

TÜRKSAT6A Communication Satellite Electric Propulsion Subsystem Development Status

IEPC-2017- 384

*Presented at the 35th International Electric Propulsion Conference
Georgia Institute of Technology • Atlanta, Georgia • USA
October 8 – 12, 2017*

B.Ç. Aydın, D. Uluşen, İ.S. Gülle, Y. Yurttaş, O. Cherkun., A. Tsybulnyk, and S. Neugodnikov

TÜBİTAK UZAY Space Technologies Research Institute, Ankara, Turkey

Abstract: TÜRKSAT6A platform which is the very first communication satellite platform of Turkey is under development since December 2014. This paper gives a brief overview on the electric propulsion subsystem of the satellite which is utilized for performing east-west station keeping maneuvers.

Nomenclature

EPS	=	Electric Propulsion Subsystem
F	=	Filter
FDV	=	Fill-Drain Valve
FR	=	Flow Restrictor
GEO	=	Geostationary Earth Orbit
HALE	=	Hall Thruster Propulsion System Development Project
HET	=	Hall Effect Thruster
HPT	=	High Pressure Transducer
IS	=	Isolation Valve
LPT	=	Low Pressure Transducer
LV	=	Latch Valve
P	=	Pressure
PPCU	=	Power Processing and Control Unit
PR	=	Pressure Regulator
QTM	=	Qualification Test Model
RV	=	Relief Valve
STM	=	Structural Thermal Model
T	=	Temperature
T6A	=	TÜRKSAT6A
TP	=	Test Port
XFCU	=	Xenon Flow Control Unit
XFCV	=	Xenon Flow Control Valve
XPT	=	Xenon Propellant Tank

I.Introduction

TÜRKSAT6A (T6A) satellite is Turkey's first indigenous GEO satellite which is expected to be launched in 2021. The satellite operates at 42°E with an operational lifetime of 15 years. An experimental electrical propulsion subsystem (EPS) is planned to be used onboard in order to perform east-west station keeping maneuvers. Optionally, the subsystem might be utilized to implement de-orbiting maneuvers after completion of the mission. The main goal of this experimental subsystem on the T6A platform is to gain heritage to the subsystem and its equipment.

The model philosophy of T6A platform is shown in Figure 1. The structural-thermal models (STM) of subsystem equipment are already manufactured and the integration of satellite system level STM begins in the last quarter of 2017. Since all equipment of EPS are in development status and do not have flight heritage, all have an extra qualification test model to be integrated and tested in the first half of 2018.

II.Subsystem Overview

Electric propulsion activities in Turkey started with HALE (Hall Thruster Propulsion System Development) project² in 2010. The project is dedicated to build an infrastructure to develop and test a qualification model Hall thruster system. The initiation of TÜRKSAT6A satellite project transformed the outcome of HALE into a flight ready product by tailoring and adapting it to T6A platform. The equipment performance characteristics, sizes and interface features are modified

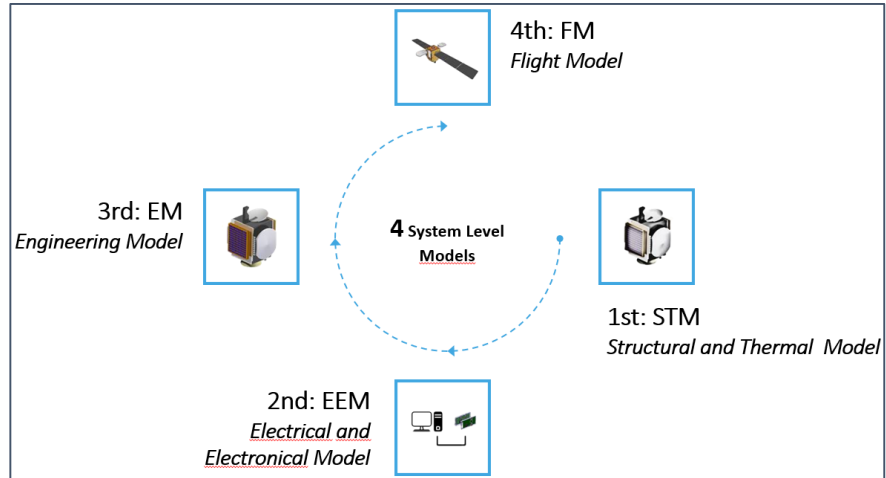


Figure 1. System level model philosophy of T6A platform.

according to T6A platform requirements. T6A mission is a great opportunity to qualify the subsystem and its equipment in space and more importantly in GEO environment.

