OPTIMIZING A SPACE MISSION USING ION PROPULSION

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DOI: 10.19062/1842-9238.2015.13.3.15

Abstract: *The purpose of this paper is to describe a method of optimizing a space mission using ion propulsion, the calculation method of the parameters that belong to a spacecraft equipped with ion propulsion, the speed variation of a spacecraft depending on the evacuation speed of the particles for variation t, variation α and other parameters. The following elements will be calculated: the evacuation speed variation depending on the potential acceleration, force variation depending on the potential acceleration, flow rate variation depending on the potential acceleration.*
Keywords: *mission, ion propulsion, optimization, parameters, payload, propellant*

1. INTRODUCTION

From the oldest times one of the biggest dreams of humans was the flight, especially the flight to other planets. One of the first previews of this idea was the great scientist Konstantin Eduardovitch Tsiolkovsky [3]. We can say that the history of modern rocket flying and astronautics starts in 1903 with the famous article "Investigation of Universal Space by Means of Reactive Devices, [6] from which the following quote is taken. That article contains the rocket equation of Tsiolkovsky in differential form, which is the fundamental mathematical expression in the field of space propulsion.

In the field of electricity the first scientists who see the possibility and the potential of electrical propulsion are: Robert H. Goddard [8], in 1906, expressed many of them just as simple information; Konstantin Eduardovitch Tsiolkovsky which in 1911 published an idea of electric propulsion: "It is possible that in time we may use electricity to produce a large velocity for the particles ejected from a rocket device" [6] and Professor Herman Oberth, which in 1929, included a chapter on electric propulsion in his classic book about rockets and space travel [5]. There are three types of electrical propulsion systems: electro-thermal, electrostatic (ionic) and electromagnetic; a detailed description of these propulsion systems can be found in reference [1].

For studying the travel to Mars it was chosen the electrostatic (ionic) propulsion system. This propulsion system was developed since the beginning of 60's by projects NASTAR. Over the time this systems were made and perfected especially for satellites, in order to do the orbit correction and satellite transfer from an orbit to another.

After perfecting these propulsion systems they were used during some Terra outer space missions, the first success mission which used ionic propulsion was in 1998 during the American Deep space mission 1 [10]. Another successful mission which used the ionic propulsion was the Japanese mission Hayabusa [11] from the year 2003 which had as main objective the study of an asteroid. The last major success mission which used the ionic propulsion was Dawn [12] launched in 2007, the purpose of the mission was to study the Vesta and Ceres asteroids, which arrived at her destination in 2015 passing near Mars by using the planet's gravity in order to continue the travel. A future interplanetary mission will be made by ESA and JAXA in 2017 and it will be a travel to Mercury planet, the name of the mission is BepiColombo [13].

In this paperwork we try the optimization the performances of a spacecraft, especially by optimizing the propulsion system seeing the technological actual limits and the calculation extension of the improvement possibilities.

2. THE RUNNING PRINCIPLE OF THE ELECTRIC PROPULSION SYSTEMS

The running principle of electrical propulsion systems consists of making the gas molecules or, in general the particles which have to be ejected, sensitive to the action of an electric field and to send them the desired energy using this field. The known method for making a conductor from a gas it is by ionizing it, in this case the gas becomes sensitive to the action of an electric or magnetic field. If we ionize a gas in a given chamber we obtain negative and positive charges. In a ionic rocket the charges are separated first, the negatives from the positives and the ion obtained are accelerated in a particle accelerator.

Electrostatic propulsion, regardless of type, consists of the same series of basic ingredients, a propellant source, several forms of electric power, an ionizing chamber, an accelerator region, and the means of neutralizing the exhaust. While Coulomb accelerators require a net charge density of one polarity, the exhaust beam must be neutralized to avoid a space-charge build-up outside of the craft which could easily cancel the operation of the thruster. The neutralization is given by the injection of electrons downstream as in picture 1, a schematic diagram of the NASTAR ion thruster, as used on Deep Space 1 [7]. The neutralization of the ion fascicle as one of the most difficult problems of this propulsion system.

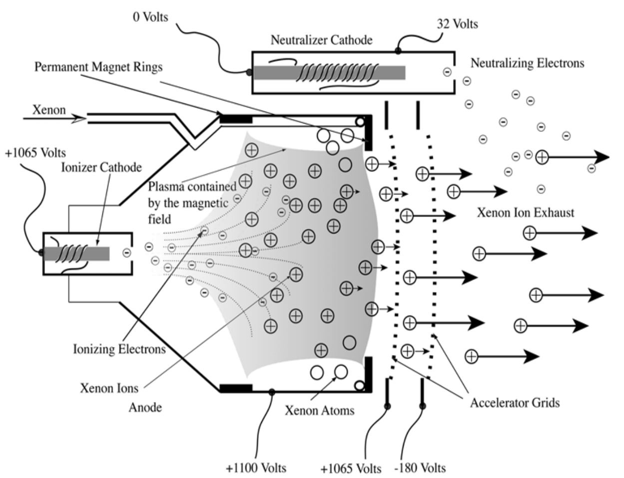

Fig 1 The schematic diagram of the NASTAR ion thruster.

