A Review Paper on Pulsed Plasma Thruster

[1]Hardik Brahmbhatt [2]Harsh Kapadia [3]Prof.Dhaval P Patel [4]Prof.Sajan Kumar Chourasia

[12]BE Mechanical student ,Gandhinagar Institute of Technology ,Gandhinagar ,Gujarat –382721 ,India .

[34]Assistance Professor ,Gandhinagar Institute of Technology ,Gandhinagar ,Gujarat –382721 ,India .

Abstract:

In this paper, the design of Liquid Pulsed Plasma Thruster (PPT), its types, its Acceleration mechanism, its Thruster design, advantages and applications are discussed. The Pulsed Plasma Thruster is electrical spacecraft propulsion engine. It's offering great advantages like compactness, light weight over other electric propulsion systems. As the name suggest it is used plasma as the fuel to produce more thrust power more effectively than any electric propulsion engine. The present paper gives an overview of Pulsed Plasma Thruster.

Keywords: Pulsed Plasma Thruster, Electric Propulsion, Liquid propellant,PPT.

Nomenclature

PPT	Pulsed Plasma Thruster
PPU	Power Processing Unit
PTFE	Poly Tetra Fluoro Ethylene
EO1	Earth Observing 1
LP-PPT	Liquid Propellant – Pulsed Plasma Thruster

1. INTRODUCTION

In recent years, Pulsed Plasma Thrusters (PPTs) have attracted a lot of attention as promising thrusters [1].PPT is an electric propulsion device uses electric power to ionize and electromagnetically accelerate plasma to high exhaust velocities as shown in Fig. 1 which is used for attaining a high specific impulse [2] .

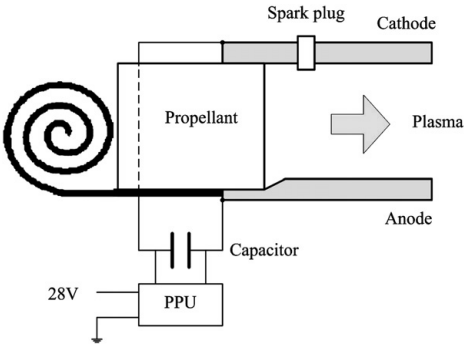

Fig. 1: Basic schematic diagram of PPT[2]
Fig.1 Working Process

It is one of the most effective device which is used for station-keeping, orbit raising and attitude control of small spacecraft [2].Because of their advantages like compactness, lightweight and robustness compared to other electric propulsion systems [4].

2. FUNDAMENTALS

PPT is self-contained propulsion system.it is consist a power source, power processing unit (PPU), an energy storage unit, and the thruster and power is provided by solar cell. The energy storage unit provides a high current pulses through the thruster to perform work. At the first stage of PPT, capacitor is charged to the desired voltage. The spark plug is ignited to trigger the discharge[2].

A schematic of a PPT is shown in Fig. 2. Energy has been released during discharge pulse which is stored in a capacitor bank [5].The capacitor which is fully stored with energy, it powers a high current duration plasma discharge and produce anelectro – magnetic field. After that molecules of propellant are ionized. And due to this action of $\vec{j} \times \vec{b}$ electromagnetic Lorentz force and gas-expanding force, the plasma is accelerated to high exhaust velocities and the finally the thrust is generated in PPT.

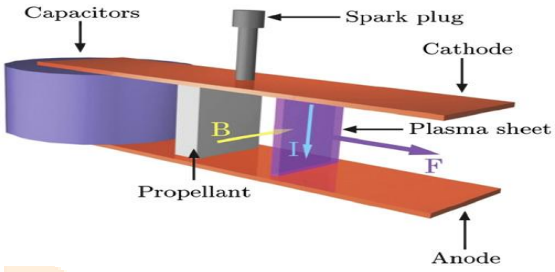

Fig.2 working principle of a PPT[5]

3 .TYPES

3.1 Solid propellant

Most of the PPTs are using Teflon (PTFE) as solid propellant [1]since it is very stable in vacuum. Teflon consists of carbon and fluorine [3].