The physical architecture of the EPS on T6A platform is illustrated in Figure 2. The subsystem is consisted of two Hall Effect Thrusters (HETs), a Xenon Feed Control Unit (XFCU), a Power Processing and Control Unit (PPCU) and a Xenon Propellant Tank (XPT).

The thrusters are located on the west panel of the platform. The XFCU and XPT are located at the back of the thrusters' panel in order to simplify and shorten the piping lines between the mentioned units. The PPCU is located on the north panel due to two reasons: space limitation on the west panel and need for transfer of the heat dissipated by the unit. The thrusters are positioned with a certain angle with respect to the satellite panel so that both thrusters' thrust vectors pass through the satellite's center of gravity (CoG).

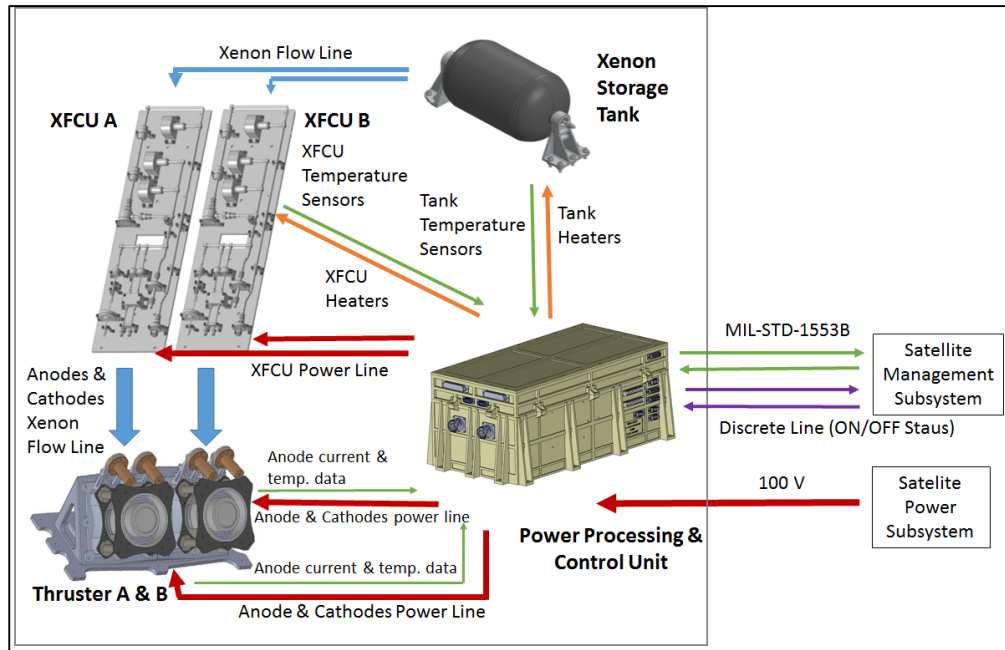


Figure 2. Electric Propulsion Subsystem (EPS).

A. Hall Effect Thruster

Hall Effect Thrusters of the subsystem are designed at TÜBİTAK UZAY aiming to achieve an overall performance similar with SPT-100¹ type of thrusters, such as minimum 70 mN thrust, 1500 s specific impulse, and 45% anode efficiency. At least 3500 hours of operation lifetime is targeted which is relatively longer than the operating time on T6A platform. According to the mission analyses, with 70 mN thrust, 120 minutes operation every two weeks is sufficient in order to perform east-west station keeping maneuvers. The operation time is equally shared by two thrusters and only one thruster operates at a time due to the power consumption constraints on the satellite.

Several prototypes of the Hall thrusters are designed, manufactured, and tested in TÜBİTAK UZAY vacuum test facility until the targeted technical specifications are met. In the final design, the HET's magnetic system consists of 1 inner and 4 outer coils, and it provides the required radial magnetic field strength for a wide range of working regimes without causing saturation in any part of the system. Magnetic circuit and anode parts are manufactured from pure iron and stainless steel while the discharge channel is constructed from Boron Nitride. Engineering models of the HET and cathodes along with their operation photographs in TÜBİTAK-UZAY vacuum chambers are shown Figure 3.

