Progress in Testing of QM and FM HEMP Thruster Modules

IEPC-2013-274

Presented at the 33rd International Electric Propulsion Conference,
The George Washington University • Washington, D.C. • USA
October 6 – 10, 2013

A. Lazurenko[1], A. Genovese[2], B. van Reijen[3], J. Haderspeck[4], S. Weis[5], and P. Holtmann[6]
Thales Electronic Systems GmbH, Ulm, 89077, Germany

M. Schirra[7]
Kempten University of Applied Sciences

K. Ruf[8] and N. Püttmann[9]
Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR) - Raumfahrtmanagement, Bonn, 53227, Germany

Abstract: Thales Electronic Systems GmbH develops and qualifies an electric propulsion system based on the High Efficiency Multistage Plasma Thruster (HEMPT). The HEMPT Assembly is being developed under the HEMPTIS DLR contract. It shall be used in the frame of the ESA (SGEO) program, the platform developed by OHB System AG for the Hispasat AG1 mission. Four HTM Flight Models (FM) and one HTM Qualification Model (QM) were characterized for initial performance according to the acceptance/qualification program by now. These tests included a HTM long-time operation at the nominal operation point (>4 h @1000V, 1.38A), a characterization in the range of anode voltages 850..1050V and anode currents 0.3..1.45A, three nominal operation pulses (with typical mission firing duration of 40 min each) at different HTM interface temperatures, as well as the plasma beam characterization. The HTM FMs and HTM QM comply with the requirements, operated stable in the whole range of voltages and currents and have low performance variation. In particular, the thrust was ≥44 mN and the total specific impulse >2400s. Beam characterization confirmed the compliance to the requirements on the plasma beam sputtering ability. The HTMs demonstrated a stable and reproducible ignition of neutralizer and thruster.

Nomenclature

EP	= *Electric Propulsion*
FCU	= *Flow-Control Unit*
FM	= *Flight Model*
HTA	= *HEMP Thruster Assembly*
HTM	= *HEMP Thruster Module*
HV	= *High Voltage*

[1] Testing Manager, Plasma Devices, alexey.lazurenko@thalesgroup.com, corresponding author
[2] Testing Engineer, Plasma Devices, angelo.genovese@thalesgroup.com.
[3] Components R&D Manager, Plasma Devices, benjamin.reijen@thalesgroup.com.
[4] System Engineer, Plasma Devices, jens.haderspeck@thalesgroup.com.
[5] System Engineering Manager, Plasma Devices, stefan.weis@thalesgroup.com.
[6] Program Manager R&D, Plasma Devices, peter.holtmann@thalesgroup.com.
[7] Professor for Physics and Electrical Engineering, martin.schirra@fh-kempten.de
[8] Project Manager, Technik für RF-Systeme und Robotik, klaus.ruf@dlr.de.
[9] Head Systems for Satellites, Technik für RF-Systeme und Robotik, norbert.puettmann@dlr.de.

I_a	=	*anode current*
I_{sp}	=	*specific impulse*
IF	=	*Interface*
MMS	=	*Mechanical Mounting Structure*
NTR	=	*Neutralizer*
PSCU	=	*Power Supply and Control Unit*
QM	=	*Qualification Model*
RPA	=	*Retarding Potential Analyzer*
THR	=	*Thruster*
TRP	=	*Temperature Reference Point*
U_a	=	*anode voltage*

I. Introduction

THALES Electronic Systems GmbH (TES, former TED) develops and qualifies an electric propulsion (EP) system based on the High Efficiency Multistage Plasma Thruster (HEMPT) [1]. The HEMPT Assembly (HTA) is being developed under the HEMPTIS DLR contract in the frame of the Small Geostationary Satellite (SGEO) program, the platform developed by OHB System for the Hispasat AG1 mission.[2]. TES will deliver to the customer one HTA consisting of four flight (FM) HEMPT thruster modules (HTM) and one power supply and control unit (PSCU-PFM from Astrium). The acceptance test sequence, prior delivery, includes performance, mechanical, thermal-vacuum and end-to-end tests. Additionally, two HTM qualification models (QM) and one PSCU engineering-qualification model will undergo the qualification test sequence and then the lifetime test. By August 2013, four HTM FMs and one HTM QM were performance characterized at Thales vacuum test facility ULAN. First results are reported here.

