Effect of Propellant Geometry on Electrical Breakdown in a Pulsed Plasma Thruster

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Abstract This paper presents a brief on the effect of propellant geometry in a pulsed plasma thrusters. The propellant being used is Teflon(PTFE) which has a varied characteristics at vaccum conditions at different energy densities. The study is highlighted on the effect of varied voltages imposed on the thruster for better efficiency. At a certain point the thrusters starts to arc in an irregular manner which led to this study. This paper mainly related to the breakdown voltage and the paschen curve of the teflon.

Keywords : Pulsed Plasma Thruster(PPT), Paschens' curve, Thruster, Plasma, Propulsion, Auger effect.

Introduction

Pulsed plasma thruster is a type of spacecraft propulsion also known as Plasma Jet Engines in general. Plasma thrusters use an arc of electric current adjacent to a solid propellant, to produce a quick and repeatable burst of impulse. PPTs are excellent for attitude control, and for main propulsion particularly small spacecraft with a surplus of electricity (those in the hundred-kilogram or less category). However they are also one of the least efficient electric propulsion systems, with a thrust efficiency of less than 10%. An important factor that depends on the pulsed plasma thrusters is the energy applied to ionize the propellant. The propellant behaves in different fashion at different energy levels also dependable on the geometry of the teflon. This behaviour is charecterized by the paschens curve named after the F. Pashchen.

Paschens law

The law essentially states that, at higher pressures the breakdown characteristics of a gap are a function of the product of the gas pressure and the gap length, usually written as V= f(*pd*),where *p* is the pressure and *d* is the gap distance

Paschen's Law reflects the Townsend breakdown mechanism in gases, i.e, a cascading of secondary electrons emitted by collisions in the gap. The significant parameter is pd, the product of the gap distance and the pressure. Typically, the Townsend mechanism apply at pd products less than 1000 torr cm, or gaps around a centimeter at 1atm. Furthermore, some modifications are necessary for highly electronegative gases because they recombine the secondary electrons very quickly.

Primary factors: Electric field strength is the primary factor .In general high voltage breakdown is most likely to occur where the electric field is highest, but this depends on: Materials and gasses :Pressures ,Temperatures ,Surfaces , magnetic field, stray beams, charges, photons

The origin of electric currents in a gas is from the electrons and positive ions produced at the time of ionization of neutral gas atoms, which move under the influence of an external electric field. This kind of field gives the charge carriers a drift velocity so that a uniform current can persist between the two electrodes. As the electrons are lighter in mass when compared to the ions, they have very large average kinetic energies and are mainly responsible for ionization of atoms. Under the electric field, the electrons drift toward the anode (+ electrode) and the ions drift toward the cathode (- electrode).

Breakdown in a gas system is mainly caused by two important processes namely Ionization and Secondary electron generation.

Ionizing of the propellant: when the ionization energy of an electron is lesser than the energy of the incoming electron in a gas molecule, that electron will be imparted with an energy that separates itself from the molecule resulting in the formation of a positive molecular ion.

Electron generation: defined by the *Auger effect.* If the energy released from the recombination of a positive ion and an electron from the cathode exceeds the work function of an electron in the conduction band of the cathode, which is defined as the energy difference between the vacuum and the electron band, then this electron will be ionized out of the cathode. Thus electrical breakdown occurs once this condition is met , additional charge carriers are generated.

There are two types of breakdowns that can occur at vaccum conditions :
Global breakdown and local breakdown
Global Breakdown occurs when there is a Complete rupture or failure of the insulation between two electrodes. This type of breakdown is less encountered as the major insulations are always checked before firing stars. Global break down can only occur when a highly conductive channel is formed between the two electrodes.
Local Breakdown takes place when there is a Partial breakdown of part of the insulation between two electrodes. Local breakdowns are common as the insulators might crack due to higher temperatures or voltages and can go undetected. sometimes insulating with Teflon tapes might lead to small air gaps or improper covering between the electrodes resulting in local breakdown.
The journey towards high voltage breakdown depends on the degree of non uniformarity of the electric field. Geometry of electrodes and materials and environment all play a critical role .

Equation for breakdown is given by fitting to empirical data.

Here are three equations:

Breakdown voltage

$$V_{\text{breakdown}} = B * p * d / (C + \ln(p * d) \qquad (1)$$

Where

$B = 365\ \text{Vcm}^{-1}\ \text{Torr}^{-1}$

$C = 1.18$

Breakdown field strength:

$$E_{\text{breakdown}} = p * (B / (C + \ln (p * d))) \qquad (2)$$

where:

