Plasma Focus Thruster

Executive Summary Report

Contract nº.: 4000129618

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Acronyms and Abbreviations

DPF	Dense Plasma Focus
EM	Engineering Model
EMC	ElectroMagnetic Compatibility
EPS	Electric Propulsive System
FR	Fire Retardant
HET	Hall Effect Thruster
KO	Kick-Off
OMN	Omnidea Ltd.
PDS	Position Detection Sensor
PFM	Proto Flight Model
PFT	Plasma Focus Thruster
PPT	Pulsed Plasma Thruster
QM	Qualification Model
TAM	Total Available Market
TVAC	Thermal-VAcuum Cycling test
USA	United States of America

I_{SP}	Specific Impulse
I_{BIT}	Impulse Bit
η	Propulsive Efficiency

Reference Documents

[RD 1] Schönherr et al, "Coaxial Air-Fed Pulsed Plasma Thruster Research and Development for RAM-EP Application. ", 2018

[RD 2] M. Krishnan, "The Dense Plasma Focus: A Versatile Dense Pinch for Diverse Applications," in IEEE Transactions on Plasma Science, vol. 40, no. 12, pp. 3189-3221, Dec. 2012, doi: 10.1109/TPS.2012.2222676.

1 Introduction

The Plasma Focus Thruster activity was developed under the GSTP contract no. 4000129618 by Omnidea, Ltd. The TRL of the technology was increased from 2 to 3.

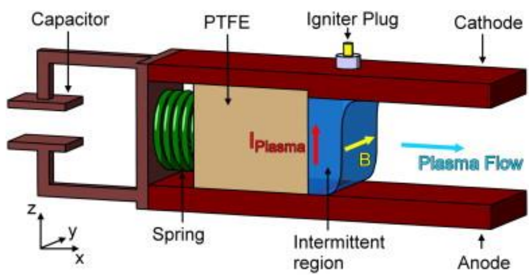
In recent years, the number of launched small satellites has exponentially increased. As small satellites market expands, electric propulsion systems became one of the most used technology. Among electric thrusters, PPTs are one of the simplest and have a long heritage in space applications. This technology is mainly used for orbit maintenance and satellite attitude control. This project aimed the development of an innovate discharge chamber configuration, that will increase the specific impulse and electric efficiency. The new configuration is based on Dense Plasma Focus (DPF) technology. So far, the main uses of this technology have been nuclear applications and X-ray and neutron source. Plasma Focus Thruster is the name given to the new electric discharge chamber configuration proposed.

The main objective of this project was to demonstrate the feasibility of a proposed concept solution of a Plasma Focus Thruster (PFT) by designing, manufacturing and testing a breadboard model. This simple Electric Propulsion System (EPS) is aimed to surpass the current design solutions and to answer the needs of the increasing demand for propulsion systems of small satellites (e.g., CubeSats). By the end of the project, the occurance of the magnetic pinch effect, using much lower energies than current technologies, in vaccum, was achieved. When this pinch effect is achieved, a strong magnetic field goes into the anode's central hole which will further accelerate the ions to higher exhaust velocities compared to typical PPTs.

2 PPT and DPF devices

A Pulsed Plasma Thruster (PPT) is a propulsion system that uses electrothermal and electromagnetic acceleration to generate thrust. Two configurations are in use.

Plate Electrodes PPT (PE-PPT) generate thrust by accelerating ions with an electrical potential between the parallel plates. The other PPT configuration, the coaxial one have far less flight heritage than the PE-PPTs.



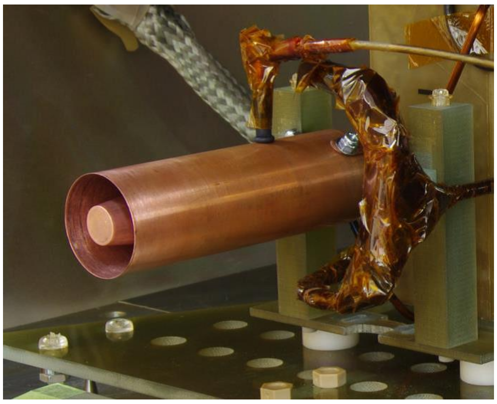


Figure 1 – Left, Plate electrodes PPT system. [RD 2]. Right, Coaxial configuration PPT [RD 1]

Table 1 - PPT advantages, disadvantages and usages.

Advantages	Disadvantages	Usages
• simplicity of their components • low cost	• low efficiency • low specific impulse	• altitude control • fine pointing applications • drag compensation in low orbits • small orbit transfers

DPF is one of the existing technologies for plasma generation and acceleration. The discharge process of a DPF can be divided in 3 phases: initiation, axial rundown, and radial implosion, as shown in Figure 2.

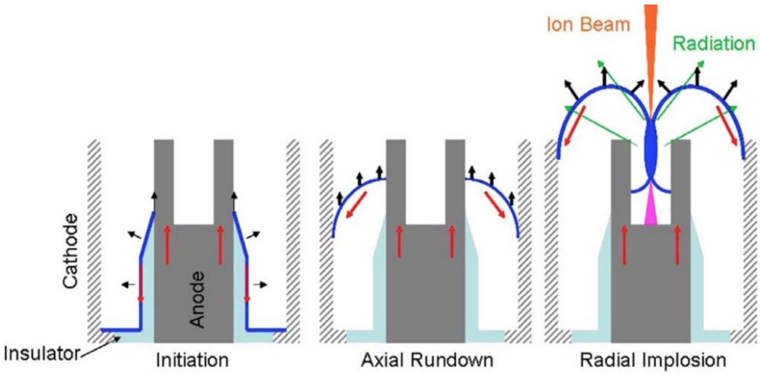


Figure 2 - DPF discharge procedure: initiation, axial rundown and radial implosion [RD 2].