Each thruster of the EPS has two cathodes, one of which is redundant. A Cesium based

hollow cathode³ is designed by implementing two stage structures. The first stage operates on low voltage Cesium arc discharge and enables electron emission. The second stage has a gas propellant feed to enhance the electron transport and create a high density plasma column. Implementation of Cesium discharge and gas feeding stages allows for cathode operation with only a one power supply at lower temperatures when compared to typical hollow cathodes.

Prototyping phase of the HET and cathode development are finished and full thruster performance characterization activities are ongoing. Preliminary performance data can be seen in Figure 4. The given test results are acquired for

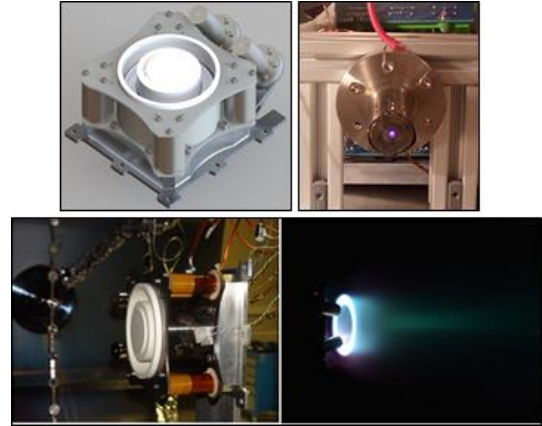


Figure 3. Engineering models of HET and cathode, thruster operation at TÜBİTAK-UZAY's facilities.

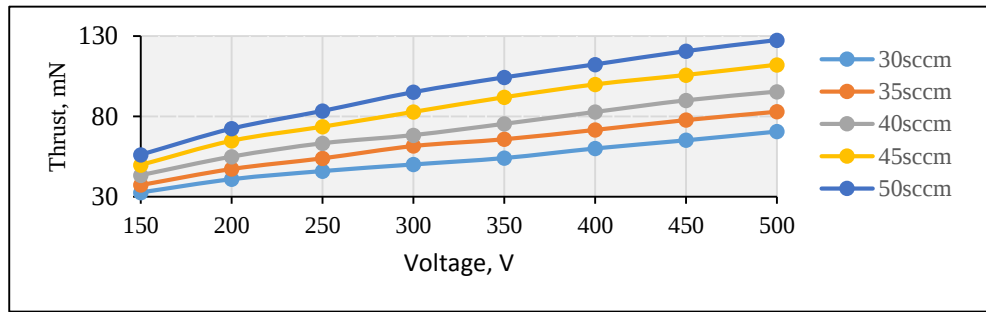


Figure 4. Performance data of HET.

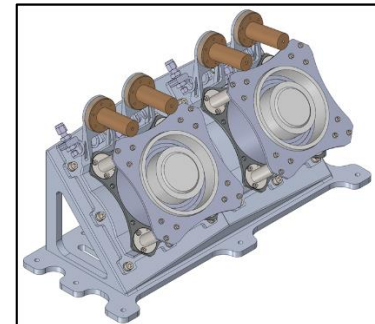
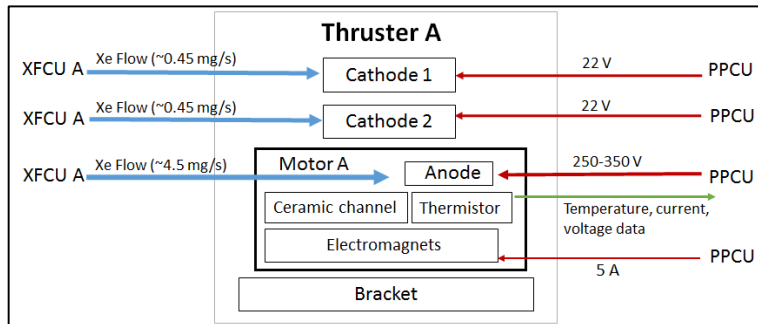


Figure 5. Interfaces of Thruster A, Thrusters A&B mounted on the bracket.

varying anode mass flow rates and discharge voltage levels, while keeping other parameters, such as magnetization current, cathode mass flow rate, cathode current etc., constant. The vacuum level during the tests is better than $5 \cdot 10^{-5}$ mbar at 50sccm Xe load. The magnetic field strength is optimized for 300V performance.

