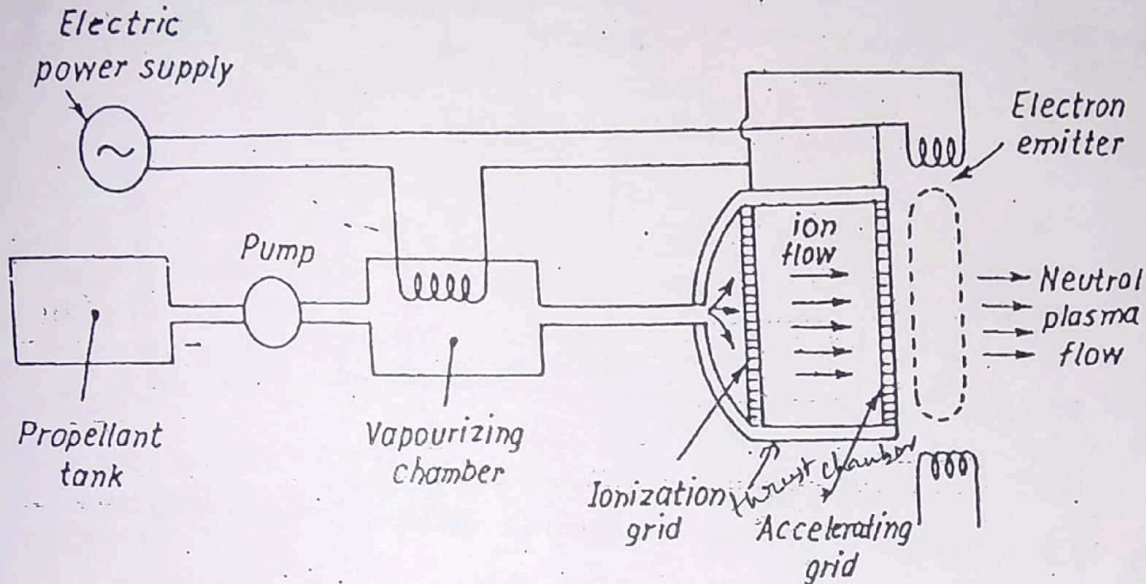


Fig. 13.8. Schematic diagram of an ion rocket engine.

The figure shows a schematic diagram of Electrostatic or Ion rocket engine. The major components are (i) Propellant supply tank and propellant feed mechanism (ii) Thrust chamber, and (iii) Electric power supply. The Thrust chamber incorporates a vaporizing chamber, an ionization chamber, an accelerating grid and an electron emitter. The propellant is first heated and vaporized and then passed to the ionization chamber, where electrons are stripped to ionize it. The resultant ions are then accelerated electrostatically with D.C. voltage drop (in excess of 10,000 volts) and discharged to produce thrust. The Electrons tripped in the ionization chamber are collected and injected into the ion stream aft of the accelerating grid to neutralize the ion beam and prevent the ions from being attracted back to the grid. Removal of electrons is also necessary to maintain a neutral charge on the space vehicle.

3. Electro magnetic: For this application of electrical energy, a stream of electrically conducting fluid is accelerated by the interaction of electric and magnetic fields on propellant, plasma. A plasma is a high temperature electrically neutral gas containing electrons, ions and neutral molecular species.

Ex. Magneto – plasma Rocket Engine

The magneto plasma-dynamic propulsion system is an electromagnetic space propulsion system somewhat similar to an ion engine. It utilizes a magnetic field functioning as a "magnetic nozzle" to confine the accelerated gas.

In the magneto plasma rocket an electrical plasma (an energized hot gas containing ions, electrons and neutral particles) is accelerated by the interaction between electric currents and magnetic fields ejected at high velocity (1000 to 50,000 m/sec).

