Space Propulsion Research Vacuum Facility of the Bogazici University Space Technologies Laboratory

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***Abstract*—Development of reliable, successful and robust technologies for space systems demands realistic testing facilities. Low pressure levels are required for simulating the space vacuum conditions in earth's orbit or interplanetary-space. Therefore, establishment of a vacuum facility devoted specifically to the testing of thrusters is needed in order to develop, study and test thrusters to be deployed on spacecraft or satellites. In this study, the design, acquisition and manufacturing processes, and capabilities of a 1.5 m diameter and 2.7 m long cylindrical vacuum facility, that will primarily be used for the development and testing of electric spacecraft thrusters, at the Bogazici University Space Technologies Laboratory (BUSTLab) are presented.**

Keywords— vacuum chamber, test facility, space propulsion.

I. Introduction

Satellites and spacecraft moving in an orbit or in interplanetary space use propulsion systems that use the principle of conservation of momentum to provide thrust. Typical in-space propulsion systems convert the chemical energy stored in the on-board propellant into kinetic energy. Propulsion systems that use other sources of energy (batteries, solar panels, radioactive sources of energy, nuclear reactors, etc.) are being developed as an alternative to the standard space propulsion systems. Since in these alternative propulsion systems, the energy carried by the vehicle is not limited to the energy stored in the propellants chemical bonds, these types of propulsion systems can provide higher levels of impulse for the same amount of propellant or can accomplish certain missions with less amount of propellant.

There are numerous ways of using external energy sources for propulsion. In some of these systems the propellant is ionized and plasma is obtained, this plasma is then accelerated with the help of electromagnetic forces and expelled from the spacecraft at high velocities to produce the desired thrust. These thrusters, also called plasma rockets, are being considered for use in earth orbiting satellites of various types (communication, meteorology, military, intelligence, etc.) as they provide possibilities for the extension of satellite life as well as the reduction of amount of fuel required for its lifetime. Additionally, the development and use of these thrusters will be significant for the realization of certain manned and/or unmanned interplanetary missions.

Ground testing of the components that are used in space missions is of crucial importance in order to ensure that the components would work successfully in space conditions. Furthermore, ground testing of spacecraft components gives researchers the ability to eliminate any possible problems in advance, since it is very difficult and in most cases not possible to repair the components after launch. Because of these reasons, establishment of space conditions on earth is an indispensable need for researchers. In order to develop and test thrusters to be deployed on spacecraft or satellites, vacuum facilities that provide the vacuum environment that is similar to the vacuum environment in low earth orbit are needed. At this point, high quality vacuum systems emerge to satisfy this requirement. Pressure levels below 10^{-6} Torr are required for the simulation of space conditions. Moreover, for the examination of the thermal effects in space environment on spacecraft components, establishment of a thermal test section in vacuum system is also another need that researchers demand.