The interface of Thruster A with other subsystem equipment is given in Figure 5. The mechanical bracket that the thrusters are mounted on are designed in such a way the thrust vector passes through CoG. The qualification test model of the thruster assembly is in manufacturing process. The qualification test campaign begins in November 2017.

B. Power Processing and Control Unit

The Power Processing and Control Unit (PPCU) is responsible for supplying the necessary power to all subsystem equipment, controlling the thruster operation, collecting equipment telemetries, performing thermal control, serving as the interface between the EPS and the satellite management unit. The overall control interface of the PPCU with both the EPS and the satellite platform is shown in Figure 6. The electronic boards of PPCU are designed according to the requirements for GEO environment and all control and monitoring channels have internal redundancy, ensuring high reliability of operation.

As mentioned previously, thrusters of the subsystem are not operating simultaneously.

PPCU has two independent and identical set of electronic boards for each thruster; however, only filter card is utilized for both thrusters' power and control lines. In each set of electronic boards, there is one power processing and one power control board. PPCU has 100 V regulated bus for both high power input (input current up to 17A) and low power input (input current up to 3 A), and generates 300 V (output current up to 5A) for discharge (anode), 20 V (output current up to 5A) for cathodes and 28 V for heaters and valves' electronics control of XFCU.

Power Processing Board generates the voltages and currents for anode (discharge) and cathodes. Anode power supply is built on high performance full bridge transformer topology. UC1825 controller is applied for obtaining a reliable source with good technical characteristics. The power supply has also a circuit which limits the inrush current and makes initial health check. The input and output filters are included in the design in order to reduce the noise from

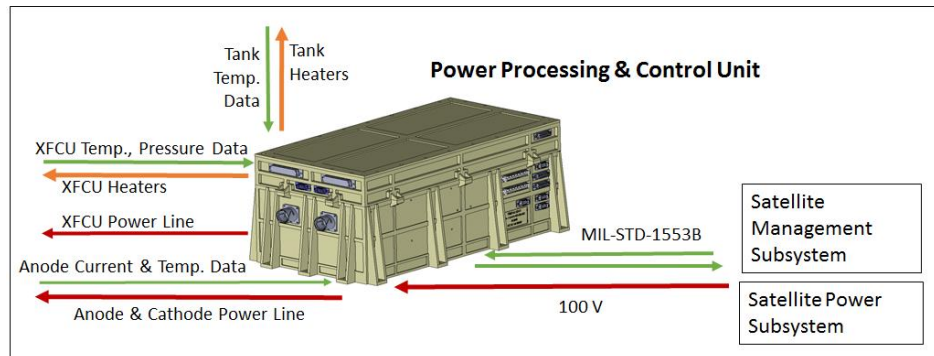


Figure 6. Interfaces of PPCU.