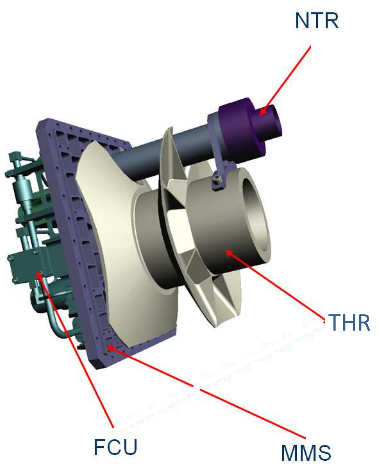

Figure 1. View of HTM.

II. Test Set-Up

A. Test Article: HTM

The HTM consists of the HEMP thruster (THR), of the hollow cathode-neutralizer of HCN500 type (NTR), of the flow control unit (FCU), of the electrical connector bracket assembly and of the mechanical mounting interface structure (MMS), on which all components are mounted (Fig. 1) [3]. The key element of the FCU is the proportional valve, situated just before the THR gas inlet. It operates in the closed loop mode with the anode current sensor (sensor is implemented at the PSCU) in order to sustain a constant anode current. NTR operates with a keeper discharge during the HTM nominal operation.

B. Test facility and test configuration

All vacuum tests of HTMs are performed at Thales' ULAN test facility in Ulm, Germany [4]. The facility has a vacuum chamber of 4 m length and 2.4 m diameter. The facility is equipped with a cryopump system, and additionally with two turbo pumps. The HTM is installed on top of the thrust balance. The facility is equipped with the retarding potential analyzer (RPA) for plasma beam diagnostics. The thrust balance is installed onto a rotational table, thus allowing a scanning of ion beam with the unmovable RPA.

For testing purposes the HTMs are mounted onto the testing frame, which allows for thermal control of the HTM mounting interface (I/F). The FCU is covered with MLI foil during the testing. The THR and NTR are surrounded with a thermal shroud during all in-vacuum tests. The thermal shroud provides

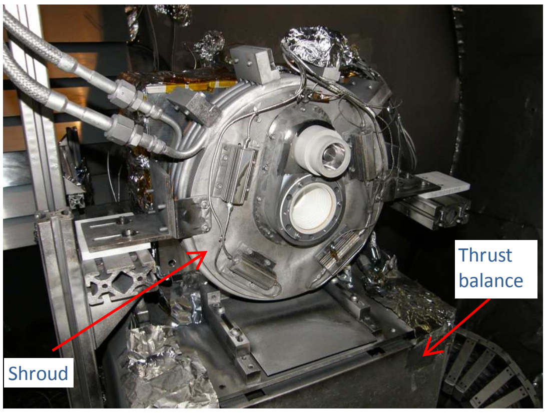

Figure 2. HTM FM1 on the thrust balance in the ULAN vacuum chamber.

a definite radiation environment: shroud can be cooled down by liquid nitrogen, maintained at ambient temperature or heated up; it also protects the optical properties of the THR radiator (Fig. 2).

The HTMs are provided with several temperature sensors during all in-vacuum tests.

The HTMs are powered with laboratory power supplies: the anode high-voltage (HV, 1000V) power supply, the NTR keeper power supply (0..50V dc) and the NTR heater power supply (0..15V ac). The HTM FCU is controlled by the FCU Driver, which simulates the FCU controlling function of the PSCU. Xe gas is fed by the facility gas supply system at a constant pressure. Xe of purity 4.0 is used. Schematically the test set-up is explained in Fig. 3.

The HTMs are operated in the floating cathode configuration throughout the tests.

