Electric Propulsion Activities at TÜBİTAK UZAY: Laboratory work and mission plans

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Abstract: The first electric propulsion activities in Turkey started with the initiation of a project (called HALE) by TUBITAK UZAY in 2010. The project was supported by the Turkish Ministry of Development and planned to be completed by the end of 2018. In the scope of this project, a facility equipped with an infrastructure for design, manufacture and test of electric propulsion systems was built at TUBITAK UZAY premises in Ankara. The laboratory in the facility houses three vacuum chambers suitable for performance and life-time tests of hollow cathodes and plasma thrusters (with power <5 kW). In this facility, plasma thruster development activities focus mainly on Hall Effect Thrusters (HETs) with powers of 1.5kW and 300W. Electric propulsion systems based on these two thrusters are planned to gain flight heritage on an upcoming GEO and LEO missions. This paper presents the summary of HET system development activities and the status of the related missions at TUBITAK UZAY.

Nomenclature

TUBITAK	=	The Scientific and Technological Research Council of Turkey
UZAY	=	Space Technologies Research Institute
HALE	=	Hall Effect Propulsion System Development Project
HET	=	Hall Effect Thruster
XFS	=	Xenon Feed System
PPCU	=	Power Processing and Control Unit
TURKSAT 6A	=	The first indigenous GEO satellite of Turkey

I.Introduction

THE Scientific and Technological Research Council of Turkey (TUBITAK), founded in 1963, is the leading agency for management, funding, and conduct of scientific research in Turkey. More than 1,500 researchers work in 15 different research institutes of TUBITAK where both nation-wide and international research projects are conducted.

Space Technologies Research Institute (TUBITAK UZAY) focuses on developing small scale spacecraft equipment since early 1998 and is capable of manufacturing and operating Earth-observation satellites. The first optical remote sensing satellite of Turkey, BILSAT, was developed by TUBITAK UZAY in 2003 in close collaboration with Surrey Satellite Technology Ltd (United Kingdom). This satellite was followed by the indigenous

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optical remote sensing missions RASAT (2011) and GOKTURK-2 (2013). Recently, TUBITAK UZAY was appointed as the main contractor to develop next generation Turkish communication satellites (called TURKSAT 6A) for TURKSAT (the only Turkish telecommunications satellite operator) to be launched in 2021 and also continues to develop subsystems for higher resolution remote sensing satellites for Turkey.

Considering the advances in space propulsion technology, TUBITAK UZAY has expanded its interest to electric propulsion systems and initiated a Hall Thruster Propulsion System Development Project (referred to as HALE hereinafter) in 2010. The main objective of the project is to establish a facility dedicated to electric propulsion system development, funding for which is provided by Turkish Ministry of Development. In this paper, first an overview of the HALE project and its final status are presented. This is followed by an introduction of the facility and system development activities performed to date. Before the conclusion remarks in the last section, planned mission applications and their current status are briefly presented.

II.HALE Project Overview

The HALE project was started in August 2010 and is planned to be completed by the end of 2018. Aiming at building the necessary infrastructure and gaining the technical background to be able to develop electric propulsion systems in Turkey, the project is planned in two main work packages: (1) Facility establishment: foundation of a laboratory equipped with space simulators, development tools, and test equipment. (2) System development: design, manufacture, and test of a space qualified 1.5 kW Hall Effect propulsion system. Below, the activities performed in each work package is summarized.

A. Facility Establishment

Construction of the building was completed at the end of 2014 and the facility is operational since the commissioning of the first vacuum chamber in December 2014. The building has 140 m^2 closed area, enclosing a 100 m^2 100,000 class clean room, mechanical and electronics laboratories and an office room (Fig. 1).

