Ion drive propulsion: an overview

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Ion Drive propulsion, also called ion engine, which is a technology that involves gas ionization and can be used instead of standard chemicals. Give an electrical charge or ionize the gas xenon, which is like neon or helium, but heavier, the ionized gas can be electrically accelerated a speed of about 30km/s by the electric field force. When xenon ions are emitted at such high speed as exhaust from a spaceship, the spacecraft can be pushed in the opposite direction.

The ion engine was firstly demonstrated by Emst Stuhliger, the German-born NASA scientist. Then at NASA Lewis Research Center (now called Glenn research center) from 1957 to the early 1960s IDP was developed in form by Harold R. Kaufman. Moreover, the ion drive propulsion was first demonstrated in space in “ Space Electric Rocket Test (SERT)” I and II by NASA Lewis Research Center. The SERT-1, which is the first test was launched in July 20, 1964, proved the technology operated as predicted in space successfully. Furthermore, the second test SERT-II, which was launched on February 3 rd 1970, verified the thousands of running hours operation of two mercury ion drive propulsions, though IDP were seldom used before the late 1990s.

“ Electric propulsion works by using electrical energy to accelerate a propellant to much higher velocities than is possible using chemical reactions. The most common propellant used in ion engines is xenon. Early ion engines used mercury and cesium, but they proved hard to work with. At room temperature, mercury is liquid and cesium is solid; they both must be heated to turn them into gases. Also, as mercury or cesium exhaust cooled, many of their atoms would condense on the exterior of the spacecraft, contaminating solar cells and instruments. Eventually researchers turned to xenon as a cleaner, simpler fuel for ion engines." (De Felice, 1999).

For IDP's operation system, it uses an electric field to accelerate charged atoms or molecules to a high velocity. Ion thrusters generally use a cathode to generate a stream of electrons, which form an electric circuit with a positively charged ring – the anode. A small magnetic field is used to aid this process (electrons spiral around the magnetic field lines, increasing the chance of electron-atom collisions). The ionized gas is accelerated out of the thruster and drifts towards an extraction grid system, so it can produce thrust. A neutraliser similar to the cathode is used to generate free electrons and balance the overall space charge of the outgoing beam so that the spacecraft does not charge itself up. To deal with this problem NASA's Deep Space 1 probe is testing a new type of ion thruster. The following description of DS-1's ion thrusters is from the official DS-1 Website:

" Its ion propulsion system (IPS) utilizes a hollow cathode to produce electrons, used to ionize xenon. The Xe+ is electrostatically accelerated through a potential of up to 1280 V and emitted from the 30-cm thruster through a molybdenum grid. A separate electron beam is emitted to produce a neutral plasma beam. The power-processing unit (PPU) of the IPS can accept as much as 2. 5 kW, corresponding to a peak thruster operating power of 2. 3 kW and a thrust of 92 m N. Throttling is achieved by balancing thruster and Xe feed system parameters at lower power levels, and at the lowest thruster power, 500 W, the thrust is 20 m N. The specific impulse decreases from 3100 s at high power to 1900 s at the minimum throttle level. (De Felice, 1999)”

Mostly, IDP is being used in aerospace application. Here are a couple of simple examples.

1. Deep Space 1 which is a spacecraft of the NASA New Millennium Program dedicated to testing a payload of advanced, high risk technologies. Also it is the first spacecraft which used ion drive propulsion.
2. Hayabusa which is an unmanned spacecraft developed by the Japan Aerospace Exploration Agency (JAXA) to return a sample of material from a small near-Earth asteroid named 25143 Itokawa to Earth for further analysis and used xenon ion engines
3. Dawm which is a space probe launched by NASA on September 27, 2007, to study the two most massive objects of the asteroid belt–the protoplanet Vesta and the dwarf planet Ceres. It is the first NASA exploratory mission to use ion propulsion to enter orbits.

There are three advantages of Ion Drive Propulsion which can probably explain why IDP is being used. First, it uses much less propellant than chemical rocketry so it may promise better reliability and simplicity than chemical rocketry or, from another perspective, it gets much more mileage out of a given quantity of propellant. Third, it could use 100% lunar or asteroid derived propellant. IDP can push a spacecraft up to about ten times as fast as chemical propulsion comparing IDP with chemical propulsion under the circumstances which ion propulsion is appropriate for. To sum up, the ion propulsion system's efficient use of electrical power and fuel enables modern spacecraft to travel farther, and it is cheaper than any other propulsion technology currently available. Ion drive propulsion is currently used for main propulsion on deep space probes and for station keeping on communication satellites. Ion thrusters expel ions to create thrust and can provide higher spacecraft top speeds than any other rocket which is available currently.

In addition, the top speed of ion drive propulsion is startling. By using the principle of relativity, a physical situation could be analyzed from any reference frame as long as it moves with some constant speed relative to a known inertial frame.

As a function of the proper time τ experienced on the rocket, the acceleration of the rocket is a (τ), in Newtonian mechanics there is a quantity which increases the way velocity called the rapidity of the rocket .

The rapidity θ will be $\theta(\tau)=\int \tau\ 0\ a(\tau)d\tau$

The velocity is then $v(\tau)= \tanh\theta$.

If $a= g$, $v(\tau)= \tanh(g\tau)$

So if one year has passed on the rocket, the time on Earth will be tanh(1. 05)= 0. 78C which means 78% of light.

Since the limit of tanh is one as $\tau\to\infty$, so the velocity of rocket will never get light speed.

A more important limiting factor is the fuel. Fusion isn’t a way around this because of $E= mc^2$ there is a limited energy can be calculate from a given mass of fuel.

If a fraction (f) of the rocket is fuel, if all the fuel are burned, the momentum of the rocket will be $\gamma m(1-f)\beta$, with m the original mass. The conservation of momentum and energy give

$m= \gamma m(1-f)+E$ fuel

$0= \gamma m\beta(1-f)+p$ fuel

$\beta=-p$ fuel $m-E$ fuel

According the formulas and result shows that the fuel and rocket go opposite directions. To maximize β, make p fuel as large as possible and subject to a fixed E fuel so assume the fuel is massless with

β fuel = 1

p fuel =−E fuel .

$\beta= 1-(1-f)$ 2 $1+(1-f)$ 2 ã€€ã€€

To sum up, even the fuel has 50% of the rocket’s original mass it just can get 3/5C.

Researching in the area of ion propulsion is pushing the envelope of propulsion technology. To achieve higher power levels and speeds, longer durations advancements are being made. As new power sources become available, higher power thrusters will be developed that provide greater speed and more thrust. Nowadays, PPU and PMS technologies are being developed that will allow NASA to build lighter and more compact systems while increasing reliability. These technologies will allow humankind to explore the farthest reaches of our solar system also it will allow humankind to explore the farthest reaches which is out of our solar system.

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