The evacuation speed at which the particles arrive it is determined in a particle accelerator. We analyzed the direct particle accelerator because it is the most used particle accelerator. This particle accelerator is described in reference [2].

According to reference [9] we will present the calculation method for the ionic engine. For starters it will be analyzed the situation of an ion which has the load q and mass m located in an electric field $\vec{E}$, determined by the tension $V_{acc} = V_2 - V_1$ which applies between A anode and C cathode, as it can be seen in the picture below.

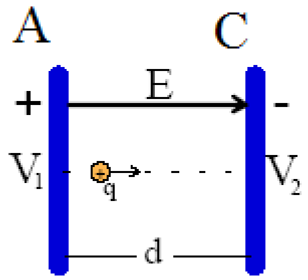

Fig 2 The schematic diagram of the electric field.

The ion is accelerated until it gets a speed v_e determined by the next equality: the kinetic energy of the electron it is equal with the kinetic energy variation of the particle, conditioned by the electric field action.

$$\frac{1}{2} \cdot m \cdot v_e^2 = q \cdot V_{acc} \Rightarrow v_e = \sqrt{\frac{2 \cdot q \cdot V_{acc}}{m}} \tag{1}$$

The below expression is valid if the particle takes off from the ion source with the speed 0, during the acceleration interval there is an uniform electric field

$$E = \frac{U}{d} \tag{2}$$

where d is the distance between the two electrodes.

In order to calculate the propulsion force produced by the ionic engine we used the expression below:

$$I = \dot{m} \cdot \left(\frac{e}{m} \right) \quad (3)$$

The propulsion force is defined as:

$$F = \dot{m} \cdot v_e = I \cdot \sqrt{2 \cdot \frac{m}{e} \cdot V_{acc}} \quad (4)$$

We have to determine the intensity of the electric current by defining the current density $j = \frac{I}{S}$.

Using the Poisson's equation we obtain:

$$\frac{d^2 V}{d^2} = \frac{\rho_e}{\varepsilon_0} \quad (5)$$

where d is the distance, ε_0 is the vacuum permeation and ρ_e current density.

Solving the equation below we obtain the current density:

$$j = \frac{4 \cdot \varepsilon_0}{9} \cdot \sqrt{\frac{2 \cdot q}{m}} \cdot \frac{V_{acc}^{\frac{3}{2}}}{d^2} \quad (6)$$

For atomic or molecular ions we obtain:

$$j = \frac{5.4 \cdot 10^{-8} \cdot V_{acc}^{\frac{3}{2}}}{M^{\frac{1}{2}} \cdot d^2} \quad (7)$$

And for circular form holes we have:

$$I = j \cdot S = j \cdot \left(\frac{\pi \cdot D^2}{4} \right) \quad (8)$$

where D is the hole diameter.

$$F = \left(\frac{2}{9} \right) \cdot \pi \cdot \varepsilon_0 \cdot D^2 \cdot \frac{V_{acc}^2}{d^2} \quad (9)$$

The electric power is:

$$P_e = I \cdot V_{acc} = \frac{1}{2} \cdot \frac{\dot{m} \cdot v_e^2}{\eta} \quad (10)$$

The performance of an electrical rocket can be conveniently analyzed in terms of the power and the relevant masses [4].

Using Țsiolkovski's equation we obtain the formula:

$$v = v_e \cdot \ln \frac{m_0}{m_f} \quad (11)$$

m_f is the final mass of the rocket, m_p is the propellant mass from aboard, v is the rocket speed at the time moment t, m_0 is the initial mass of the rocket, m is the mass of the rocket at t moment, v_e is the evacuation speed of the propellant from the engine.

Before the rocket take off, the initial mass is given by:

$$m_0 = m_p + m_{pl} + m_{pp} \quad (12)$$

m_u is the mass of the payload, m_{pp} is the mass of the power plant from aboard, $\alpha = \frac{P_e}{m_{sp}}$,

P_e is the electrical power of the power source.

Between the electrical power of the source and the power of the jet we have the relation:

$$\eta = \frac{P_{jet}}{P_e} \quad (13)$$

η is the system's performance.

$$P_{jet} = \frac{1}{2} \cdot \dot{m} \cdot v_e^2 \quad (14)$$

$$P_e = \alpha \cdot m_{sp} = \frac{P_{jet}}{\eta} = \frac{m_p \cdot v_e^2}{2 \cdot t_p \cdot \eta} \quad (15)$$

In order to determine the rocket's performances:

where t_p is the time in which the propellant is used.