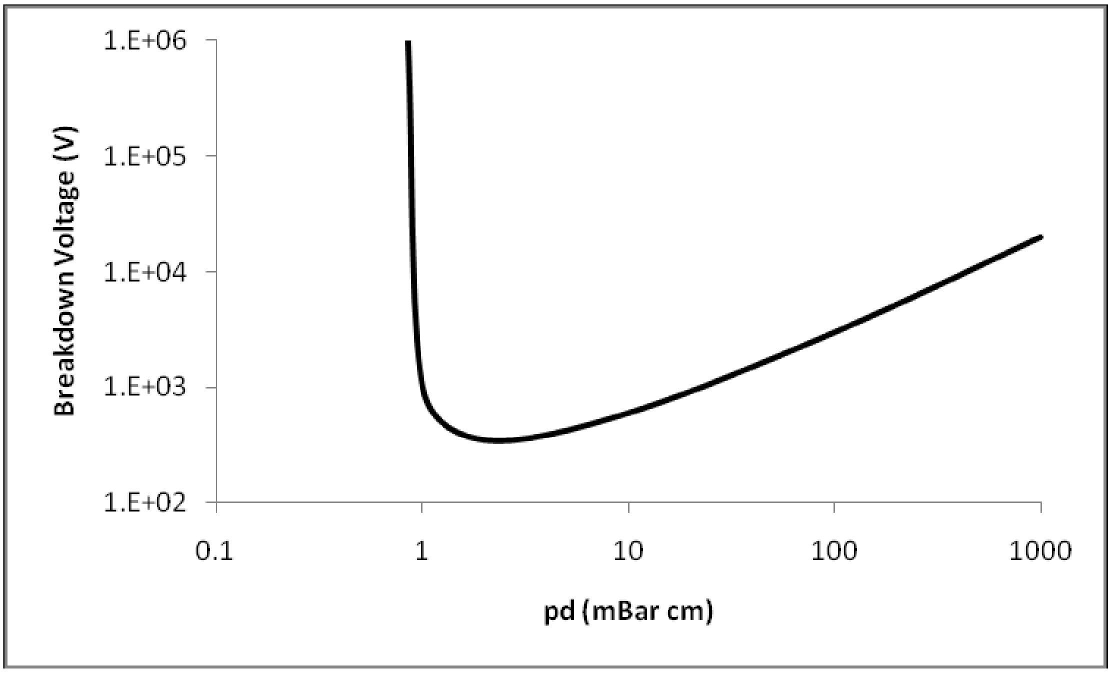
$C = \ln(A / \ln (1 + 1 / \text{gamma}))$

$A = 15\ \text{cm}^{-1}\text{Torr}^{-1}$

$\text{gamma} = 10^{-2}$

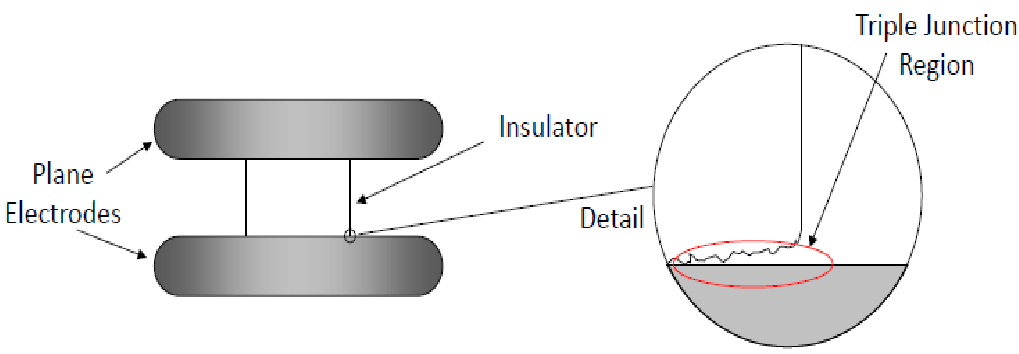
Where gamma is the (poorly known) secondary ionization coefficient

In the experiment conducted, we perform a simple investigation on the electrical breakdown of a system of air molecules between two *parallel* electrode plates of distance *d* between them and keeping the pressure constant.
Corona discharge is an important factor which is to be kept in mind, where sharp edges are highly vulnerable to arcing , hence it is necessary to avoid sharp edges in the electrodes.
In order to avoid *corona discharge* parallel plate electrodes without sharp edges were used to avoid accumulation of charges on cornered surfaces that can cause high potential gradients around them.
The value of pd plays important role in the extraction process of ions
A typical voltage which is needed to sustain the discharge depends upon the type of gas and the pressure used in the chamber and as it can be seen in Figure the typical breakdown voltage is at the order of hundreds of volts.



However, there is drastic increase at low pressures. Analysis for the low pressures gives the approximate values. One of the very important sightings also explained by paschen was that longer gaps had higher breakdown voltages.

Another important thing that was noted is that the triple junction which is always present at the tip of electrodes and also contributed to the electrical breakdown .



These triple junctions are very rarely noticed as it can be present at very minute dimensions. These triple junctions are always present but contribute in electrical breakdown only when these junctions are present at bigger dimension.

Results and Conclusion

The experiments were conducted conducted for a range of Teflon length from 10mm to 40 mm, and the voltage varied from 1500 to 2000 Volts.for lengths 10mm, 20mm, 30mm there was no electrical breakdown at any range of voltages but at 40mm length there was electrical breakdown at voltages upto 2200 Volts.when the voltage is increased to 2300 Volts the thrusters was giving results as before. This shows that breakdown voltage is high for longer distances . Theoretically from equation (1) the breakdown voltage also increases with increase in gap between the electrodes, hence directly proportional to pressure and distance between the electrodes. Finally the major focus of this paper was to show that voltage applied to the pulsed plasma thrusters in order to ionize the Teflon varies with the changing dimensions hence higher energy densities are required . Teflon being used as a propellant in PPT's will require varied energy levels for longer life leading to a better power processing unit and capacitor banks.

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