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FOREIGN TECHNOLOGY DIVISION

PLASMA ENGINES

by

Sung Yuyang

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By: Sung Yuyang

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PLASMA ENGINES

Sung Yuyang

Since the first man-made satellite was launched in October, 1957, all kinds of satellites and space ships have been delivered to space. With the advancement of aerospace technology, new forms of propulsion devices have been continuously developed. Among them is the plasma engine.

The Plasma Engine

What is a plasma engine? Before answering this question, we should learn something about the plasma first.

The plasma is an ionized gas. When a gas is exposed to electric charges, the gas molecules become ionized. If electrons are lost, the gas molecules become ions with positive charges, for instance:

$$H_2 + e = H_2^+ + 2e$$
$$H_2 + e = H_1^+ + H_1 + 2e$$

Hence the plasma is a mixture of charged ions, electrons and neutral particles. As a whole, it is electrically neutral.

The plasma in the plasma engines for aerospace application is usually produced by gases or by the gasous state of solid conducting materials.

In order to produce a plasma by ionizing the working medium, the working medium must be heated to a degree such that the mean kinetic energy of its atoms is higher than the temperature of ionization. For hydrogen or heavy hydrogen, this temperature is as high as 160,000 K. All materials available at present cannot withstand such a high temperature. But the actual temperature is lower, since the electrons and the ions within the plasma are each at an equilibrium state separately. A magnetic field is usually employed to restrain the plasma (as shown in figure 1), thereby preventing any direct contact between the high-temperature plasma and the chamber wall.

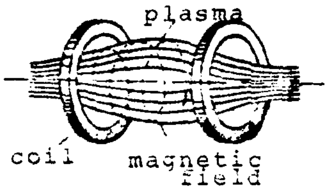

Figure 1 Plasma restrained by magnetic field

Figure 2 illustrates the principle of the plasma engine. It is composed of two electrodes (a positive and a negative electrode) and a passage enclosed by the electrodes and two insulated side walls. This passage is perpendicular to the electric field with intensity E and at the same time passes through a magnetic field with inductance B created by the magnet. The plasma is formed in the plasma generator, and is then allowed to pass through the accelerator. Since it is a charged gas, a current is produced from the positive electrode through the plasma to the negative electrode. Under the combined action of the electric field and the magnetic field, the plasma accelerates toward the exit of the accelerator, producing an ampere force. A reactive thrust is thus produced. Since electric energy is converted into kinetic energy by means of plasma (the working fluid), we call such a device the plasma engine.

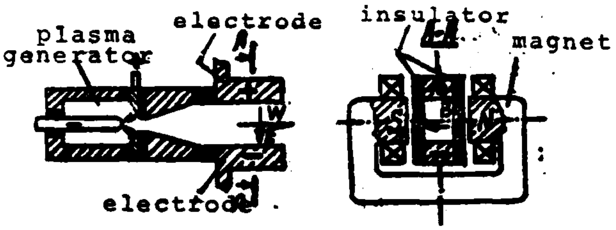

Figure 2 Principle of the plasma engine

The Energy Device

The plasma engine can be divided into two major components - the engine and the energy device. The former produces a reactive thrust and the latter supplies the electric energy required. The electricity supply in satellites and space ships is also provided by similar energy devices. Devices with power of 5 to 50 kilowatts have already been developed by some nations. There are two types of energy devices used for plasma engines: nuclear energy device and solar energy device.

Figure 3 shows the SNAP-2 energy device. The upper half of the figure illustrates the operation schematically and the lower half the physical appearance. This is an example of double loops systems. The first loop uses the sodium-potassium alloy (melting point 11°C, boiling point 784°C at a pressure of 10^5 Pa) as the heat transfer medium, while the second loop uses mercury as the working medium. The sodium-potassium alloy is at a temperature of 650°C when it comes out of the reactor, it then enters the steam generator causing the Hg (mercury) to be heated and since the boiling point of mercury at at pressure of 10^5 Pa is 357°C, after it is heated in the generator it changes froma liquid state to a gaseous state, and the mercury vapor (with a pressure of 700 kPa and a temperature of 620°C) enters the turbine and causes the turbine to rotate (at 40,000 rpm) and produce 3 kW of electric power. The mercury vapor which exhausts from the turbine enters the radiator and, after cooling the mercury changes into a liquid (with a pressure of 42 kPa and a temperature of 315°C) and then the mercury is transferred by the mercury pump to the steam generator. The whole energy device weighs 345 kg without the protection shroud.

