Section 8: Electromagnetic Propulsion

AE435

Spring 2018

6 Pulsed Plasma Thruster (PPT)

Contents

6.1 Pulsed Plasma Thruster

In 1964 Russians decided to avoid problems with tanks, valves, regulators, by using a solid propellant. The first propellant tried was Teflon, and although many others have been tried, Teflon (C_2F_4) remains the best choice. It has a density almost twice that of Lexan (2.2 g/cm3). It does not have a liquid phase, and evaporates from solid to vapor.

PPT was first flown in 1964 (Zond 2) and in 1968 (LES-6). The classic schematic is:

Figure 9: PPT Diagram

Parallel plate design. JxB acceleration.

Stored energy is:

$$\frac{1}{2}CV_o^2 \tag{8.64}$$

For a pulse rate f, then the average power is

$$a \tag{8.65}$$

Typically f 1-5 Hz.

Each pulse creates thrust, and evaporates mass, m.

Figure 9: PPT Diagram

Impulse bit is:

$$a \tag{8.66}$$

Specific impulse is then:

$$a \tag{8.67}$$

Average thrust:

$$a \tag{8.68}$$

The arc heats the Teflon to $\sim 600 - 700K$, so it ablates. This ablation continues to occur after the pulsed power is applied. And the ablation that occurs after the initial pulse is referred to as "late time ablation".

Figure 10: Late Time Ablation Illustration

6.2 Efficiency

The efficiency is calculated from a simple circuit model:

Figure 11: Efficiency Circuit Model

Assume a matched PFN:

$$R_L + Z_L = Z_o \tag{8.69}$$

Thus the voltage drop across the load is equal to that across Z_o, that is:

Thus the current is:

$$a \tag{8.70}$$

Then the charge is

$$Q_o = C_o V_o$$

And the length of the pulse is

$$a \tag{8.71}$$

Since where L, C are per section of the PFN, and

$$a$$

Then t_p

$$a \tag{8.72}$$

Recognize that for cases where Electromagnetic energy does work on a mass:

$$a$$

and the resulting power

$$a$$

which means the imepednace is

$$a$$

Also, for coaxial electrodes, Maecker (8.22) with (8.53) is:

$$a$$

$$a \tag{8.73}$$

Returning to efficiency, R_L represents losses in capacitors, switches, electrodes, etc., so let the efficiency:

$$a \tag{8.74}$$

so

$$a \tag{8.75}$$

For Example:

6.3 Two Stream Model

The first complication is that Teflon (C_2F_4) is dissociated to $C+F+F$ and then is partially ionized (C^+, F^+). Because of pressure, neutrals are accelerates to lower velocity than ions. This leads to a two-stream model.

The PPT is partially ionized. Neutral and Ions. We have a situation in PPT where the pulse results in "fast" ions and "slow" neutrals coexisting in the same channel. "Two-Fluid" model.

Consider the situation shown here:

Figure 12: Two Fluid Model

Total ablated mass is the sum of the fast and slow species.

$$M = M_f + M_s \tag{8.76}$$

Impulse bit is then:

$$a \tag{8.77}$$

Thus Isp and efficiency are:

$$a \tag{8.78}$$

$$a \tag{8.79}$$

Experimentally we can measure Ibit, m Eo. But cannot know mf, u_f, m_s, u_s. We can also calculate the Electromagnetic portion of Ibit:

$$a \tag{8.80}$$

If we say

$$a \tag{8.81}$$

Then from measured Ibit, we also know $m_s u_s$.

$$a \tag{8.82}$$

Now the problem is, what are mf ms, or uf us? We find the answer in Cosmology, more specifically a theory for the origin of the solar system by Hannes Alfven (Nobel Prize in Physics 1970). Alfven's paper "On the Origin of the Solar System" assumed the Sun and a magnetized dust cloud.

Alfven: When KE = ionization energy, particle falling in is ionized, losing all energy, so stops. In this way, atoms of H, He, Ne, etc. stop at different radii.

So for the PPT it is assumed that uf cannot exceed us by more than uc:

What is uc for Teflon (CF2)? Carbon: Fluorine: Example, assume

Conclusion: Most efficient PPT has highest degree of ionization, which minimizes ms and raises Isp.

6.4 PPT Modelling