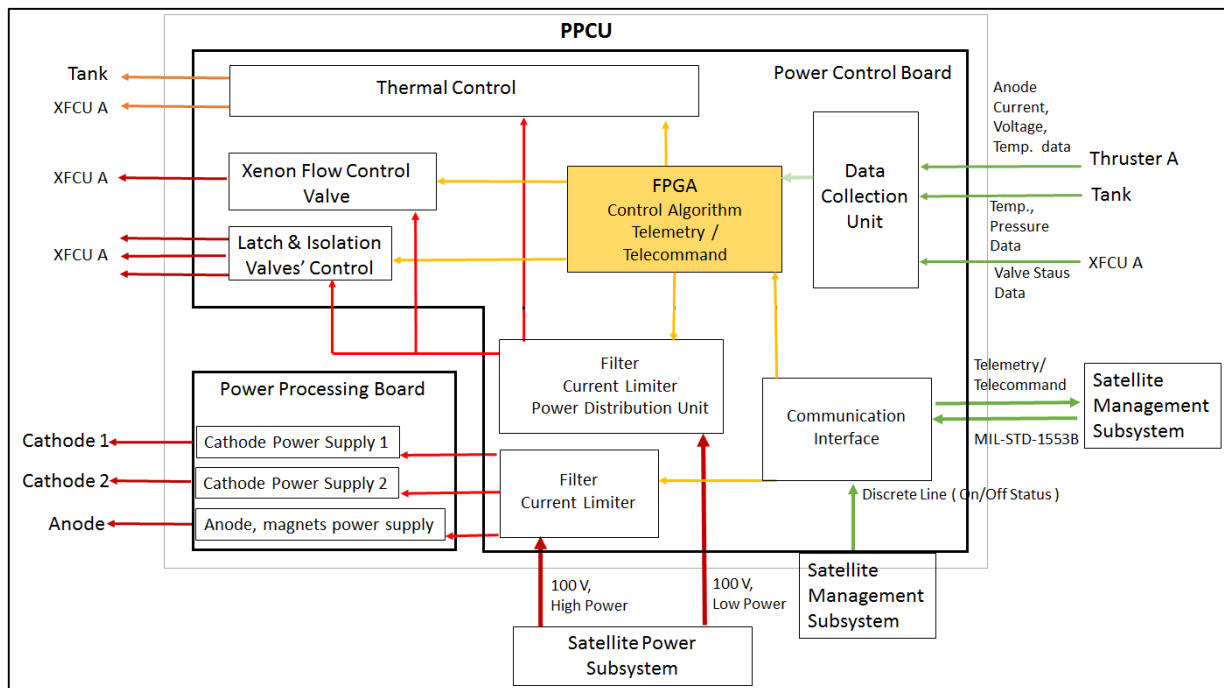


Figure 7. Block Diagram of PPCU.

the power supplies to acceptable levels. Built-in sensors transmit the current, voltage, and temperature data to the Power Control Board. The rated anode output power is 1350 W with 300 V output voltage, 100 V bus voltage (input voltage range: 95-105 V), and maximum 94% efficiency.

The cathode power supply converts the input voltage to a predetermined current in order to feed cathode. The source is built on a flyback converter topology to maintain the output current for different cathode operation phases, such as startup, transient, and nominal modes. For the control, a UC1842 is used. The input and output filters reduce the noise from the power supply to acceptable levels. Built-in sensors transmit current, voltage, and temperature data to the Power Control Board. The output current is 2.5 A with 5-20 V output voltage (depending on the cathode characteristics), 100 V bus voltage (input voltage range: 95-105 V), and an efficiency value between 75-85% depending on the working regime, such as startup, transient, or nominal modes.

Power control card is in charge of controlling the thruster operation, performing thermal control for XFCU and XPT, serving as an interface with the satellite management unit, and collecting health data from other subsystem units. Prototype and qualification models of the board have additional interfaces for manual control of the system state. Logical blocks of the control board and their characteristics are listed below:

1. The Input Side Data Acquisition Unit
 - Input voltage (3 channels)
 - Input current (1 channel)
2. The Output Side Data Acquisition Unit
 - Temperature (5 channels)
 - Temperature (8 channels)
 - Pressure (3 channels)
 - Anode current (4 channels)
 - Anode voltage (1 channel)
 - Cathode voltage (2 channels)
 - Cathode current (2 channels)
3. Xenon Flow Valve Control Unit
4. Thermal Control Unit
 - XFCU elements, XPT, Electronic circuit elements, Anode
5. Power Supplies Control Unit
6. Cathodes Power Supply Control Unit
7. Anode Power Supply Control Unit
8. MIL1553B Remote Terminal Interface Unit
9. RS422 Terminal Interface Unit
10. System Integrity Monitoring Unit

Block diagram of the PPCU is given in Figure 7.

Mechanical design and prototype of the PPCU are seen in Figure 8. The unit has an approximate total mass of 15 kg, which includes the box and electronic boards. Power processing and filter cards are located on the bottom part of the box while control cards and DC-DC converters are placed on a plate at the top. Qualification model of the PPCU is manufactured in the beginning of 2018 and qualification test campaign is to be carried in the second quarter of 2018.



Figure 8. PPCU Prototype.

C. Xenon Flow Control Unit

Xenon Feed Control Unit (XFCU) has two branches, each of which supplies the necessary Xenon flow to each thruster. The design of XFCU is carried out according to the operation characteristics of the developed HETs and the accommodation constraints on the T6A platform.