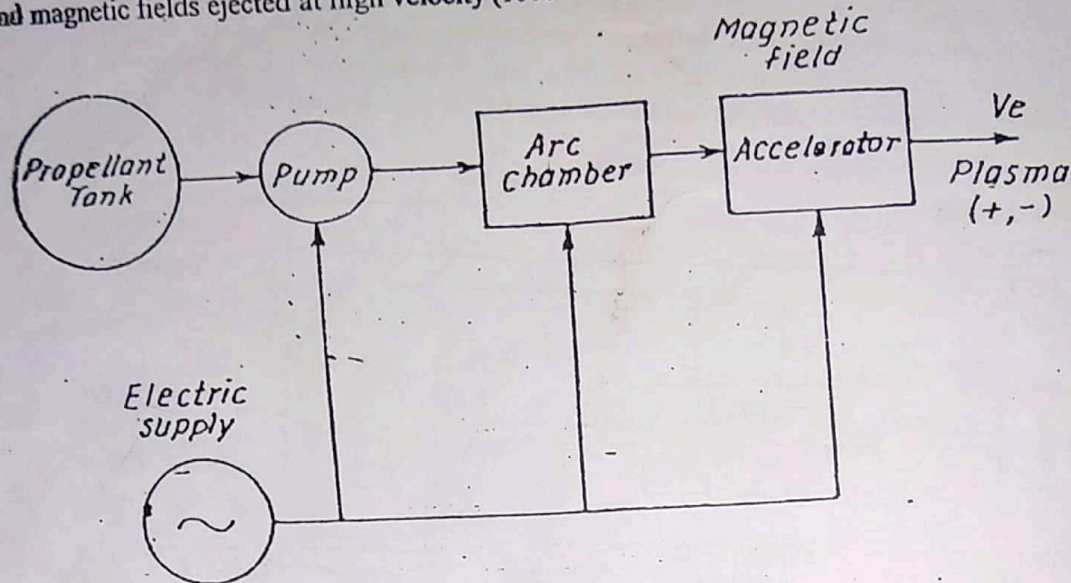


Fig. 13.9. Principal elements of a magneto-plasma rocket engine.

Fig shows principal elements of Magneto - Hydrodynamic (MHD) (or) Magneto - Plasma rocket engine. MHD engines produce thrust from the interaction between magnetic and electric fields. The force which results is customarily called the $J \times B$ force, where 'J' is the current density and 'B' is the applied magnetic field. The nature of this resulting force, which accelerates the propellant, is analogous to the force which rotates electric motors.

The magneto-plasma rocket engine uses an arc chamber to produce conductive plasma, similar to arc plasma engine. The plasma then passes through an accelerator. Two different methods can be used to accelerate the plasma (a) the charging or collapsing of magnetic fields, or (b) the interaction of an electric current and a steady magnetic field. The first method is cyclic and can impart extremely high velocities to the plasma (up to 2,40,000 m/sec). The second method is continuous but imparts somewhat lower velocities to the plasma (upto 15,000 m/sec).

The applications for electrical propulsion system are

- (1) For changing the orbits for overcoming perturbation of earth satellite.
- (2) For correcting space flight trajectories

The propellant is pumped through the heat exchanger and then expanded in the exhaust nozzle. Normally the gas is heated at 2500°C and the hot gas is controlled by hot gas valves and exhausted through one or more nozzles. The large mirror has to be pointed towards the sun and this requires the mirror to be adjustable in its orientation. Performance can be two to three times higher than that of a chemical rocket and thrust levels in most studies at low (1 to 10N) since large lightweight optical elements cannot withstand drag forces without deformation, the optical systems are deployed outside the atmosphere. Problems being investigated include rigid, lightweight mirror or lens structures, operational life, minimizing hydrogen evaporation and heat losses to other spacecraft components. To date the solar rocket has not yet provided the principal thrust of a flying spacecraft.

III. SOLAR SAIL

The solar sail is another concept which does not require the expansion of a propellant through the nozzle for propulsion. Here the radiation pressure at the sun rays is employed for obtaining the propulsions force or the thrust. It is basically a big photon reflector surface. The power source for the solar sail is the sun and it is external to the vehicle.

Besides large surface areas solar powered rockets have another severe limitation. Solar energy captured is inversely proportional to the square of the distance from the sun. Therefore, the thrust of solar-powered rocket varies with the distance from the sun.