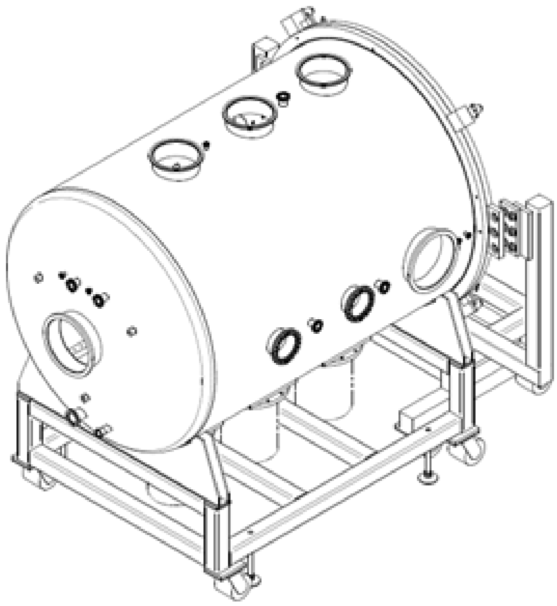

Fig. 1. Technical drawing of BUSTLab vacuum chamber

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In this paper, the design, acquisition and construction of a vacuum facility that is being used in the development and testing of in-space propulsion systems are presented. The constructed vacuum facility provides the vacuum environment that is similar to the environment in low earth orbit even when a plasma thruster is in operation inside the chamber (when releasing gas into the chamber). The vacuum facility will primarily be used to develop electric spacecraft thrusters that run on xenon or argon propellants. The facility is able obtain a base pressure of $2x10^{-8}$ Torr and is able to maintain a vacuum level of $3x10^{-5}$ with 10 sccm (~ 1 mg/min of xenon) of gas is being released by the thruster. The parts of the built vacuum chamber were purchased separately and then put together to have a functioning test facility. To our knowledge, this chamber is the first vacuum chamber in Turkey that is capable of supporting space propulsion research.

II. VACUUM CHAMBER

The vacuum chamber established at Bogazici University Space Propulsion Laboratory (BUSTLab) is 1.5 m in diameter and 2.7 m in length. A 3-D technical drawing of the chamber can be seen in Fig. 1. After the installation of the mechanical pump and cryogenic pumps, and all the necessary ports for electrical and gas connections, BUSTlab vacuum chamber became fully operational on 17 December 2014. It took approximately 13 months to make chamber ready for experiments from the time it was first brought into laboratory. Fig. 2 shows the picture of the chamber inside the laboratory.

The chamber has seven ISO-320 ports: the three located at the bottom of the chamber are F type and the four located on the two sides, and front and rear walls are K type. The chamber also has three ISO-250 K ports located at the top wall. There are also two of 8 inch CF, ten of 2.75 inch CF, eight of 1.33 CF, one KF40 and one KF63 ports on the vacuum chamber. A picture of the chamber during its manufacturing at the manufacturer's Kurt J. Lesker's, Pittsburgh, PA, USA facilities is shown in Fig. 3.

Fig. 3. A picture of the chamber during its manufacturing at Kurt J. Lesker's manufacturing facilities in Pittsburgh, PA, USA

Currently, the vacuum chamber is integrated with one mechanical and two cryogenic pumps that are used to decrease the pressure to the desired levels. The chamber is rough pumped with a rotary vane pump with roots blower with a pumping capacity of 253 m^3/h. A picture of the mechanical pump placed at the back wall of the chamber is shown in Fig. 4. The rough pump down of the chamber takes about 35 minutes (from 760 Torr to $2x10^{-3}$ Torr). The chamber is then pumped with two 12-inch cryopumps each with 3100 liters per second argon pumping capacity. The cyyopumps are attached to two water cooled helium compressors. These two compressors are placed on the side of the chamber inside the laboratory. The chilled water to both of the compressors are provided by an air cooled chiller. The chiller is located outside the laboratory. The chiller has a rated cooling capacity of 16.8 kW (14448 kcal/h) for water exit temperature of 15 ^oC at the ambient temperature of 25 ^oC.

