

In-Space Propulsion and De-orbit of Satellites in LEO Using Electromagnetic Force

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Abstract

Satellites in Low Earth Orbit (LEO) experience considerable atmospheric drag and hence may be subjected to orbital decay over a prolonged period of time. But scientists and engineers are interested in these orbits for parking their satellites as it requires less energy to do so. Also the onboard amplifiers can be of less power output in such cases. Now in order to compensate for the loss in altitude due to the drag induced in satellites in LEO, energy of some sort has to be imparted to the satellite, sometimes more frequently, so that it gains velocity and returns to its original orbit. Also every satellite requires manoeuvre such as pitch, roll and yaw, to point the antennas towards the desired ground station. Chemical rockets or thrusters are being used widely to serve this purpose of orbital transfer and manoeuvring. But it has its own pros and cons. This paper studies the possibility of employing a propellant less propulsion system using the earth's magnetic field as a replacement for the conventional chemical thrusters. Also the number of satellites in orbit has been increasing and no steps are being taken to get rid of them as they may compromise the safety of other satellites in orbit. This paper also tries to find a solution for that problem by employing the same system to induce electromagnetic drag on the satellite and force it to de-orbit, once they are dysfunctional, thereby reducing the space debris.

1. Introduction

Any space craft should be equipped with an artificial propulsion system which is used to 'push' the satellite in space. This is mandatory as the satellite needs to be boosted

frequently in order to compensate for the loss in energy so that it stays in that particular orbit.

Conventional propulsion technique is the usage of certain chemicals, which liberate energy on reacting with other chemicals. This energy would be utilized to ‘push’ the satellite by using the principle of Newton’s third law of motion. But this poses one serious disadvantage.

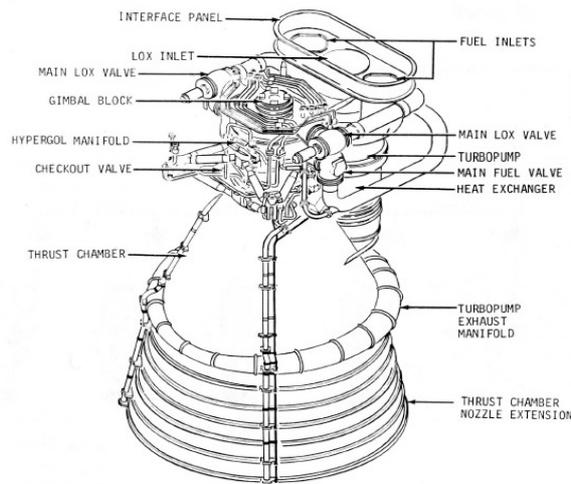


Fig. 1: Rocket dyne F1 Engines, Saturn V first stage.

The chemical propellants required should be carried by the satellites and hence there arises a restriction as to how much to carry. They also contribute to mass and weight which is a serious factor when concerned about space propulsion. For instance, the Space Shuttle, during liftoff carried nearly 541,000 litres of LOX and 1,450,000 litres of LH, which is 20 times heavier than that of the shuttle.

Also, the liquid cryogenic engines are one of the complex parts of the satellite. Still they do have advantages and hence are being widely employed. The figure shown is a typical cryogenic engine, powered by chemical propellants ^[1].

2. Earth’s Magnetic Field

The earth’s magnetic field is the natural magnetic field that surrounds the earth. It behaves exactly as a bar magnetic that is tilted at an angle of 11 degrees with respect to the spin axis. The lines move from north to south and extend from the core to over tens of thousands of kilometres above the ionosphere. The strength varies from .50 Gauss at the core to 0.24 Gauss at an altitude of 300km. The main purpose of the field is to protect the earth form the solar wind. However, they can also be used for satellite propulsion ^[2]

3. Force Experienced by a Current Carrying

3.1 Conductor

Consider any conductor of length L , moving through a magnetic field of induction \mathbf{B} . A current \mathbf{I} is passed in it and let θ be the angle between the current element and the magnetic field. A force F acts on the system in a direction perpendicular to both the magnetic field and the current element.

This is given by the following equation.

$$\vec{F} = \int_0^L I(L) m d\vec{L} \times \vec{B}.$$

This is in accordance to the Lorentz force equation as it is the total force due to the entire moving electron in the magnetic field. This force is 0 if the angle θ , which is the angle between the current element and the magnetic field, is zero and maximum when the angle θ is 90 degrees. The direction of the force developed is given by the Fleming's left hand rule.^[31]

4. Possibility of Electromagnetic Propulsion

We have the natural magnetic field all around the earth. It runs from North Pole to the South Pole. So if we could have a conductor and pass known current through the conductor, then according to the theory discussed above, a force is generated, which acts on the entire system. So if this system is mounted on a satellite, then we would have a propellant less propulsion system, propelled by the earth's magnetic field. Though it sounds simple, they have a lot of practical challenges that should be faced before implementing it. The actual working of such a system is discussed below.

5. How to achieve a Complete Circuit?

The first problem which would arise is to completing the circuit without making any loops. We could easily design a closed circuit by using circular loops. But such a design will not be effective here as the forces induced would be in opposite directions and hence would cancel out which is undesirable. Hence the design should be such that the current element has to be in a straight line. The solution to this problem is as follows.