3. RESULTS OF MISSION OPTIMIZATION

The performances of the mission will be optimized depending on different parameters as it can be seen below:

For study of the performances we know about the mission η=0.7, α=500, $\frac{m_{pl}}{m_p}=3$, $\frac{m_{pp}}{m_p}=0.15$, $t=10^7\ s$.

The following information is known about the ionic engine:

The working fluid is xenon which molecular weight is 131.3 kg/kg-mole, the distance between the acceleration grids d= 2.5 mm, the diameter of each hole of the grid D=2 mm, the number holes in the grid No=2200.

After variation the parameters obtain:

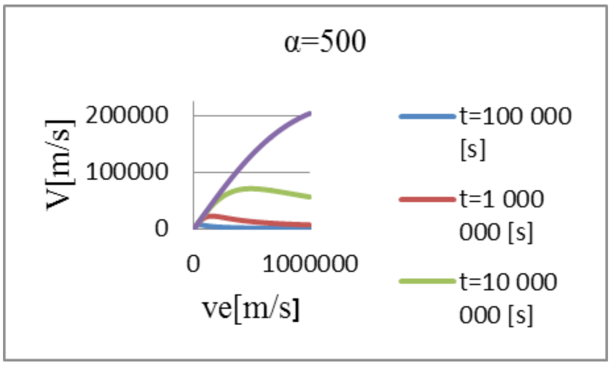

Fig. 3 Rocket speed variation depending on the evacuation speed of the particles for variation of t.

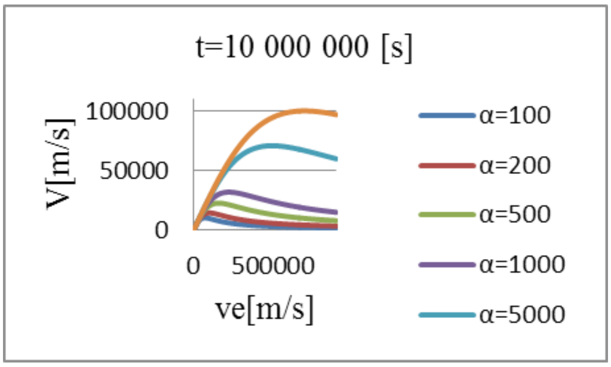

Fig. 4 Rocket speed variation depending on the evacuation speed of the particles for variation of α.

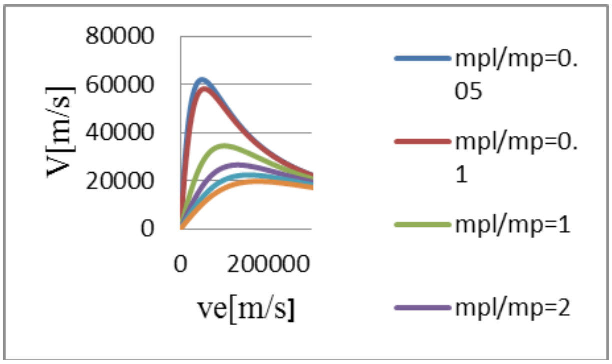

Fig. 5 Rocket speed variation depending on the evacuation speed of the particles for the $\frac{m_{pl}}{m_p}$.

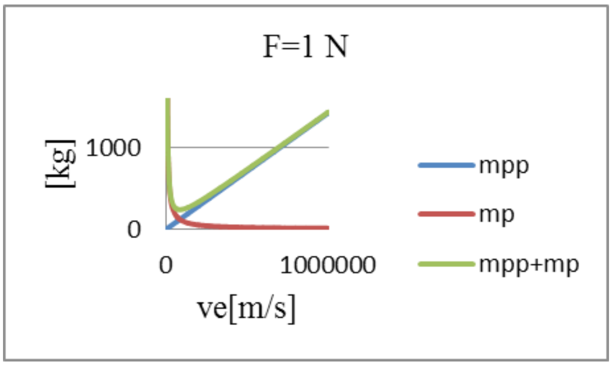

Fig. 6 m_{sp}, m_p and m_p+m_{sp} variation depending on the evacuation speed of the particles.

