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Alta FT-150: The Thruster for LISA Pathfinder and LISA/NGO Missions

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Abstract.
FT-150© FEEP thruster has successfully completed an endurance test at Alta's Micropropulsion laboratory. The updated thruster design dramatically enhances performance with respect to previous FEEP devices and marks a major step forward in the LISA Pathfinder and NGO programmes as well as space propulsion capability in general. The test campaign took place in two parts. Firstly, the new design was tested to validate that the new configuration was compliant with the requirements of the Lisa Pathfinder mission with particular emphasis on the achievement of required total impulse and minimum and maximum thrust levels.The second part of the campaign was aimed at testing a worst-case DFACS profile of the LISA Pathfinder mission using the Elegant Breadboard Power Control Unit (EBB PCU) commanding at 10 Hz and acquiring at 50 Hz. Both purposes of the campaign were successfully met. A total impulse of more than 1080 Ns and a firing time of more than 3500 hours were achieved. No degradation of efficiency and performance was recorded over the entire test. During the first part, more then 600 Ns of total impulse and about 2000 hours of firing time were achieved. Different thrust profiles were commanded with an average thrust of about 87 μN. The minimum and maximum thrust were 1 μN and 150 μN respectively. Short periods at zero N (i.e. thruster switched-off) were also commanded. The measured mass efficiency and specific impulse, 60% and 8000 s respectively, demonstrated that the current design of the thruster is fully compatible with the much larger impulse requirement of LISA mission. The simulation of the worst-case DFACS cycles at 10 Hz was also successfully performed. Three different DFACS cycles representative of the worst cases were performed. These cycles highlighted one of the main advantages of this technology: the controllability and response time that can be verified immediately with electrical feedback parameters like total voltage and beam current (data collected at 50 Hz during the test). The thrust noise was also calculated from electrical parameters, filtered to obtain flawless acquisition at 50 Hz. The article provides a view of the thruster configuration, vacuum facility and test set-up, the electrical parameters of the thruster, the main parameters recorded by the diagnostic system and the details of the behavior of the TA-PCU system during the performance of the worst DFACS profile of the LISA Pathfinder mission.

1. Introduction

FT-150© FEEP thruster is designed for extremely fine position and attitude control applications. It generates thrust by ejecting Cesium ions at about 100 km/s of speed with a very low noise level. The ions are extracted from the emitter tip and accelerated by the strong electric field created by an electrode placed in front of the emitting slit. The total voltage applied to the

electrodes is between 7 kV and 13 kV. The propellant is fed from the reservoir to the emitter by capillarity alone.

1.1. Main elements of the thruster

The thruster is made of the following sub-assembly equipment and parts:

- the Thruster Unit (TU), made of the electrodes and electric insulator. This is the core of the thruster where the thrust is generated. It is designed by Alta;
- the propellant reservoir (Tank Assembly), where propellant is kept sealed during on-ground and launch phases. It is designed and supplied by Astrium France;
- the Lid Opening Mechanism (LOM), that provides a protective functions to the Thruster Unit during storage, integration and launch. It is designed and supplied by RUAG;
- the Heater Assembly (HA), attached to the Tank Assembly surface, providing the thermal power required to break the disc of the propellant reservoir, to activate the thruster (i.e. priming procedure) and maintain it at operational temperature. It is designed by Alta.

Figure 1 shows the Thruster Assembly integrated in the connector bay.