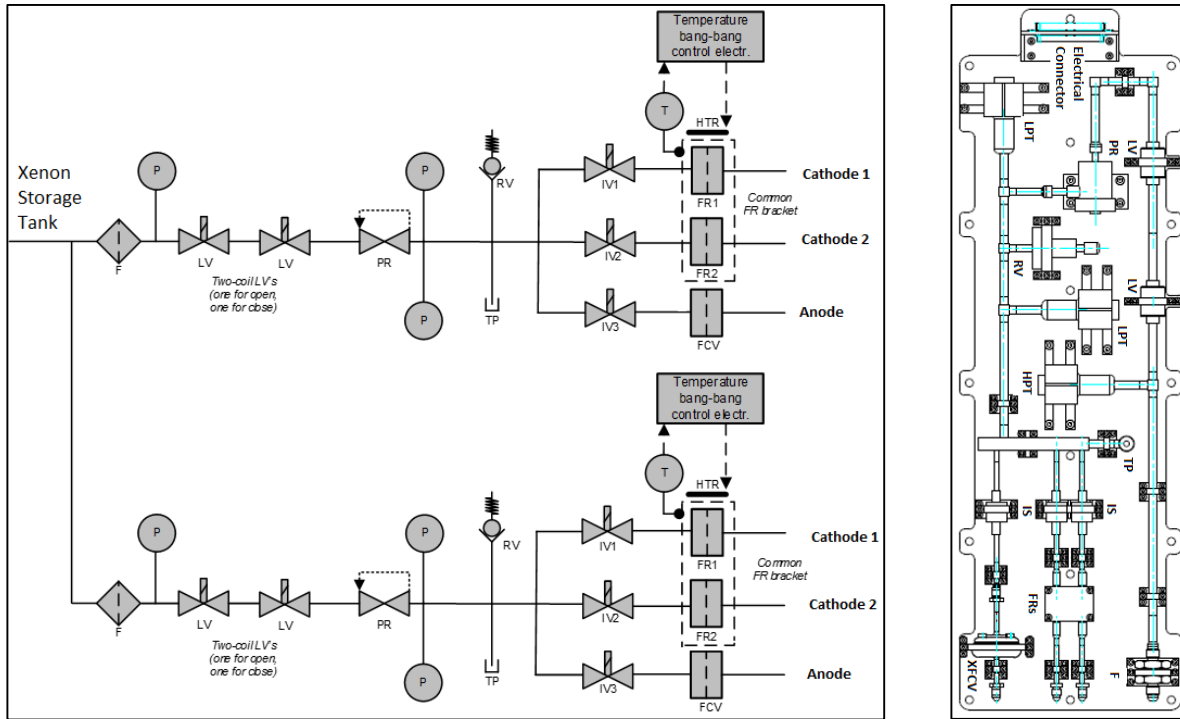


Figure 9. Block Scheme of XFCU A & B, CAD model of XFCU A.

The operation pressure of the XPT is maximum 150 bar. The XFCU decreases this pressure to 2.5 bar and provides two different flow rates for the anode and two cathodes. Anode flow rate is variable from 0 up to 10 mg/s, and cathode flow rates are fixed at 0.45 mg/s. The dimensions and mass of the one XFCU branch is 568 mm x 180 mm x 70 mm and 3.6 kg, respectively.

The block diagram and design of one branch is shown in Figure 9. As seen in in Figure 9, the XFCU includes a filter at the inlet, two latch valves in series, and a mechanical

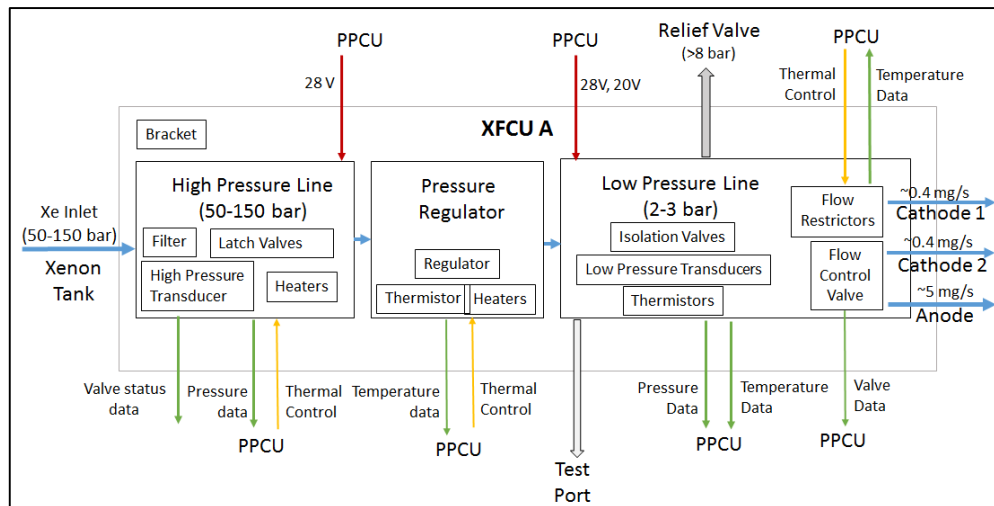


Figure 10. Interfaces of XFCU A.