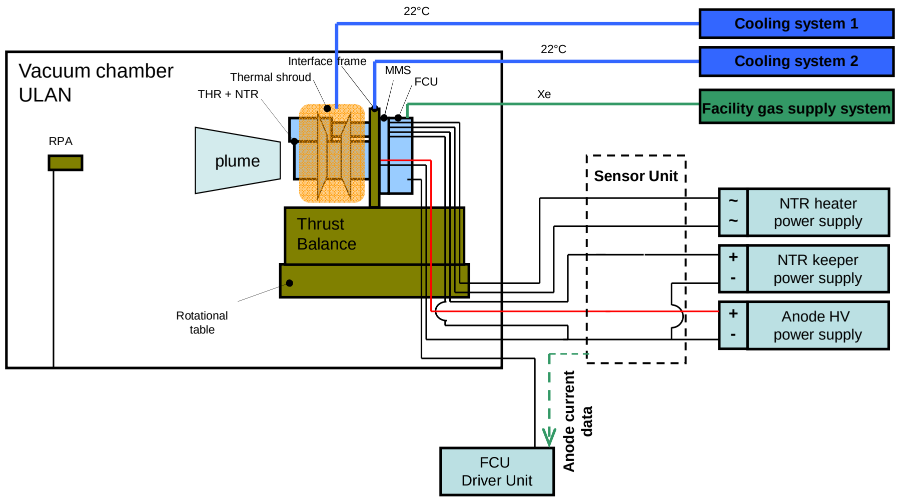

Figure 3. Test set-up (ULAN vacuum chamber).

III. Test Results

A. Test Program

HTM-FMs and HTM-QMs are tested according to the acceptance / qualification program, correspondingly. The two test programs differ in temperature conditions of the HTM I/F (during all in vacuum tests), in temperature conditions of the thermal shroud and in number of environmental cycles (during the thermal-vacuum test), in imposed mechanical loads (at the mechanical tests). Temperature conditions and mechanical loads for the HTM-QMs are more severe. Moreover, the HTM FMs will perform the end-to-end test, and the HTM QMs will perform the lifetime test. By August 2013 an initial performance characterization of the HTM-FM1 to FM4 and of the HTM-QM1 was carried out. It included:

- HTM operation over 4 hours at the nominal SGEO operational point U_a = 1000 V, I_a = 1.38 A, at ambient shroud temperature and ambient I/F temperature (+22°C);
- HTM operation in the extended range of parameters: U_a = 850 .. 1050 V, I_a = 0.3 .. 1.45 A, at ambient shroud temperature and ambient I/F temperature;
- HTM beam characterization at the nominal operational point;
- HTM thrust pulses of 40 min THR firing duration, at the nominal operational point U_a = 1000 V, I_a = 1.38 A, at ambient shroud temperature and ambient I/F temperature; moreover, two HTM FMs and the HTM QM were also pulsed at “cold” (< -10°C) and hot (> +60°C) I/F temperatures.

Thrust measurements were performed during the 40 min thrust pulses.

B. HTM operation during 4 hours

HTM continuous firing over 4 hours at the nominal operational point demonstrates the capabilities of each HTM-FM and HTM-QM for long-duration thrust pulses, which are far outside the nominal thrust pulse duration. HTMs attained a thermal equilibrium state at the end of 4 hours firing with the THR TRP change rate below 2 K/h. All HTM temperatures were within their expected limits.

C. HTM operation in the extended range of parameters

Each HTM was operated under eight extended operational modes, 5 min for each operational mode. Each of the extended modes was obtained by combining a value of anode voltage from the range 850 .. 1050 V and a value of anode current from the range 0.3 .. 1.45 A, with the maximum anode power limited to 1.45 kW. The HTMs performed stable without anomalies during all eight extended operational modes. Thus, all HTM FMs and the HTM-QM1 have demonstrated the capability to operate continuously under non-nominal anode voltages and non-nominal anode currents without degradation. It is worth to mention here that the prolonged operation at the most severe extended mode with 1.45 kW anode power was verified with the HTM engineering qualification model, and will be verified with each HTM at the upcoming thermal-vacuum test.

D. HTM beam characterization

The ion beam of each HTM was characterized in terms of ion current density and ion energy (potential) at approx. 1 m from the thruster exit at the nominal operational point. This characterization was performed in the horizontal plane of THR. Ion current and energy were input data for an ion sputtering analysis with the SGEO satellite configuration. Each HTM was found to comply with the SGEO sputtering requirements.

