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Analysis and design optimization of electrodes setup for MPD thruster

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ABSTRACT

Magneto Plasma Dynamic thruster is one of the developing fields in the history of propulsion. It comes under the concept of electric propulsion which involves production of plasma with the help of electrical components in order to produce the thrust required to move the satellite or a spacecraft. The main reason for using the electric propulsion is to increase the range of the spacecraft or a satellite; moreover it could replace large amount of chemical propellant hence providing space for more payload. It gives more opportunity for Δv missions. Significant amount of thrust can be produced with the help of the experimental setup. It has got the following blocks: High current power supply, ignition circuit, thruster which converts electrical energy into kinetic energy and measuring unit. The voltage source along with the high voltage transformer and capacitor banks were the notable components in this unit. The Thruster Electrode setup and measuring units are two important and crucial setup which requires more analysis and prepare design. Hence this paper mainly focuses on the thrust production for various thruster electrodes parameter.

KEY WORDS: Electrode, Energy, Thruster.

1. INTRODUCTION

Plasma as conductor: In gaseous state certain portion of the particles are ionized to become plasma. Plasma has defined boundary and the presence of a non-negligible number of charge particles makes the plasma highly conductive so that it responds strongly to electric and magnetic fields. Quasi-neutrality makes the plasma currents close on themselves in electric circuits. Such circuits follow Kirchhoff's laws and possess resistance and inductance.

Parschen's law: Design of MPD thruster Electrodes is based on PASCHEN's law, gives the relationship for breakdown voltage as function of pressure and gab distance between electrode as V = f(pd)

$$V = \frac{a(pd)}{\ln(pd) + b} \quad \text{(Equation 1)}$$

Where b = ln(A / ln (1 + 1 / r)), V is the breakdown voltage in volts, p is the pressure, d is gap distance.

Thrust calculation of MPD thruster: The body forces on the ionized gas can be decomposed into three separate analyzing modes. The first mode is contribution due to radial current density uniform over the surface of a rod of constant radius, which gives raise to self-magnetic field given as

$$B_\theta(r,z) = \frac{\mu \cdot I}{2\pi r}\left(1 - \frac{z}{z_0}\right) \quad \text{(Equation 2)}$$

The force density is function of current density and magnetic field. The total force contribution due to radial current over the flow direction with constant radius cathode is then given by integral over discharge gap volume with anode radius r_a and cathode radius r_c is

$$F_z = \frac{\mu \cdot I^2}{4\pi}\ln\left(\frac{r_a}{r_c}\right) \quad \text{(Equation 3)}$$

The second force contribution is from current entering the conical cathode tip, which is taken in to account by extending the limits of integration, and which results in a second term in the total force equation. And the resulting total blowing force contribution is

$$F_z = \frac{\mu \cdot I^2}{4\pi}\ln\left(\frac{r_a}{r_c} + \frac{1}{2}\right) \quad \text{(Equation 4)}$$

The final force is due to pumping action as a result of current entering the conical tip normal to the Surface which is

$$F_c = \frac{\mu I^2}{8\pi} \quad \text{(Equation 5)}$$

Combining these three force components yields the total force as

$$F = \frac{\mu \cdot I^2}{4\pi}\left(\ln\frac{r_a}{r_c} + \frac{3}{4}\right) \quad \text{(Equation 6)}$$

Analysis of Electrode parameters: The geometry shown below shows the cross section view of the thruster electrode for which the thrust developed is derived in equation 1-6.

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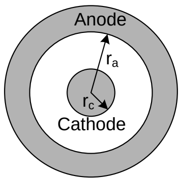

Figure.1. Cross section of thruster electrodes Layout

The thrust generated is a function of ratio of anode radius to the cathode radius and the total current which is given by equation 7.

$$I \approx \sqrt{\frac{F4\pi}{\mu\left(\ln\frac{r_a}{r_c}+\frac{3}{4}\right)}}$$

(Equation 7)

The total thrust is direct function of current which rising quadratically with respect to current value