pressure regulator in the high pressure section. Downstream of the regulator, a manifold distributes the flow into three lines on which isolation valves are placed upstream of the flow control valve and two flow restrictors. The unit also includes one high and two low pressure transducers, temperature sensors, heaters for diagnostics and a relief valve for safety. All components of the XFCU are integrated by AS4841 standard fittings and Swagelok Orbital Welding with Micro weld head series 8 in TÜBİTAK UZAY facilities.

As mentioned previously, a commercial flow control valve (Nanospace) is used for a variable anode flow. The resolution of the flow rate is ≤ 0.1 mg/s at 2.5 bar, 20 °C. The accuracy of the commercial flow restrictors (Moog-Bradford) is $\pm 12.4\%$ mg/s. The overall control interface for one branch (XFCU A) is given in Figure 10. Thermal control of XFCU is performed by PPCU. The integration of engineering and qualification model of the XFCU starts in October 2017 and January 2018, respectively. Qualification Test campaign is planned be performed in the second quarter of 2018.

D. Xenon Propellant Tank (XPT)

The Xenon propellant tank stores approximately 13 kg of Xenon, which is determined according to mission lifetime of 15 years. Limits on the propellant tank dimensions are set according to the calculated Xenon amount and the accommodation restrictions on the platform. The tank has a Titanium cylinder and composite overwrapping with a volume of approximately 8.3 lt. Table 1 presents the T6A Xenon tank requirements. Overall control interface of the XPT is given in Figure 11. Thermal control of the tank is performed by PPCU.

Table 1. Tank Design Parameters

Parameters	Requirements
MEOP	150 bar
Proof Pressure	225 bar
Burst Pressure	min 300 bar (1:2)
Operation Cycle	min 50 cycles
Tank Size	Ø204.5 mm OD x 382 mm long, boss to boss
Propellant Weight	min 10 kg Xenon gas
Tank Weight	3.7 kg
Tank Capacity	min 8.3 lt
Compatibility	Xenon, Argon, Helium
Leakage	$< 1 \times 10^{-6}$ std cc/s He @ MEOP
Operating Temperatures	-5 °C to 65 °C
Natural Frequency	> 140 Hz, filled

The manufacturing and qualification testing of the tank are carried out at both İZOREEL Composite facility located in İzmir and TÜBİTAK UZAY facilities (vibration tests) located in Ankara, Turkey. After each test, including pressurization loading, volumetric capacity checks are made. The tank volumes before and after the proof pressure tests are measured to verify that the tank satisfies the requirement. Deionized water is used to conduct this examination.

The proof pressure test is conducted at the pressure of 225 bar for 5 minutes and, subsequently, helium leak test and volumetric capacity examination are made. As a result of proof pressurization XPT is undergone a permanent volumetric growth of 1.6%, which is under 10% limit. Helium leak test is applied to XPT after each pressurization and is performed under MEOP. All tests that are made after proof, fatigue, and vibrations tests satisfy the limit value of 1×10^{-6} scc/s. Resonance search, sinusoidal and random tests are performed in qualification stage. Vibration test is carried out according to ECSS-E-HB-32-26A. The Xenon gas weight is taken into consideration during the tests. A test fluid 3M PF5060 is used in order to maintain the equivalent weight with that filled with Xenon gas. The XPT is subjected to minimum 50 cycles during the operation life. Pressure cycling test is

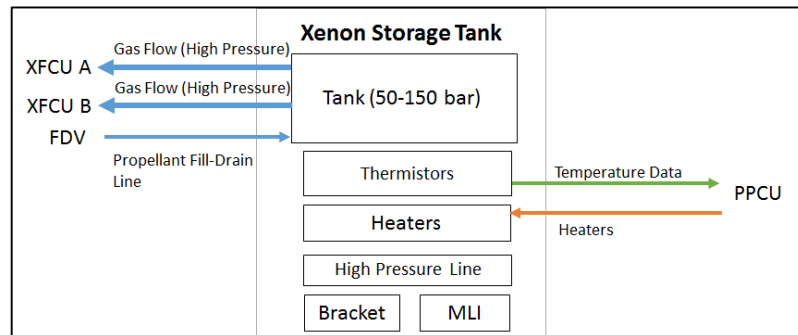


Figure 11. Interfaces Xenon Tank.