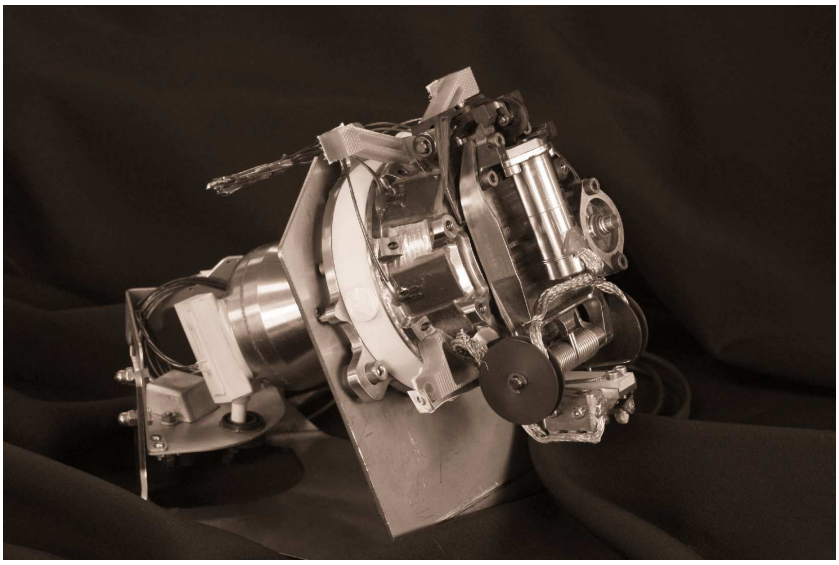

Figure 1. FT-150© FEEP Thruster Assembly

2. The endurance test

2.1. Test article

The test article was composed by:

- the truster unit, fully representative of the flight model in terms of performance and functionality. The electrostatic head was identical to the flight model while the LOM was fully representative of the flight model in terms of electrostatic and mechanical functionality (just the lid was not present);
- the propellant reservoir, composed by a glass feeding system that allows to maintain a maximum hydrostatic pressure of 2 mbar on the emitter tip.

2.2. Facility and set-up

The thruster was integrated in the vacuum facility (namely LFF). An aluminum honeycomb target was placed in front of the thruster to entrap the ions of the beam and reduce the back-flown. Thruster was installed on the mounting plate of a beam diagnostic system in order to perform beam scanning to determine the plume density profile. The system consists of two rotary single filament probes to measure the shape of the plume in both in-plane and out-of-plane directions. Two Quartz Crystal Microbalances (QCM) were installed close to the thruster to measure the contamination. One QCM was placed in order to have the collecting surface towards the target (firing direction) to collect the metallic back sputtering due to ions impingement on the target or the chamber walls while the other QCM was placed in order to have the collecting surface facing the back side of the facility to be shielded by metallic back sputtering and only collect vapors of cesium reaching the thruster.

2.3. Thrust profile

The first part of the test was performed using a laboratory power supply in order to validate the compliance of the design with the requirements of the LISA Pathfinder mission and, in particular, to achieve the required total impulse and minimum and maximum thrust levels without degradation of the performance over time. After the priming and stabilization, the thruster was commanded at constant thrust 100 μN up to the achievement of 230 Ns of total impulse, then slow-rate cycles in the range of 80-100 μN were completed up to the achievement of 418 Ns of total impulse. Finally, thrust profile of the previous TAPT#2 (ref. Ceccanti et al. (2009)) endurance test was commanded up to 603 Ns. The second part was performed connecting the thruster to the Elegant Breadboard Power Control Unit (EBB PCU), provided by Selex Galileo, in order to test a worst-case DFACS profile in terms of maximum thrust and thrust variation within 100 ms, as well as to measure the thrust noise with the available electrical parameters. The thruster was commanded at 10 Hz and the telemetry was acquired at 50 Hz by using a dedicated set-up. The third part of the test was performed always with the thruster driven by the EBB PCU setting the thrust at different levels in order to record the electrical parameters and extrapolate the thrust noise and time response. This characterization was performed at 100, 70, 40, 20, 10, 4, 2, e 1 μN of thrust levels. The emitter voltage was then set at 11.5 kV in the fourth and last part of the test. This allowed to record the stability of the thruster at maximum power level of the EBB PCU, to measure the maximum thrust achievable by the thruster at this level and evaluate the status at the end of test.

2.4. Main results

Total Impulse. The main result of the test was the achievement of 1084 Ns of total impulse and 3515 hours of firing with no degradation of performance and efficiency[1].

Mass Efficiency and Specific Impulse. Mass efficiency and average specific impulse were 60% and more than 8000 s.

DFACS profile. Plot of figure 2 shows the thrust response of the thruster to the DFACS science mode command. The thruster was commanded at 10 Hz and the telemetry was acquired at 50 Hz

Thrust noise. Thrust noise was calculated from the recorded electrical parameters and filtered to obtain flawless acquisition at 50 Hz. It was below 0,05 μN/$\sqrt{}$Hz at 100, 70, 40, 20, 10, 4, 2, and 1 μN of thrust levels.