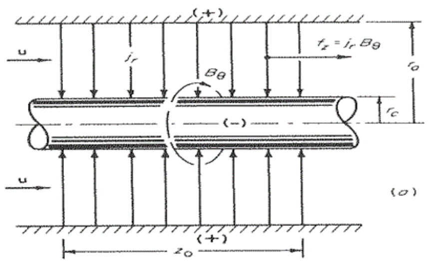

Figure.2. Blowing force from radial current

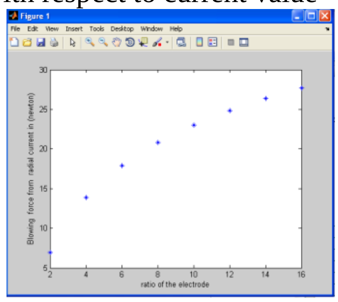

Figure.3. Blowing force from radial current for various electrode ratio

Considering the blowing force from the radial current through the above plot it can be seen as the electrode ratio increases, the blowing force also increases and saturates at a point.

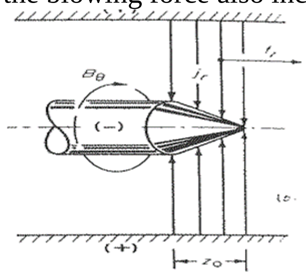

Figure.4. Blowing force due to radial current at conical tip

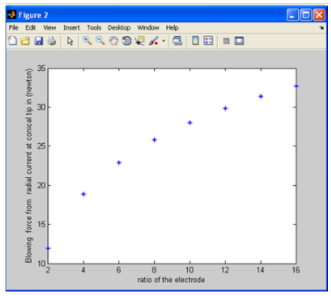

Figure.5. Blowing force at conical tip for various electrode ratio

Considering the blowing force from the radial current tip through the above plot it can be seen as the electrode ratio increases, the blowing force also increases.

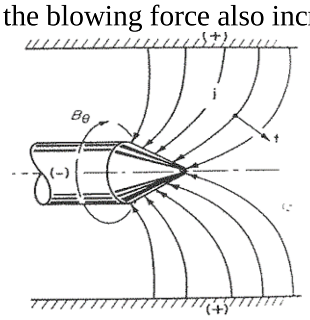

Figure.6.Pumping force due to radial current at conical tip

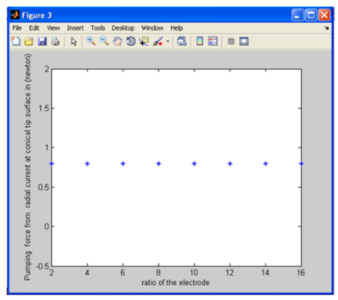

Figure.7. Pumping force at conical tip for various electrode ratio

Considering the pumping force from the radial current tip surface through the above plot it can be seen as the electrode ratio increases, the pumping force remains constant. By combining all three forces which gives total force with respect to ratio of electrodes. The following characteristics shows the ratio of anode and cathode radius versus force.

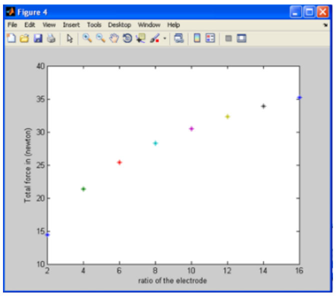

Figure.8. Total force for various electrode ratio

Electrode Design: The electrodes should withstand high temperature, current and should be good conductor. The cathode which should withstand core temperature; hence tungsten will be suitable material and anode which can be copper. The elecrode setup not only cathode and anode design. It should include setup for insulation between electrodes, inlet for gas flow, anode adjustment.

Electrode Design for various Anode cathode Ratio: The setup developed should be flexible to attach different radius anode, and should have cathode thread for fine adjustment. Figure shows below such a design.

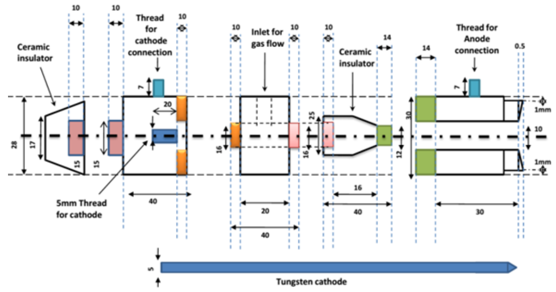

Figure.9. Electrode setup for anode, cathode attachment

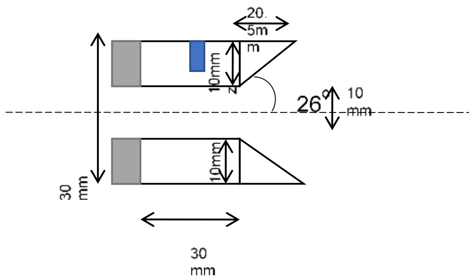

Figure.10. Electrode ratio 2 With Flad Angle of 26 degree

Figure.11. Electrode ratio 2(front and back view)