As a result of proof pressurization XPT is undergone a permanent volumetric growth of 1.6%, which is under 10% limit. Helium leak test is applied to XPT after each pressurization and is performed under MEOP. All tests that are made after proof, fatigue, and vibrations tests satisfy the limit value of 1×10^{-6} scc/s. Resonance search, sinusoidal and random tests are performed in qualification stage. Vibration test is carried out according to ECSS-E-HB-32-26A. The Xenon gas weight is taken into consideration during the tests. A test fluid 3M PF5060 is used in order to maintain the equivalent weight with that filled with Xenon gas. The XPT is subjected to minimum 50 cycles during the operation life. Pressure cycling test is

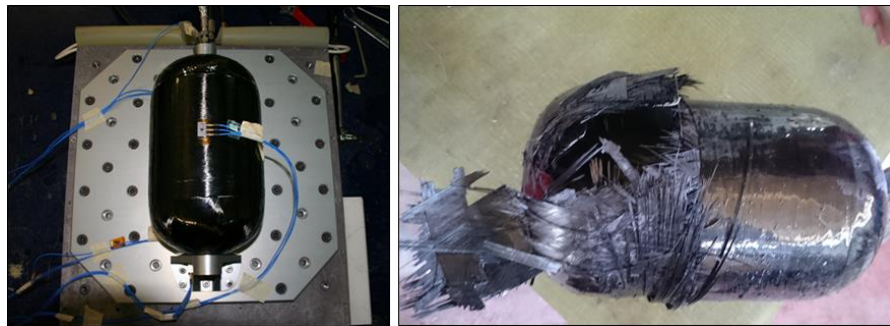


Figure 12. Vibration Test Bench and Qualification Test Model after Burst Test.

carried out with 55 pressure cycle in MEOP. Additionally, the XPT is subjected 1 proof pressure cycle, 1 MEOP cycle and additional MEOP cycles for each Helium leakage tests which totally makes 61 pressure cycles. The XPT has not shown any leakage after the total pressurizations. Qualification test model of the tank is subjected to burst testing and is resisted to pressurization until much higher values. The burst happened nearly 700 bar. The failure after burst is shown in Figure 12.

III.Conclusion

Turkey's first indigenous communication satellite platform, TÜRKSAT6A, also has the very first electric propulsion subsystem (EPS) on board. To date, EPS equipment design activities and prototyping phase are completed and STMs are manufactured. Equipment level performance and functional tests are currently ongoing at TÜBİTAK UZAY facilities and manufacturing of the QTMs are underway. Satellite system level STM integration and test activities are planned to be conducted in December 2017 at Spacecraft Assembly, Integration and Test Center (USET) in Ankara, Turkey and the TÜRKSAT6A launch is expected in 2021.

Acknowledgments

The authors would like to thank TÜBİTAK KAMAG (Public Research Grant Committee) for their financial support of TÜRKSATTÜRKSAT6A satellite. Electric propulsion team of TÜBİTAK UZAY is deeply appreciated to find a chance to be onboard on T6A platform. We want to express our sincere gratitude to Mr. C. Levent Ertürk and Mr. Bülent Avenoğlu for always believing in our team and supporting our work.

References

Proceedings

¹Charles, E. G., "Performance Evaluation and Life Testing of the SPT-100," *23rd International Electric Propulsion Conference*, 1993.

Unpublished Papers and Books

²Ulusen, D., "Electric Propulsion Activities at TÜBİTAK UZAY: Laboratory work and mission plans," *35th International Electric Propulsion Conference* (to be published).

³Cherkun, O., "Cesium Hollow Cathode with Internal Discharge and Gas Feed for Electric Propulsion Applications," *35th International Electric Propulsion Conference* (to be published).

⁴Akin, B., "Design, Analysis and Manufacture of Composite Overwrapped Xenon Propellant Tank," *35th International Electric Propulsion Conference* (to be published).