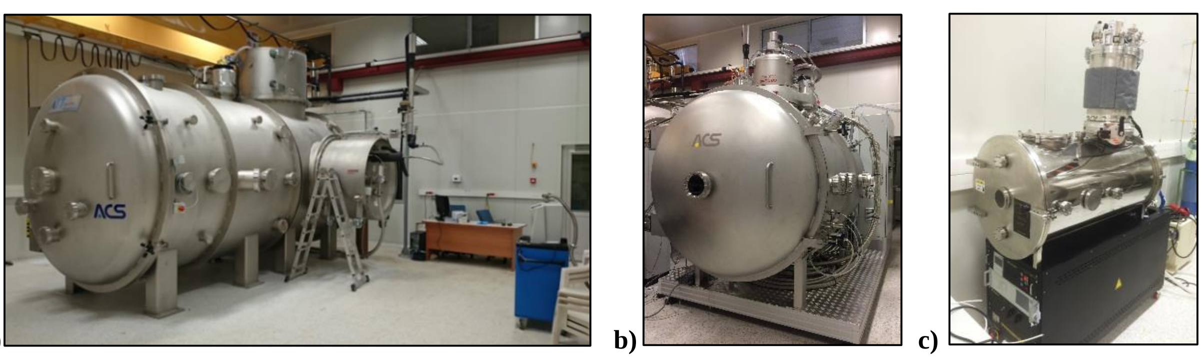
Figure 1. Electric Propulsion Facility at TUBİTAK UZAY

1. Vacuum chambers

Currently there are three operational vacuum chambers in the clean room area dedicated to propulsion system tests. The first and the biggest chamber with dimensions 2.3 m diameter and 4.5 m length (Fig. 2a) is placed on a seismic block for noise isolation and planned to be used mainly for performance and lifetime tests of high power (<5 kW) thrusters.

The second chamber is 1.5 m in diameter and 2 m in length (Fig. 2b). The base and operating pressure (under 4.5 mg/s Xenon load) are maintained at 5 10^{-7} Torr and 10^{-5} Torr, respectively, with a roughing and cryo pumping system (one cryopump and 4 cryopanels). The chamber is used mainly for the demonstration tests of relatively high power thrusters (1.5 kW) and performance tests of low power thrusters (<400 W).

The third and the smallest chamber dimensions are 60 cm diameter and 110 cm length (Fig. 2c) with an ultimate background pressure of 10^{-7} Torr. This chamber is used for the performance and life tests of hollow cathodes. In addition to cathode development, it is also utilized for the thermal tests of propellant feed systems.



a) b) c)

Figure 2. Vacuum chambers in the Electric Propulsion Facility at TUBİTAK UZAY.

Specifications of the three chambers in the facility are summarized in Table 1.

Table 1: Technical specifications of the vacuum chambers

Feature	Unit	VTC 1	VTC 2	VTC 3
Ultimate background pressure	Torr	2x10-7	1 x 10^-6	5x10-8
Pressure variation rate	hours	<12 hours	<3 hours	<4 hours
Operating pressure (Xenon load of 4.8 mg/s)	Torr	13 x10-6	x 10^-5 Torr	
Operating time limit	hours	2000	2000	
Leak rate at 760 Torr pressure differential	Mbar l/s of He	<2 x 10-8	<2 x 10-8	<2 x 10-8
Useful dimensions (Diameter x Length)	mm	2350 x 4500	1500 x 1200	600 x 1100
Internal net capacity	liters	~18700	~ 3500	~310
Chamber construction		stainless steel (AISI 304L)	stainless steel (AISI 304L)	stainless steel (AISI 304L)
Weight	kg	8500	3200	<1000
Inside structure for mounting test setup		4 non-magnetic stainless steel profiles	4 non-magnetic stainless steel profiles	2 non-magnetic stainless steel profiles
Beam target		Graphite panel	Graphite panel	NA
Access		A hinged door, opening angle: >120°	A hinged door, opening angle: >120°	A hinged door, opening angle: >120°
Pumping system	Oil-free	Primary vacuum system Turbomolecular pump 3 cryogenic pumps	Primary vacuum system Turbomolecular pump A cryogenic pump and 4 panels	Primary vacuum system Turbomolecular pump Cryogenic pump
Pressure sensors		Low pressure gauge High pressure gauge Full range sensor RGA	Low pressure gauge High pressure gauge Full range sensor	High pressure gauge
Portholes D= 160 mm and 63 mm		35 flanges 3 view ports	20 flanges 2 view ports	14 flanges 2 view ports
Venting		With GN2 or dry air	With GN2 or air	With GN2 or air
Control of the system		PLC touch screen/PC	PLC touch screen/PC	Touch screen
Other features		Seismic block		

2. Development and Diagnostics Tools

Various development and diagnostic tools have been acquired in the facility for design and optimization of the plasma thrusters and other propulsion system components. A list of the facility equipment is given below:

- Thrust stands
- Plume (plasma) analysis tools
- Thermal analysis tools (thermal camera, thermocouples, view ports)
- Thermal vacuum test setup for propellant feed systems

- Magnetic field measurement bench with a 3-axis magnetometer
- Test equipment including power supplies, DC loads, flow controllers, digital signal analyzers
- Development tools including orbital welding machine, ultrasonic cleaners, 3D printer, vacuum furnace, lathe, winding machine, soldering and silver brazing machine etc.