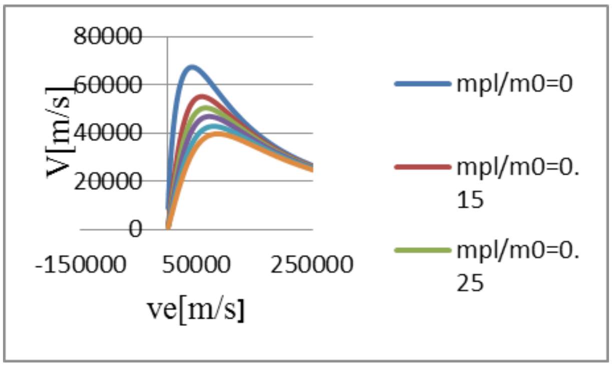

Fig. 7 Rocket speed variation depending on the evacuation speed of the particles for $\frac{m_{pl}}{m_0}$.

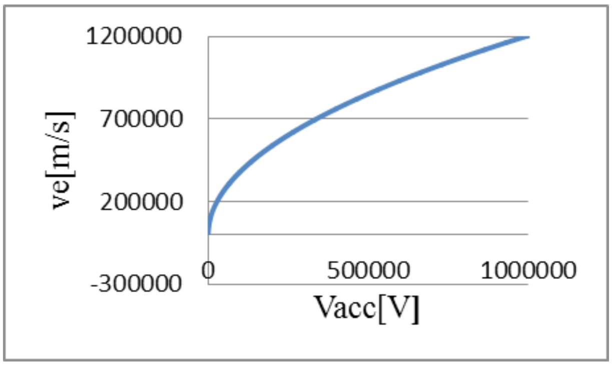

Fig. 8 Evacuation speed variation depending on the potential acceleration

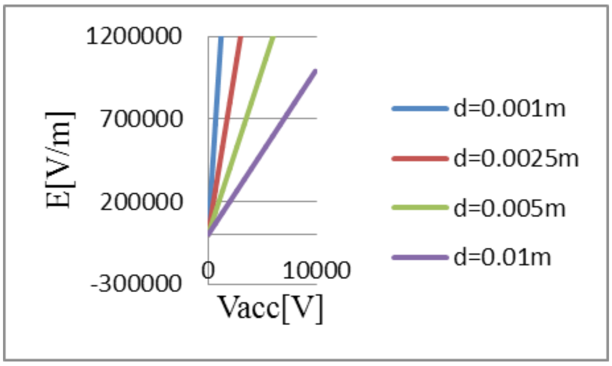

Fig. 9 Electric field variation depending on the potential acceleration

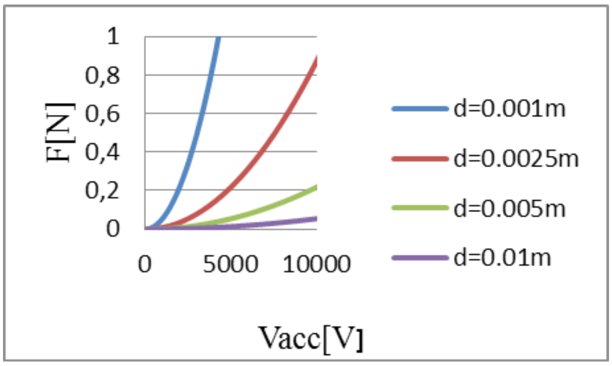

Fig. 10 Force variation depending on the potential acceleration

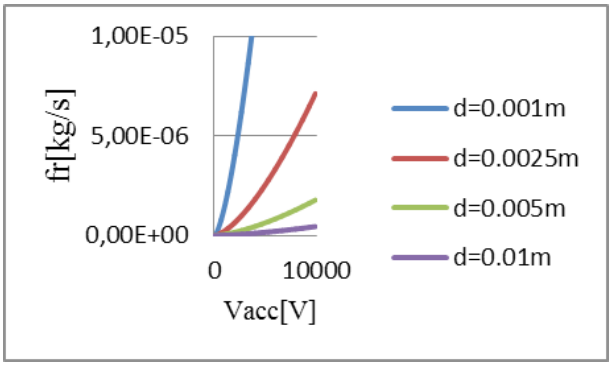

Fig. 11 Flow rate evacuation depending on the potential acceleration

CONCLUSIONS

As you can see in the figure 3 the variation of the ship's speed is maximum with the evacuation speed for each time of the mission.

From the figure 4 it can be seen that for each α there is a maximum for the speed rocket depending on the evacuation speed of the particles for variation of α. Therefore if there would be high values for the α parameters the rocket could achieve higher speeds for the ship.

For choosing the propellant quantity aboard figure 5 shows that the maximum speed that can be achieved by the ship for a certain evacuation speed of the particles.

From the figure 8 it can be seen the variation of speed of particles depending on the potential of acceleration so the higher the potential for acceleration, the higher the exhaust speed.

The variation thrust and propellant flow is greater as long as the distance d between the two boards is less, so a higher electric field is present.

For a certain space mission, a spacecraft that must reach a certain speed, it can be chosen a certain optimal exhaust speed depending on the parameters studied in this article.

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