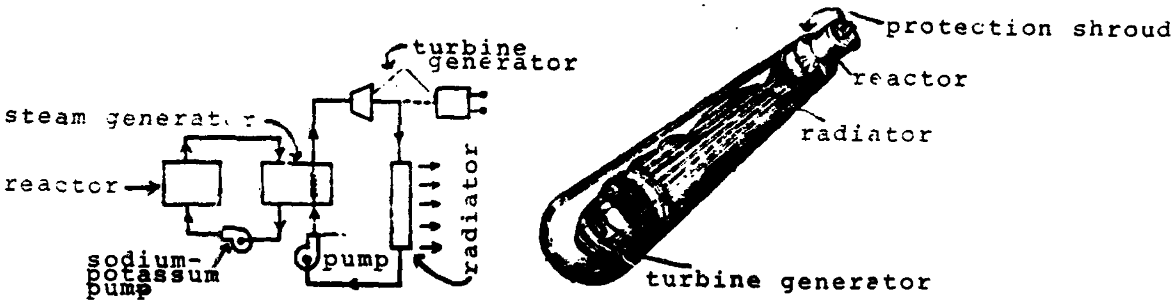

Figure 3 The SNAP-2 energy device

Since there exists the problem of critical mass for nuclear fuel, the solar energy device is usually employed for plasma engines of relative low power.

For apparent safety reasons, the nuclear energy device on manned space ships must be kept at a distance from the cockpit. Figure 4 shows the position of the device on a space ship. This energy device has a power of 25 kilowatts and weighs 3600 kilograms, excluding the protection shroud. The protection shroud weighs 2000 kilograms, and the distance between the device and the cockpit is 15 meters. Figure 5 shows another kind of energy device.

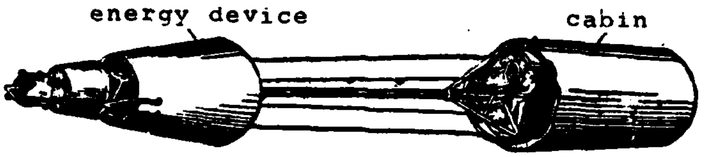

Figure 4 The position of SNAP-2 energy device on a space ship

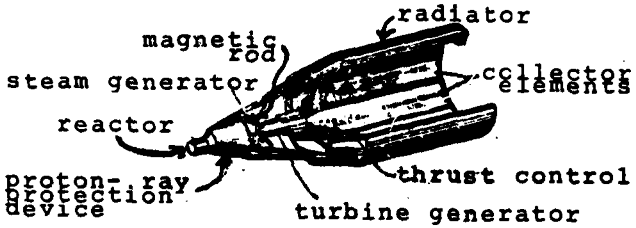

Figure 5 The structure of an energy device

Characteristics and Applications

The plasma engine has the following characteristics:

1. high specific impulse (10^2 - 10^4 seconds)
2. low thrust (10^{-3} - 10 Newtons)
3. long duration
4. multiple actuation
5. low efficiency
6. a thrust to weight ratio of less than 1

The last property indicates that the plasma engine must be launched to orbits by other kinds of propulsion devices (such as liquid propellant rocket engines or solid propellant rocket engines) before it can function. Since high thrust is not needed for space flight, this kind of engine is especially suitable for the positioning, attitude control and orbital adjustment of satellites, space ships and space stations.

Being a low thrust, long duration power device, the plasma engine has certain distinct advantages. For a chemical fuel rocket engine, a thrust of 0.01 kilogram with a duration of 1 year requires some 1240 kilograms of high heating-value fuel of 250 seconds specific impulse. Including the shrouds and the accessories, the entire device may weigh several tons. To meet the same requirements, a plasma engine of much smaller weight is needed. Its operation is also more reliable.

Based on operational principle, plasma engines can be categorized into two major types: the continuous type and the impulsive type. The former does not have capacitor components and is thus simpler. The satellite "Meteorite" launched by the Soviet Union in 1971 was equiped with two continuous plasma engines with a thrust of 0.02 Newton. The satellite was transferred to the synchronized orbit in February, 1972 by these plasma engines.

Nowadays, the burn-out impulsive type plasma engine is most commonly used in aerospace applications. Readily volatile solid conductors such as $C_2H_4F_4$ are used as the working medium in this kind of plasma engines. When the capacitor discharges electricity, the working medium is heated and sublimates. The resulting gas is ionized immediately, and is then accelerated to high speed under the actions of the electric field and the magnetic field, thereby producing thrust.

In December 1964, the Soviet Union lanuched the "Zond-2" automatic planetary station (distance from the earth 5,370,000 km) toward Mars. Six burn-out impulsive type plasma engines were first used for spacecraft orientation. These engines were controlled by signals and varied their operations according to the commands. They could keep the space station at a certain position relative to the Sun for a given period.

The Lincoln Test Satellite-6 launched by the United States in 1968 was equiped with four Fairchild impulsive type plasma engines to maintain the east-west attitude of the satellite. Each of them has an impulsive period of 6 seconds. The impulse duration was 1.5 seconds when the engines operated in series. Each engine was able to discharge 12×10^6 times, with a thrust of 2 milligrams each time. They could operate in space for over two years. Recently, the two impulsive type plasma engines developed by our country were tested in flight for the first time and were proved to be satisfactory. This indicates that the development of electric rockets in our country has reached a new level and entitles us to be the fourth nation on earth to test electric rockets.

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