Thrust is the most fundamental thruster parameter that has to be measured in the electrical propulsion facility. For thrust measurements, two thrust stands have been planned to be developed in the scope of the project. The first stand design is based on an inverted pendulum approach (Fig. 3a). In this design, thrust is determined by measuring the displacement of the upper plate due to the thrust created by the thruster mounted on it.[1] The displacement is detected by a Linear Variable Differential Transformer (LVDT) placed at the bottom plate. Required range of the displacement of the LVDT is determined by the thrust to be measured and the thrust stand's spring constant. A series of flexures are manufactured in different lengths, widths, and thicknesses to measure a wide range of thrust. This stand is mainly used in testing of 1.5 kW Hall thrusters in the biggest vacuum chamber.

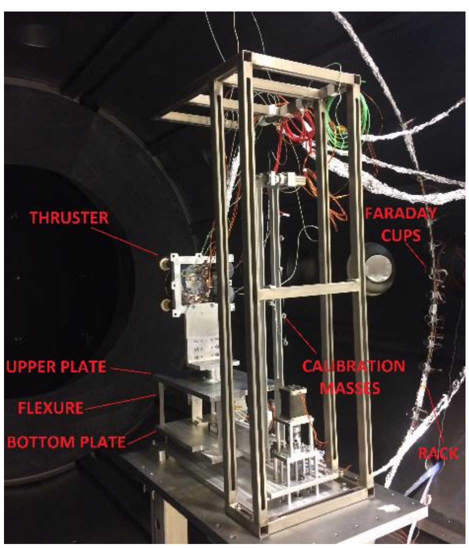
The second thrust stand design is based on a pendulum approach. In this design, displacement due thruster operation is determined by utilizing a laser probe rather than an LVDT. Currently, this stand is under development and is planned to be used in low power Hall thruster characterization (<400W) in the medium size vacuum chamber.

In both thrust measurement systems, calibration is done automatically under vacuum by moving known masses which apply a force to the stand in the thrust vector direction. Also, the thrust stands are mounted on stiff structures in the chambers to decrease the possible facility effects. Accuracy and uncertainty of the stands are still to be carefully calculated considering the instabilities and temperature variation observed during thruster operation. All sources of disturbances are to be determined and characterized for every thrust measurement for every thruster under test.

For detailed plume characterization, beam current density and distribution, plasma temperature and potential, and ion energy density and distribution should be measured. For such measurements, an RPA, an emission probe and Langmuir probes with a variety of dimensions are designed and their first prototypes are manufactured, which are planned to be used in detailed characterization of the 1.5 kW Hall thruster in the following months. Another critical parameter that determines the performance and lifetime of plasma thrusters is the plume divergence. For plume measurements of 1.5 kW thruster, Faraday probes are utilized.[2] Several Faraday probes are installed on a semicircular rake which is rotated remotely by a rotary table at the bottom of the chamber (Fig. 3a). The rotation axis of the rake passes through the thruster's exit plane and when it is rotated, it spans 180 degrees tracing a 1 m radius hemispherical area in front of the thruster.

In the facility not only thrusters but also other system components including cathodes and propellant feed systems are developed. For the performance testing of the cathodes, the smallest chamber is equipped with thermal analysis tools and view ports. This chamber is also used for the thermal performance tests of propellant feed systems (XFS). The main functions of the thermal vacuum test setup of XFS are (Fig. 3b):

- To measure leak rate (Pfeiffer ASM 380 leak detector)
- To conduct proof tests (Maximator booster station with DLE 30 booster)
- To determine flow rate accuracy (Bronkhorst F-101D mass flow meters)
- To perform qualification tests in the operating temperature range (Julabo FP50-HL refrigerated circulator)



a)

b)

Figure 3. a) Thrust stand b) Thermal test setup in the Electric Propulsion Facility at TUBİTAK UZAY.