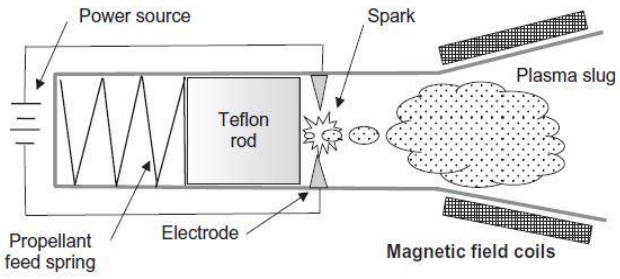

Fig.3 Schematic diagram of PPT using Teflon propellant[6]

Teflon consists of fluorine which can damage solar cells and carbon which can affect the transmission factor of the optics [3].Moreover, space craft contamination by the exhaust gas of carbon and fluorine would become a serious problem. The problems associated with Teflon PPTs are their low efficiency and contamination to space craft. The low efficiency mainly causes a low speed of the ejected vapour from Teflon surface and emission of large particles during the main discharge. By practical studies it was shown that a liquid propellant PPT had higher specific impulse and low thrust power ratio than Teflon PPT but it maintain same thrust efficiency [1].

3.2 Liquid propellant

As shown in Figure LP-PPT consists of electrodes, an intermittent injector and an igniter. The amount of liquid droplets provided by the intermittent injectors into the inter-electrode region.After feeding the liquid droplets, the igniter generates a spark and the some of the liquid droplets are converted into a plasma. 10kA-order discharge current is provided in circuit after closing it with plasma. Because of discharge current, other liquid droplets are also converted into plasma which is then accelerated electromagnetically and electro thermally. As a result of this process, thrust is generated by the plasma propagation [3].

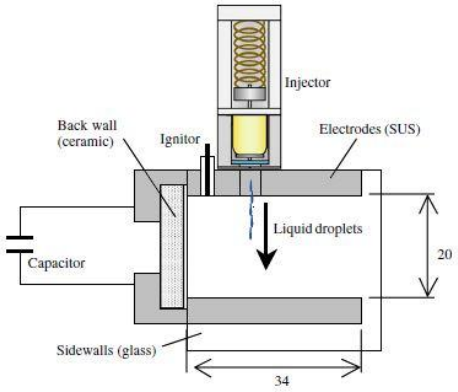

Fig.4 Schematic diagram of PPT using Liquid propellant[1]

Several PPTs using liquid propellant were introduced over the last decade. Scharlemann and York show that water is very effective propellant producing much higher specific impulse than Teflon, because it does not contain carbon and halogen [3, 7]. Micro liquid PPT was demonstrated at Johns Hopkins University (Applied Physics Lab). JHU / APL thruster prototype weights about 13.5 g (without PPU) and also uses water as a propellant [7].

4. Thruster Design

In this section the thruster design will be briefly discussed:

The thrust is determined as a function of displacement,period, impact angle and mass of target [2]. Thrust efficiency is defined as ratio between the kinetic energy of plasma plume and energy stored in capacitor bank [5]. The basic design of SIMP-LEX thruster is shown in Fig. 5.

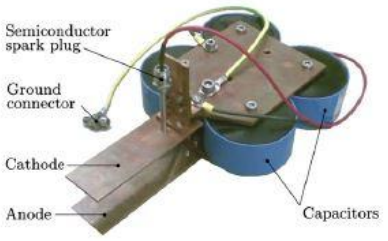

Fig. 5 Base Design of SIMP-LEX [5]

The new ADD SIMP-LEX thruster is designed as shown in Fig.6 to increase the performance of the previous PPT models developed [5].

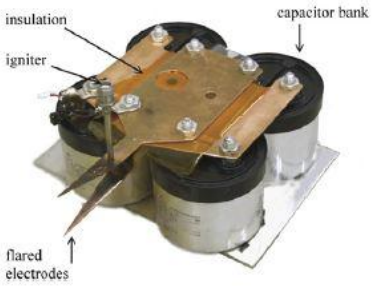

Fig. 6 ADD SIMP-LEX Thruster , optimize from SIMP-LEX [5]

To increase the performance there are mainly two parameters are considered which are described below [5]:

1) Capacitance and

2) Initial Inductance.

By placing the electrodes on the top of the each other,separator only by the insulator the initial inductance of the thruster was reduced from 60 to 20 nH. From a structural point of view ADD SIMP-LEX is a parallel plate PPT based on two copper electrodes separated by 10 μm Kapton foil.

5. Acceleration Mechanism

Generally, in PPT (Pulsed Plasma Thruster) there are two types of acceleration mechanism which are described below:

1) Electromagnetic Acceleration

In the electromagnetic acceleration stage, a thrust is produced by accelerating ionized particles in electric field and self- induced magnetic field; the combination of electric and magnetic field is employed to accelerate the propellant [2, 7].

2) Electro thermal Acceleration

In the electro thermal acceleration stage, by gas expansion thrust is produced which is caused by discharge. It occurs nearsurface of propellant where the discharge happens [2].