E. Thrust pulses

The HTMs performed a fully representative thrust pulse - operational sequence as applied to the SGEO mission, including a HTM start-up, operation and a shut-down. This sequence was carried-out with all HTMs under I/F and shroud ambient temperatures (+22°C). HTM-FM1, HTM-FM2 and HTM-QM1 have additionally performed two thrust pulses at “cold” (<-10°C) and “hot” (>+60°C) I/F temperatures, in order to verify the operation of the FCU at two temperature limits and to obtain thermal data prior thermal-vacuum testing.

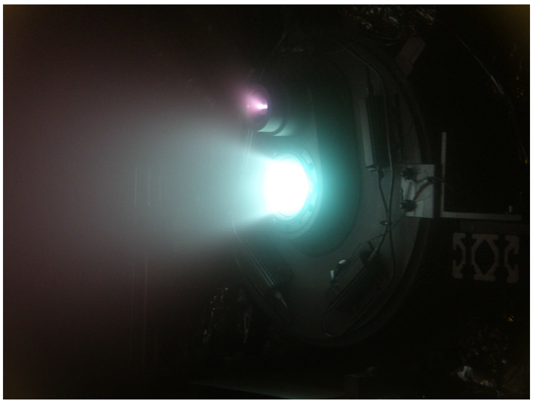

Figure 4. HTM-QM1 operation in the ULAN vacuum chamber.

The HTM FMs and HTM-QM1 performed the start-up sequences at all I/F temperatures without anomalies. NTR and THR ignited reliably. NTR and THR ignition times were in the expected limits; they are highly reproducible within 4 s between different thrust pulses and from one HTM to another.

THR operated stable at U_a = 1000 V, I_a = 1.38 A, with a low cathode-to-ground voltage < │-15V│ (Fig. 4).

Thrust was measured at the end of each pulse.

All HTM FMs and HTM QM have very close values of thrust ≥44 mN, providing more than 2400 s of total specific impulse (with the requirement >2300 s) at 1.4 kW electrical power (THR+NTR), see Table 1.

Parameter	HTM FM1			HTM FM2			HTM FM3	HTM FM4	HTM QM1		
HTM I/F temp. case	amb.	cold	hot	amb.	cold	hot	amb.	amb.	amb.	cold	hot
Thrust, mN	44.5	44.5	44.6	44.1	44.1	44.1	44.3	44.1	44.2	44.3	44.3
Power (THR+NTR), kW	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
I_{sp}, s (HTM)	2420	2430	2400	2420	2460	2420	2460	2460	2430	2450	2420

Table 1. HTM performance data.

IV. Conclusion

Initial performance characterization of four HTM FMs, FM1 .. FM4, and of one HTM QM1 has demonstrated the compliance to major SGEO mission requirements. Very low performance deviation from one HTM to another demonstrates also the high reproducibility of the HEMP technology. The upcoming test activities will include mechanical and thermal vacuum tests, as well as end-to-end test (with HTM FMs) and lifetime test (with HTM QMs).

Acknowledgments

This work is supported by the Federal Ministry of Economics and Technology through the German Aerospace Centre DLR, under contract number 50RS0803.

OHB qualification temperature data and operational timing is provided as courtesy of OHB Systems AG.

References

[1]S. Weis at al. "Overview, Qualification and Delivery Status of the HEMPT based Ion Propulsion System for SmallGEO", *33rd International Electric Propulsion Conference (this conference)*, IEPC-2013-, Washington, DC, 2013.

[2]M. De Tata et al., "SGEO Development Status and Electric Propulsion Subsystem Overview", *Space Propulsion Conference 2012*, SP2012_2354314, Bordeaux, 2012.

[3]N. Koch, et al., "The HEMPT Concept - A Survey on Theoretical Considerations and Experimental Evidences", *Proceedings of the 32th International Electric Propulsion Conference*, IEPC-2011-236, Wiesbaden, 2011.

[4]A. Lazurenko, et al. Overview on Testing Infrastructures and Diagnostic Tools for HEMPT based Ion Propulsion Systems, *Proceedings of the 32nd International Electric Propulsion Conference*, IEPC-2011-146, Wiesbaden, 2011.