IV. NUCLEAR ROCKET PROPULSION

In a nuclear rocket nuclear energy is used to heat the propellant or the working fluid to obtain high stagnation temperature in the thrust chamber. Nuclear energy is utilized in this rocket propulsion as in the form of fission energy release, radioactive isotope decay and fusion energy release. Nuclear rocket engines produces very large thrust and thus have quite low thrust to weight ratio are only useful space operations in gravity free fields.

Three different types of nuclear energy sources have been investigated for delivering heat to working fluid. Usually liquid hydrogen is widely used in such rockets, which subsequently can be expanded in a nozzle and thus accelerated to high velocities (6000 to 10000 m/sec)

There are three types. They are

1. Fission reactor
 - a. Solid core reactor rocket
 - b. Gas core fission rockets
2. Radioactive isotope decay source
3. Fusion reactor

- (3) For space vehicle altitude control
- (4) For achieving interplanetary transfers for solar system escape. In this last case electric rocket can be stated in an earth satellite orbit and used to overcome
 - a. A relatively weak gravitational attraction at some distance from the earth, by spiraling into successively higher orbits.
 - b. The gravitational attraction of the sun to achieve a transfer path from one planet to another since electrical rocket engines are useful in space light, they always operate in a vacuum. Electrostatic and electromagnetic acceleration devices require a vacuum for satisfactory operation.

II. SOLAR ROCKETS

Several technologies exist for harnessing solar energy to provide the Power for spacecraft and also to propel space craft using electrical propulsion. Solar cells are used to generate the electric power from the sun's radiation. Heat energy from solar radiation can be used for heating a propellant such as hydrogen.

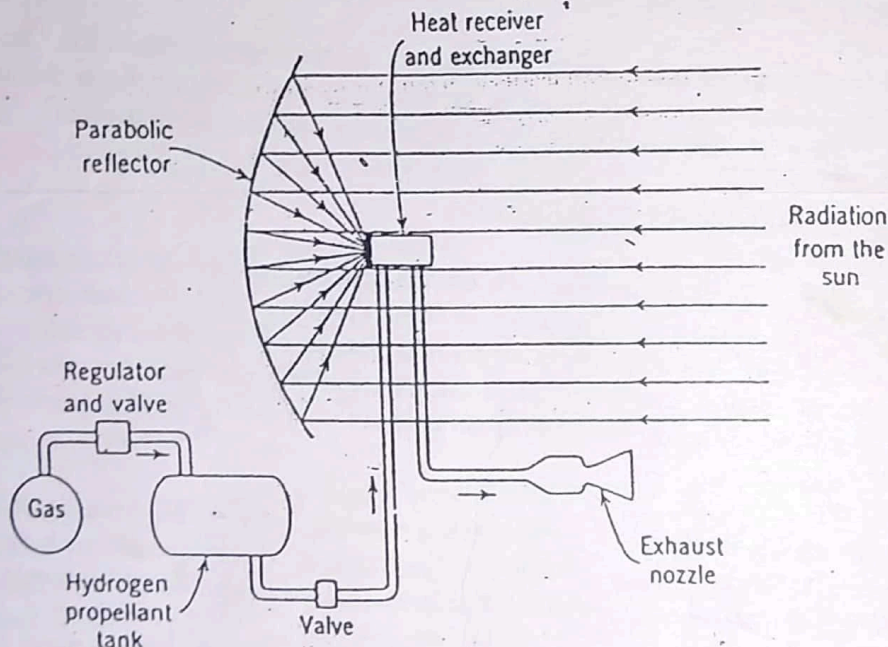


FIGURE 1-11. Simplified schematic diagram of a solar thermal rocket concept.

Fig shows the schematic diagram of solar rockets. It has a receiver. The receiver is made of high temperature metal (such as Tungsten or rhenium) and has a cooling jacket or heat exchanger. It heats a working fluid, usually liquid hydrogen. Sunrays are focused on the heat exchanger by a large parabolic reflector.