For the better performance of PPT, its necessary to improve the electromagnetic force and gas expanding force (electro thermal force) because of low thermal acceleration efficiency is caused low thrust efficiency. By Ameliorating, the electro thermal acceleration will improve the thrust efficiency. For the electro thermal acceleration coaxial electrodes and for electromagnetic acceleration parallel plate electrodes are used. To achieve the high efficient PPT which combined the advantages of parallel plate electrodes and coaxial electrodes [2].

6. Advantages

Pulsed Plasma Thruster offers several advantages which are described as below:

- Robust design and flexibility regarding their power consumption level [5].
- Light weight, compactness and robustness compared to other electric propulsion system [4].
- High scalability in terms of geometry, power input and performance and relatively low cost [8].

7. Application

- It is used for station keeping, attitude control of micro,nano and picosatellites, i.e. Cubesat and orbit rising of small aircraft [2, 8].
- Pulsed Plasma Thruster is the first example of electric propulsion which is successfully employed in space with Zond-2(USSR) in 1964 and LES-6(USA) [5, 8].
- It is used in Earth Observing 1 (EO1) spacecraft was launched in 2000 which uses one dual-axis PPT for pitch axis control and momentum management [6].
- It is used in orbit operations like drag compensation, trajectory modification and orbit transfer [6].

8. Conclusion

Pulsed Plasma Thrusters are promising alternatives to any other electric propulsion engine. The advantages of using Pulsed Plasma Thrusters over any other engine is its light weight, compactness and robust design. Currently, Pulsed Plasma Thrusters is visualised as the next generation engine for space craft. This is hope that this review paper provides an overview and highlight of Pulsed Plasma Thrusters.

9. Acknowledgement

The authors would like to thank Prof.Dhaval P Patel and Prof.Sajan Kumar Chourasia (Assist. Prof. at Gandhinagar Institute of Technology) for his valuable suggestions regarding review paper.

10. References

1) Hiroyuki , Koizumi . , Yoko , Kawazoe . , Kimiya , Komurasaki . , Yoshihiro , Arakawa . , 2006 , Effect of solute mixing in the liquid propellant of a pulsed plasma thruster , Vacuum 80(2006) 1234-1238 .

2) Hou , Dali . , Zhao , Wansheng . , Kang Xiaoming . , Wang , Pingyang . , 2008 , Effect of ceramic nozzle on performance of pulsed plasma thruster , Aerospace Science and Technology 12(2008) 573-578 .

3) Akira , Kakami . , Hiroyuki , Koizumi . , Kimiya , Komurasaki . , Yoshihiro , Arakawa . , 2004 , Design and performance of

liquid propellant pulsed plasma thruster , Vacuum 73(2004) 419-425 .

4) Hideto , Mashidori . , Akira , Kakami . , Takanobu , Muranaka . , Takeshi , Tachibana . , 2006 , A coaxial pulsed plasma thruster using chemical propellants , Vacuum 80(2006) 1229-1233 .

5) Anuscheh , Nawaz . , Riccardo , Albertoni . , Monika , Auweter – Kurtz . , 2010 , Thrust efficiency optimization of the pulsed plasma thruster SIMP-LEX , ActaAstronautica 67(2010) 440-448 .

6) Pasquale M. Sforza. , 2017, Space Propulsion, Theory of Aerospace Propulsion (2nd edition), A volume in Aerospace Enginnering.

7)Michael, Keidar. , Isak I. Bells, 2013, Plasma in Space Propulsion, Applications from Space to Bio and Nanotechnology.

8) S.Ciaralli. , M.Coletti . , S.B.Gabriel . , 2015, Performance and lifetime testing of a pulsed plasma thruster for CubeSat. Applications, Aerospace Science and Technology 47(2015) 291-298.

9) L.A.Lifschitz . , C.E.D'Attellis . , 2003 , Input Force Reconstruction Using Wavelets with Applications to a Pulsed Plasma Thruster , Mathematical and Computer Modelling 41(2005) 361-369 .

10) C.Charles . , R.W.Boswell . , P.Alexander . , C.Costa . , O.Sutherland . , L.Pfitzner . ,R.Franzen . , J.Kingwell . , A.Parfitt . , P.E.Frigot . , J.Gonzalez del Amo . , E.Gengembre . , G.Saccoccia . , R.Walker . , 2006 , Helicon Double Layer Thrusters , American Institute of Aeronautics and Astronautics 2006-4838 .

11) Claude R. Phipps . , James R. Luke . , 2003, Advantages of a ns-pulse micro-Laser Plasma Thruster, American Institute of Physics .