Electrode ratio 2.5:

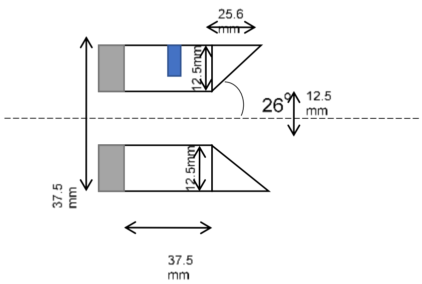

Figure.12. Electrode ratio 2.5 With Flad Angle of 26 degree

Figure.13. Electrode ratio 3(front and back view)

Electrode ratio of 3:

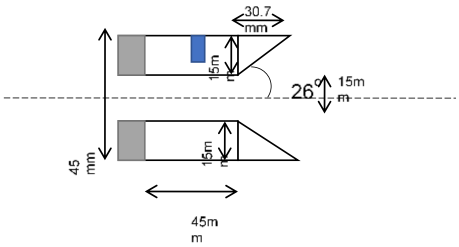

Figure.14. Electrode ratio 3 With Flad Angle of 26degree

Figure.15. Electrode ratio 3(front and back view)

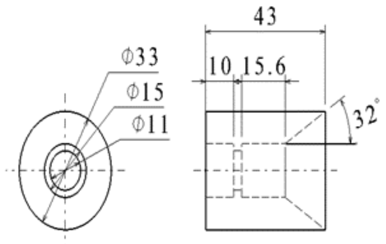

Figure.16. Electrode ratio 3-configuration

Nozzle Parameter Variation and Its Corresponding Output Thrust Variation: The nozzle length, breadth variation can bring changes in the thrust, it is applicable for gas variations too. CANOPY can be very handy to perform these operations. One among the nozzle variation for argon gas is displayed below:

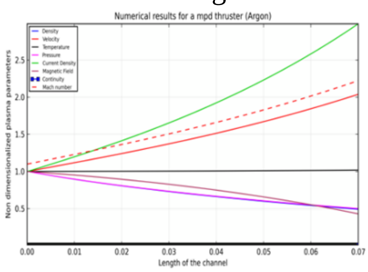

Figure.17. Parameter variation due to Nozzle dimension variations (Argon)

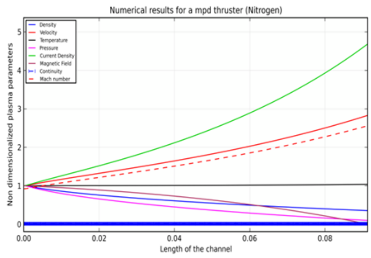

Figure.18. Parameter variation due to Nozzle dimension variations (Nitrogen)

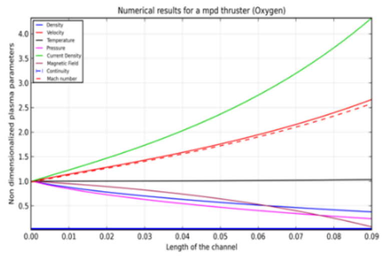

Figure.19. Parameter variation due to Nozzle dimension variations (Oxygen)

2. CONCLUSION

Thus optimization can be done while implementing the analysed values from the evolved outputs from MATLAB and CANOPY which will be very much useful in both atmospheric as well in the vacuum condition. Hence it would be a giant leap in the advancement of electric propulsion field as it comes with accuracy and predicted values.

Further Improvements:

- Need to analysis the various of current and voltage along length of the electrodes
- Implementation of the analyzed values in the experiment.

- need to find the voltage and instantaneous current at electrodes junctions and corresponding self-induced magnetic field
- Design and analysis of surge tank, solenoid valve and regulators.

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