In the facility, tools needed during system optimization, cleaning, assembly, and integration are also acquired, which includes power supplies, DC loads, thermal cameras, mass flow controllers, a 3 axis magnetometer, digital signal analyzers, an orbital welding machine, ultrasonic cleaners, data acquisition systems, and a vacuum furnace. In addition, as Xenon filling, draining, and pressure testing are needed during both ground operations and launch campaign, a ground support equipment for Xenon spacecraft loading and equipment testing is also planned to be developed in the scope of HALE project. Conceptual design of the equipment has been completed and it is planned to be manufactured by the end of 2018.

B. System Development

In TUBİTAK UZAY's electric propulsion facility, development activities focus mainly on systems with Hall Effect Thrusters (HETs) up to 5 kW power. A prototype of 1.5 kW HET system, including the thruster, cathode, propellant feed, power processing, and control units, has been designed and manufactured to date. Functional and performance tests of the unit prototypes are underway.

The block diagram of the system is given in Fig. 4. To date, design of the 1500 W Hall thruster was completed and its engineering model has been manufactured (Fig 5a). Design and manufacture of a Cesium based hollow cathode prototype has also been completed (Fig. 5a) so that stand-alone operation and coupling tests of the cathode and thruster could have been performed.[3] Initial thrust and plume measurements taken during these coupling tests confirmed a 70 mN thrust and 1500 s specific impulse at 60% anode efficiency. Plume divergence for the current thruster design has been reported to be less than 45 degrees. Optimization and lifetime tests of the thruster with the cathode are planned to be performed in 2018.

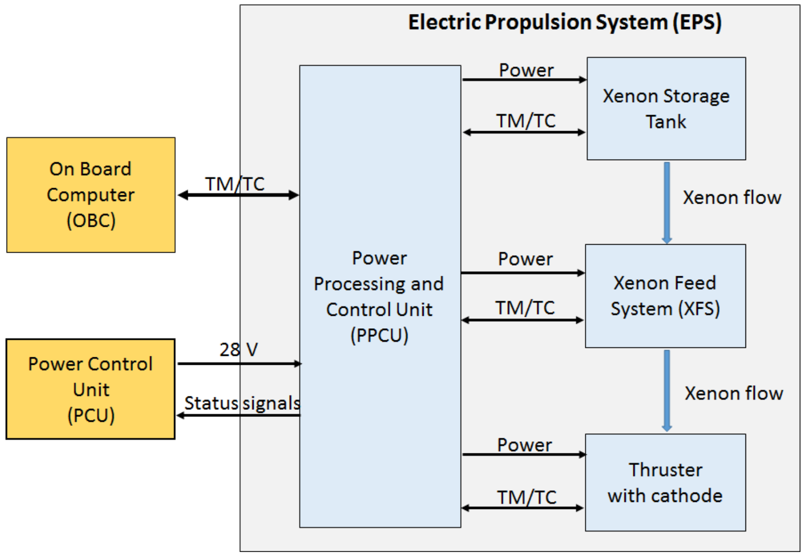


Figure 4. Block diagram of the Hall thruster propulsion system.

The propellant feeding unit consists of a Xenon storage tank and a Xenon Feed System (XFS). The storage tank is designed by TUBITAK UZAY, and its production and qualification testing (Fig 5b) is performed by a Turkish company, İzoreel Composite (located in İzmir, Turkey).[4] The tank has a cylindrical Titanium liner with a composite overwrapping and is capable of storing 13 kg of Xenon at pressures and temperatures ranging from 10 to 150 bar and from -20 to +60°C, respectively.

The Xenon Feed System (XFS) regulates the pressure and controls the Xenon mass flow between the tank and the thruster. The main functions of the XFS is to decrease the gas pressure to 2.5 bar and supply two different mass flow rates to the anode and two cathodes (one is redundant). The anode flow rate is variable between 0 and 10 mg/s, and the cathode flow rates are fixed at 0.45 mg/s. To date, design of the XFS is completed and integration of the engineering model is planned to be undertaken by the end of the year.