Advantages of DPF devices:

- ecologically clean (when compared to other types of radiation sources)
- simplicity associated to the construction and maintenance
- cost effectiveness.

3 Achievements and Status

The development process was divided into four main parts:

- Current technologies were assessed
- A design for the breadboard was devised
- The breadboard was manufactured and a test setup was prepared
- Testing was conducted according to the test plan and results were analysed.

Omnidea Ltd. proposed design solution, consisted of a hybrid solution which merges the design of a coaxial PPT and a DPF. This solution intended to keep the main advantages of a PPT (simplicity, reliance, low power, and low cost), while including the most distinguishing feature of a DPF device, the magnetic pinch effect. The combination of these two technologies is expected to generate very high specific impulse values, while keeping low power consumption and compactness.

The current performance parameters of the thrusters available on the market (Table 2) were considered as a guideline.

Table 2 - PFT draft requirements, considering the performance of the current market solutions.

Parameter	PFT
Impulse bit	>100 µNs
Specific impulse	>800 s
Propulsive efficiency	>5%
Volume	<1U[1]
Mass	<1.3 kg[2]

[1] 1U = CubeSat structural unit (10 x 10 x 10 cm).
[2] Including electronics

A schematic of the developed solution, including other subsystems, is displayed in Figure 3 and some of its characteristics are presented in Table 3.

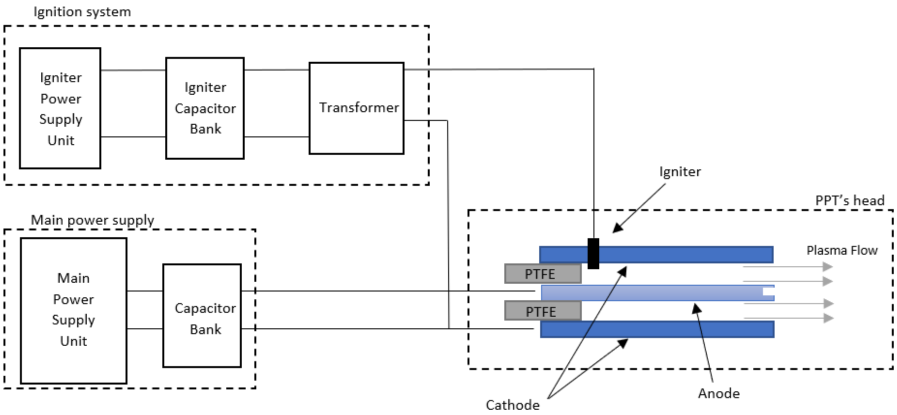


Figure 3 – Breadboard design solution schematic representation.

Table 3 - PFT target specifications.

Parameter	PFT
Design	Coaxial
Propellant	(solid) PTFE
Energy	<5.7 J
Electrodes	Copper/Tungsten alloy

From the data analysis assuming a constant mass-bit, the performance parameters were determined and compared with commercially available systems (Table 4).

Table 4 - PFT performance values.

	Average	Maximum	Reference
I_{SP} (s)	502	1004	800
I_{BIT} (μNs)	2.3	4.6	100
η	0.3%	1.0%	5.0%

4 Important Achievements

- Strong evidence was obtained that the pinch effect has indeed occurred, but not in all pulses. Pinch was observed by using long exposure photographs, where a visible glow of a magnetic pinch was observed at the anode's centre hole.
- The erosion pattern on the electrodes constitutes further evidence of such effect.
- I_{SP} values were, in some pulses, in the order of 1000 s, which is higher than typical PPTs in the market (around 800 s) which also supports this effect occurrence.
- According to the references in literature describing z-pinch in similar systems, the required energy to obtain the effect are significantly higher (at least 100 J), when compared to the supplied energy in the developed design (<5 J).

Effective pulse energy could not be achieved due to two main factors:

- The full energy intended for the tests could not be achieved due to failure of some of the capacitors
- The fact that ablation occurred only in a limited area of the propellant (~20%).

The tests results shown that plasma acceleration by magnetic pinch is indeed feasible using relatively lower energies, as long as the discharge time is kept in the order of a few hundred nanoseconds. All indicates that, with a more reliable capacitor bank construction, higher instant pulse power and homogeneous discharge, this architecture will be able to achieve a higher energy efficiency and higher I_{SP} than the existing PPT systems.

5 Benefits

Highlights of PFT product are:

- high specific impulse values
- low power consumption
- compactness.

6 Next Steps

Due to the successful results obtained during the project, Omnidea Ltd. proposed a follow-on activity with 2 years duration. The goals of this activity are to built and test an EM aligning its technical requirements to the needs of the market regarding propulsion, and achieve TRL5.

Further developments are to be pursued (QM and PFM development) pending on the success of the EM development.

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