The ionosphere is a region above the stratosphere, where there is considerable activity of charged particles. Hence there is always a decent density of charged particles in this region. This could be used in our case. We can design the conducting wire to be a long and straight. Once a potential is maintained, the electrons from the ionosphere enter the conducting wire through the anode side and pass out to the ionosphere through the cathode side. This causes a current to flow in the opposite direction and in a straight line.

5.1 Working

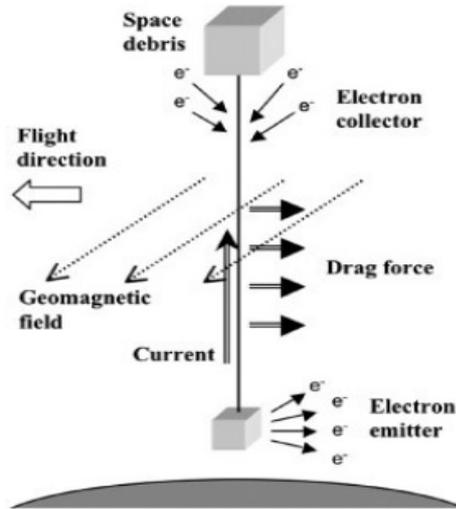


Fig. 2: Working of Electromagnetic Propulsion.

Once the satellite is launched into its orbit, electromagnetic propulsion system takes over. Two sphere like structures starts to stretch out in either direction of the satellite. They are connected to the satellites by means of a conducting wire with a protective coating. Once stretched out, the lengths of the wire would measure a few kilometres. Now a potential is maintained in the wire. As the satellite orbits in the low earth orbit, where there is appreciable density of electrons, a current is passed in the conducting wire. This current interacts with the earth's magnetic field and a force is developed.

By changing the orientation of the current element, the direction of force can be varied in accordance to the Fleming's left hand rule. The only direction in which the satellite can't be propelled is the direction of the magnetic field itself, as the force tends to zero in that direction. Hence the satellite is the least effective in the polar orbit for propelling forward. However it can always be used to raise or lower the altitude. Hence it serves as an excellent propulsion tool.

The main disadvantage of this system is that, the force produced is somewhat low to make sudden changes in orientation. Also the value of the earth's magnetic field strength is not a constant value, but changes with latitude, longitude and altitude. However, it can be used to give a constant force in the appropriate direction, so as to compensate for the loss in energy due to losses and to maintain the satellite at the required attitude^[4]

6. Possible Materials

For maximum performance, the conducting wire should be made of a material which has high strength and electrical conductivity and low density i.e. the material need to be strong as well as light. The most appropriate material would be Carbon nanotubes, which are very much lighter then steel, but many time stronger than steel.

Another such material is the synthetic M5 fibre. This is the proposed material for the manufacturing of cables in the developing ‘Space Elevator’ project. It has extraordinary properties making it as the one of the suitable materials for the development of conducting cables. Both these materials have a good electrical conductivity also. ^[5]

7. DE-Orbiting

Space pollution has become a serious threat for mankind. All the satellites which are launched remain in orbit even after their service is over. Orbital decay occurs very slowly and thus they pose a serious threat to the operational satellites in the form of collisions. Hence it has become mandatory to get rid of those satellites once it is decommissioned from service. Again electromagnetic force comes to the rescue.

8. EMF Developed in a Conductor Moving in a Magnetic Field

Consider a conductor moving in a magnetic field with a velocity \mathbf{v} , relative to a magnetic field of intensity \mathbf{B} . According to the faraday’s law of electromagnetic induction, the emf developed in the conductor is given by,

$$\Phi = \int_0^L (\mathbf{v} \times \mathbf{B}) \cdot d\mathbf{l}$$

The electrical energy comes from the kinetic energy of the moving conductor, which means that the current tends to slow down the moving conductor, as per Lenz law. The direction of the induced emf is given by the Fleming’s right hand rule.

Let P be the mechanical power which can be expressed as force times relative velocity as given by the following mathematical equation.

$$P = \mathbf{F} \cdot \mathbf{v}$$

Therefore, the time required to reduce the orbit of a satellite from radius a_2 to radius a_1 , where $a_2 > a_1$ is given by the following equation.

$$\Delta t = \int_{a_1}^{a_2} \frac{\mu_{\oplus} m}{2 a^2 P} da$$

Where, μ_{\oplus} is the earth’s gravitational parameter and ‘m’ is the mass of the satellite. This equation gives the time required for de-orbiting a satellite using this system. It can be observed that the de-orbiting rate is accelerated if we use this technique.

Also, if this system is already employed for satellite propulsion, then there wouldn't be any need to carry it separately for deorbiting.^[6]

9. Conclusions

Hence we have discussed the possibility of using electromagnetic force for satellite propulsion and also to use the same to de-orbit the satellite. There are several challenges which needed to be faced before successfully implementing this system into service. However, for sudden or quick trajectory changes, one has to still rely only on the chemical rockets.

References

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