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Variable Specific Impulse Magnetoplasma Rocket

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Abstract

This paper focuses on the operational details of the Variable Specific Impulse Magnetoplasma Rocket (abbreviated as VASIMR), which is basically a rocket using plasma as its mode of propulsion for accelerating itself into space over the conventional chemical propulsion rockets. The VASIMR is an electro-magnetic thruster. It focuses on bridging the gap between high thrust-low specific impulse and low speed-high specific impulse characteristics, the two important parameters which define the performance of a rocket. These parameters can be altered for a VASIMR as per the mission requirements by altering the amount of power supplied. Such rockets are manufactured by the Ad Astra Rocket Company whose headquarters are based in Houston, Texas, United States.

1. Introduction

This paper aims to explain working principle of the Variable Specific Impulse Magnetoplasma Rocket (VASIMR), an electro-magnetic thruster for spacecraft propulsion, which is propelled by accelerating plasma formed by ionizing an inert gas propellant. The VASIMR engine is electrode less and contains no moving parts**.** It uses radio antennas as opposed to other plasma rockets using physical electrodes. The engine consists of the following main sections: A helicon coupler used to produce plasma, a second coupler known as Ion Cyclotron Heating (ICH) for plasma acceleration and a magnetic nozzle for aligning the motion of the ions in order to obtain useful thrust.

The engine consists of a covering made up of electromagnets, and a magnetic field links the three stages. The VASIMR is advantageous over other rockets because its life expectancy is increased due to the absence of physical electrodes and because every part of the engine is magnetically shielded from the plasma. Thus, the erosion of electrodes is avoided as is the wearing of the engine components. The thrust to specific impulse ratio can be controlled by selectively portioning the Radio Frequency (RF) power to the helicon and ICH couplers, along with the proper adjustment of propellant flow.

VASIMR can process a large amount of power, leading to generation of greater thrust which can be useful for numerous purposes.

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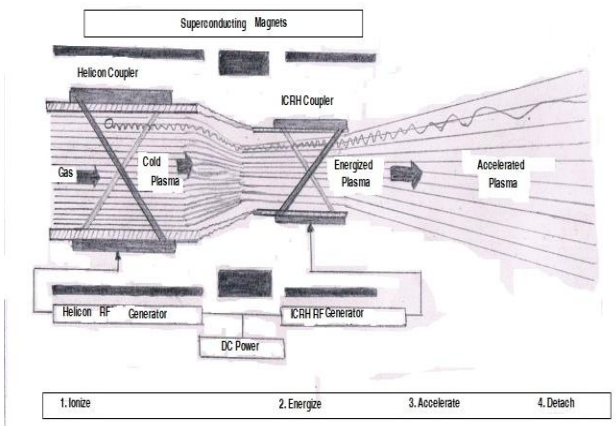
2. Diagrams.



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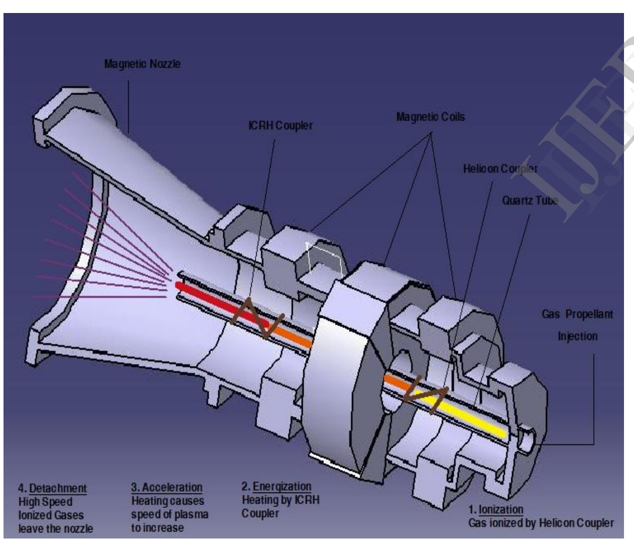

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3. Principle of operation

The working of the VASIMR can be divided into the following stages:

Stage 1: RF/Helicon coupler

In this stage, inert gas propellant such as helium or hydrogen is injected into the chamber. The helicon coupler emits Radio Frequency waves which convert the inert gas to plasma by ionizing it, i.e. by knocking out an electron free from each inert gas atom. The plasma so formed is known as 'cold plasma' and is approximately at a temperature of 60,000 Kelvin (approximately equal to the temperature of the sun's surface).

Helicons are electromagnetic waves at frequencies of 10 to 50 MHz, which, in a magnetic field energize the electrons in atoms and thereby form plasma.

Stage 2: Acceleration using electromagnets

In this stage, particles which were originally atoms are now replaced by charged particles, i.e. ions and electrons. These charged particles interact with the magnetic field produced by the electromagnets contained within the tube and can be viewed as a series of magnetic lines passing through the rocket and the ions orbiting around each line.

Stage 3: Ion Cyclotron Resonance Heating

This stage involves another coupler known as Ion Cyclotron Resonance Heating (ICRH). Plasma is heated to high temperatures in this stage. ICRH heating has been chosen because it transfers energy directly and primarily to the ions, thus maximizing the efficiency of the engine. Here, radio waves generated by the coupler strike the charged particles along their orbits around the magnetic field lines at resonance, which causes further acceleration of the particles. Resonance occurs because the frequency of the emitted waves by the coupler matches with the cyclotron frequency of the charged particles, i.e. the frequency of the particles moving perpendicular to the uniform magnetic field.