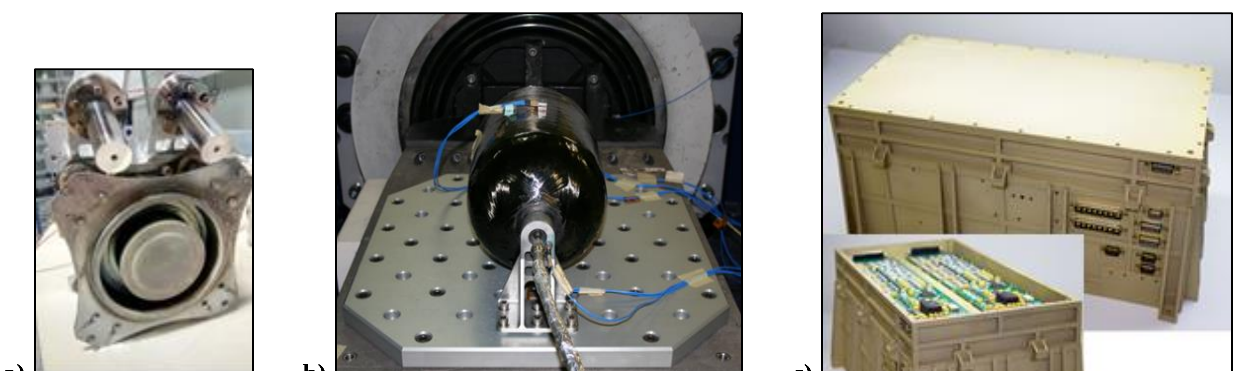


Figure 5. a) 1.5 kW Hall thruster b) Xenon storage tank c) Power processing and control unit.

One of the most critical system components is the Power Processing and Control Unit (PPCU). The unit is responsible for supplying the necessary power to all EPS units, controlling the thruster operation, collecting the telemetry from the system equipment, performing system thermal control, and serving as an interface between the EPS and the satellite management unit (The overall interface of PPCU with both the EPS and the satellite platform is shown in Fig. 4). To date, the first prototype of the PPCU has been designed and manufactured (Fig 5c), and currently performance tests are underway. Coupling tests of the thruster with the PPCU and XFS is planned to be performed by the end of the year.

III.Future Missions

At the end of 2016, TUBITAK UZAY was appointed as the main contractor for the development of next generation Turkish communications satellites for TURKSAT, the only telecommunications satellite operator in Turkey. This first indigenous GEO satellite of Turkey is called TURKSAT 6A and is expected to be launched in 2021. A flight model HET propulsion system identical to the qualified system that is being developed in the scope of the HALE project is planned to be sent into space and operated experimentally onboard TURKSAT 6A. Detailed information about tailoring of all EPS components to TURKSAT 6A and final status of the mission are presented in a separate paper.[5]

A low power HET system (<400 W) is also planned to be developed at TUBITAK UZAY's facility for a possible usage in future LEO missions. The design and manufacture of a 300 W system prototype are already underway in the scope of a new development project. Advances in this project are not the subject of the current paper; however, will be presented in a follow-up study.

IV.Conclusion

This paper briefly describes the characteristics of the electric propulsion facility founded at TUBITAK UZAY premises in Ankara and summarizes the electric propulsion activities performed in this facility since its foundation. The facility has a 100 m^2 100,000 class clean room area with electric and mechanical workshops, and houses three state-of-the-art vacuum chambers dedicated to propulsion system development. In the facility, the first chamber is located on a seismic block and equipped with a graphite beam target, a thrust stand, plume analysis probes, flow controllers, data accusation system, signal analyzers, and thermal measurement equipment to conduct performance and lifetime tests of 1.5 kW HET thrusters. Secondary chamber is equipped with similar test equipment and diagnostic tools to be mainly used for low power thruster development and demonstration tests. The third chamber is equipped with the testing tools for both cathode and propellant feed system development.

In this new facility, prototypes of a 1.5 kW HET system components, including the thruster, feed system, cathode, power processing, and control units have been already developed, and their performance and qualification testing are currently underway. A flight model HET system based on this qualified propulsion system is planned to be launched and experimentally operated on a telecommunication satellite, TURKSAT 6A, for which the main contractor is again TUBITAK UZAY and the planned launch date is 2021.

Acknowledgments

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