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[1]Note that test was voluntarily interrupted due to the needs of the vacuum chamber availability for a further endurance test

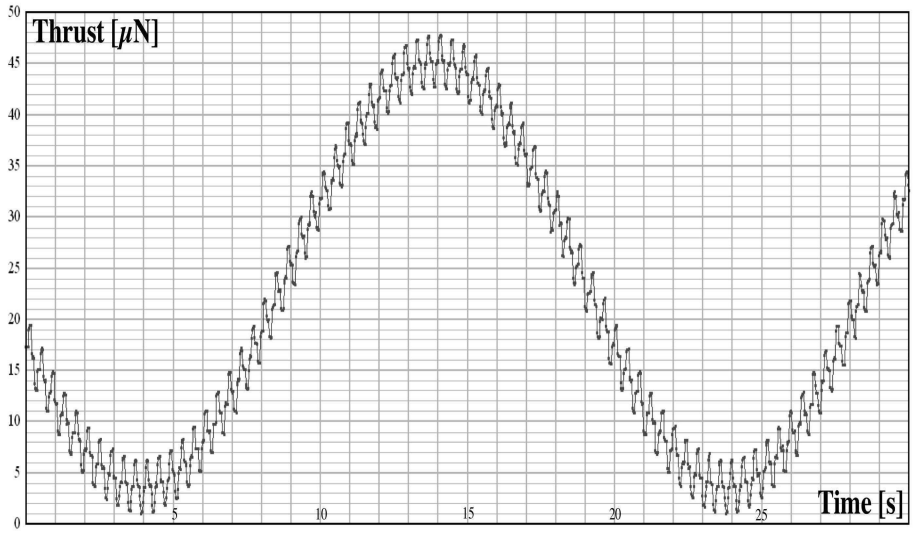

Figure 2. DFACS science mode profile

Response time. The acquisition at 50 Hz allowed to measure the response time of the thruster. Table 1 provides the response time at different thrust jump.

Thrust Jump	Time Response
From 1 to 31 μN	< 160 ms
From 31 to 61 μN	< 80 ms
From 61 to 100 μN	< 60 ms

Table 1. Response time at different thrust jump

Minimum and maximum thrust. The minimum thrust was set at 1 μN. The maximum thrust reached at the end of life was 390 μN with the emitter voltage set at 11.5 kV and the accelerator voltage set at 1.7 kV.

3. Summary and conclusion

Table 2 provides the characteristics of the FT-150© FEEP Microthruster. The performance of the FEEP thruster highlighted one of the main advantages of this technology in general and of the FT-150© FEEP Microthruster in particular such as the controllability, response time and thrust noise that can be verified immediately with electrical feedback parameters, like total voltage and beam current.

References

Ceccanti, L., Paita, L., Cesari, U., De Tata, M., Giusti, N., Balducci, P., Del Pistoia, M., Nicolini, D., & Di Napoli, L. 2009, 3200 hours Endurance Testing of the Lisa Pathfinder FT-150 Thruster, Paper, IEPC, University of Michigan, USA

Characteristic	**Value**	**Remarks**
Power	6 W	Operative condition @ 100 μN of thrust
Total Impulse	> 6000 Ns (design)	1100 Ns demonstrated by Endurance Test
Mass efficiency	60%	Measured during Endurance test
Specific Impulse	> 8000 s	Average Isp measured during Endurance test
Thrust noise	< 0,05 N/ $\sqrt{}$Hz	Calculated by electrical parameters recorded at 50 Hz at the following thrust levels:100, 70, 40, 20, 10, 4, 2, and 1 μN of thrust levels
Time response	< 160 ms < 80 ms < 60 ms	From 1 to 31 μN From 31 to 61 μN From 61 to 100 μN
Minimum thrust	1 μN	Several switch-off during the test
Maximum thrust	390 μN	At 13.2 kV of total voltage
Thrust Accuracy	below 100 nN	50 nN is the digital resolution of the Power Control Unit

Table 2. Main achievements of the endurance test and thruster characteristics