This resonance is facilitated by reducing the magnetic field in the region which slows down the orbital motion of the ions and electrons around the field lines. The interaction of the RF waves with the plasma at resonance causes the temperature of the plasma to rise to the order of 1 million degrees Kelvin, which is approximately 200 times the temperature of the surface of the sun.

Stage 4: Magnetic nozzle

As a result of the extremely high temperatures obtained in the ICRH stage, thermal motion of the ions is obtained. However, this motion of the ions is perpendicular to the direction of motion of the rocket. Thus, in order to obtain useful propulsion, this perpendicular motion has to be converted to linear motion. The magnetic nozzle, which is the final stage of the VASIMR, is used for achieving the same.

The nozzle is a divergent one, and as it diverges, it causes the magnetic field lines to expand. As a result, the spiral paths of the ions around these field lines begin to elongate. With the increasing divergence of the nozzle, the paths eventually straighten out and motion of the ions ultimately becomes linear. As a result, ions speeds of about 100,000 mph or 50,000 m/s are obtained, causing the rocket to be propelled.

4. Power sources

The high power requirements of the VASIMR engine necessitate the supply of a large amount of electricity which might require some thought process. The following sources of energy are being used for generating the required energy depending on the mission for which the rocket is being used:

- **Solar power**
  In the missions where fuel consumption or the specific impulse is a major factor for consideration, the Solar Electric Propulsion (SEP) method is employed. As VASIMR develops high power, solar energy can be effectively used for reducing the fuel requirements for transportation in space.SEP can be utilized for the following missions
  - Lunar cargo delivery
  - Satellite re-fuelling
  - Drag compensation for space stations
  - Low Earth Orbit Large Debris Removal

- **Nuclear power**
  Of all the useful energy sources of energy available on earth, a nuclear reactor core has the highest energy density, which can be used for generating a large amount of power in VASIMR engines. The main constraints of conventional rockets are the large trip times and the limitations of payload mass. VASIMR employing Nuclear Energy Propulsion (NEP) can overcome these problems and thus can be used for the following missions
  - Manned missions to planets could become a reality because such nuclear powered spacecrafts could reduce the transit time to mars to less than 3 months.

- Movement of large payloads such as robotic cargo from Earth to outer space could be made possible due to the high energy produced by the nuclear reactors.

5. History and Future

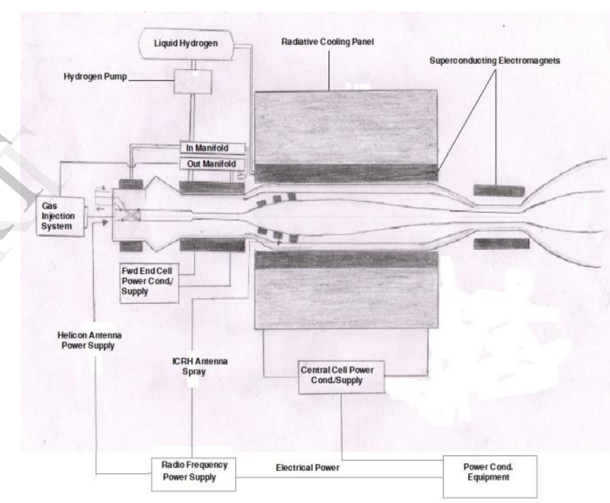
VASIMR engine are manufactured by the Ad Astra Rocket Company, which was set up in January 2005 by Franklin Chang-Diaz. In the same year, the company signed a Space Act Agreement with NASA and was granted access to the Advanced Space Propulsion Laboratory (ASPL), where the 50 Kw engine prototype was constructed for testing in a vacuum chamber.

It was found capable of producing 0.5 Newton thrust with the efficiency being 59% calculated as: 90% N_A coupling efficiency × 65% N_B ion speed boosting efficiency. In 2007, a 100 Kw engine was developed by the company which produced an output about three times the output of the 50 Kw version with an increased efficiency of 80%.

Next, the development of the 200 Kw engine followed in 2008 which was capable of producing 5 Newton thrust. In this 30 Kw was utilized by the helicon coupler for generating plasma and 70 Kw was used in the ICRH stage. Two VASIMR prototypes developed using this engine are the VX-200 and the VF-200. The VX-200 was tested in 2010 and was found to produce 5.75 N thrust with a specific impulse of 5000s. The efficiency was found to be 72%.

The VF-200 is to be tested on the International Space Station, and is expected to be launched in 2015 as stated in June 2012. The VF-200 consists of two 100 Kw engines with opposite magnetic dipoles in order to avoid any net rotational torque due to interaction with the magnetosphere. The success of the VASIMR test on the space station is expected to yield the following revenue-giving applications:

- Reduction in the cost of maintenance of the ISS in a stable orbit to about 1/20th of its present cost.
- The payload delivery to the moon could be tripled using a combined chemical-VASIMR transfer stage rather than using only a chemical rocket.
- Satellite missions such as manoeuvrability, refuelling, repair, completion speed can be improved over the current standards.



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6. Conclusion

The paper gives a detailed and simplified understanding of the working of the VASIMR, which is of mighty potential for future space missions because it can aid in missions such as reduced transit times between planets which could make human missions to planets such as Mars a reality, increased payloads for lunar cargo delivery, satellite repositioning and refuelling, drag compensation fo00r space stations and many others. Also, the high life expectancy of these rockets due to absence of electrodes is an added advantage.

The few disadvantages such as the management of the high amount of heat created and the interaction of the magnetic fields with on-board devices are also being worked upon. Superconducting electromagnets to contain the plasma and use of thrusters with magnetic fields oriented in different directions to create zero net torque are the answers to these questions. In short, the VASIMR has a great scope in the future and other applications can be found out.

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