Fig. 2. Picture of the chamber placed in the laboratory

Fig. 4. The picture of the mechanical pump and the roots blower

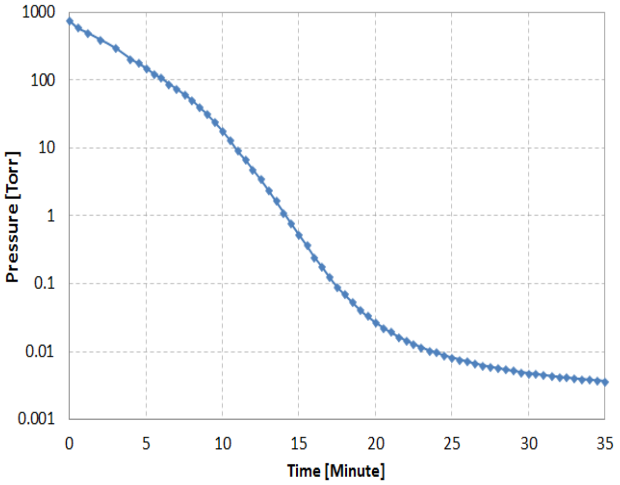

Fig. 5. Chamber pressure versus time for the rough pumping of the chamber

III. Vacuum Chamber Operation and Testing

The reduction of the base pressure inside the vacuum chamber consists of two stages. In the first stage, only the mechanical pump is operational. Fig. 5 shows the chamber pressure as a function of time for the rough pumping of the chamber. When the chamber pressure is reduced to the order of $4\text{x}10^{-3}$ Torr, the mechanical pump port valve is shut off and the mechanical pump is shut down. At this point, the second stage of the pumping process is started by opening the gates of the two cryogenic pumps. Reduction of base pressure from $4\text{x}10^{-3}$ Torr to 10^{-6} Torr level by the cryogenic pumps takes only few minutes. With the cryogenic pumps the base pressure of the chamber could be brought down to $2\text{x}10^{-8}$ Torr levels. The duration to reach the base pressure depends on the size of the experimental setup, and the cleanliness level of the equipment inside the chamber.

As discussed in the introduction section, the vacuum facility should provide the vacuum environment that is similar to the environment in low earth orbit even when a plasma thruster is in operation inside the chamber (when releasing gas into the chamber). Thus, in order to determine

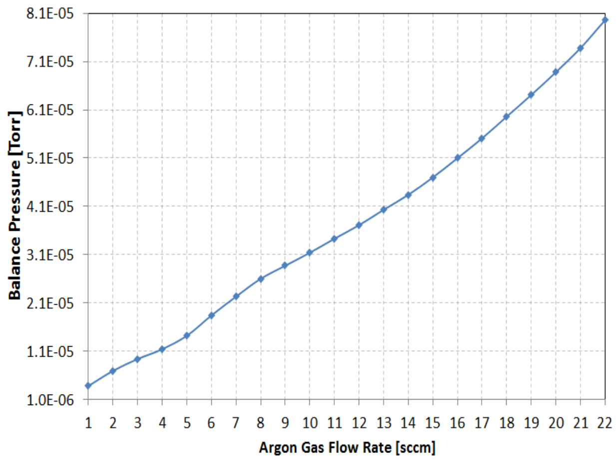

Fig. 6. Chamber pressure versus argon gas flow rate

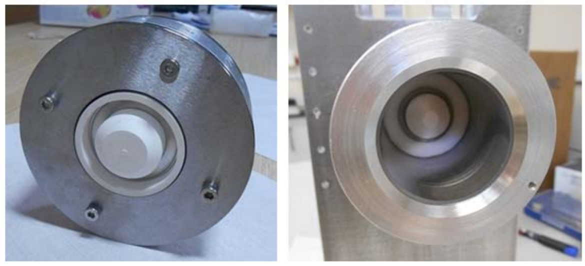

Fig. 7. Pictures of the HK40 Hall effect thruster (left) and CFHT-40 cusped field Hall thruster (right)

the balance pressure inside the vacuum chamber for various propellant flow rates, argon gas is released into the chamber at flow rates regulated by two MKS mass flow controllers. Balance pressure levels of the vacuum chamber for various argon gas flow rates fed into the chamber are presented in Fig. 6. It is observed that from 1 sccm up to 22 sccm argon mass flow rate, the balance pressure inside the chamber shows a linearly increasing tendency with increasing mass flow rate. The balance pressure is around $3\text{x}10^{-5}$ Torr for a gas flow rate of 10 sccm. The results show that the pumping rate of the chamber is suitable for the plasma thruster testing.

IV. Preliminary Thruster Testing

At BUSTLab we have recently designed and built an SPT type Hall Thruster and a cusped field Hall thruster, and tested them in BUSTLab vacuum chamber. Fig. 7 shows the pictures of the SPT type and the cusped field Hall effect thrusters. The prototype cusped field Hall thruster (CFHT-40) along with the radio frequency (RF) cathode built at BUSTLab were placed inside the vacuum chamber and CFHT-40 was operated with high purity argon propellant gas at 400 V discharge voltage and 1.2 A discharge current. A picture of the thruster and the cathode placed inside the BUSTLab vacuum chamber is shown in Fig. 8. During different argon gas flow rates ranging from 2 to 5 sccm, and

Fig. 8. Pictures of the cusped field Hall thruster and the RF cathode placed on a stand inside the BUSTLab vacuum chamber for testing

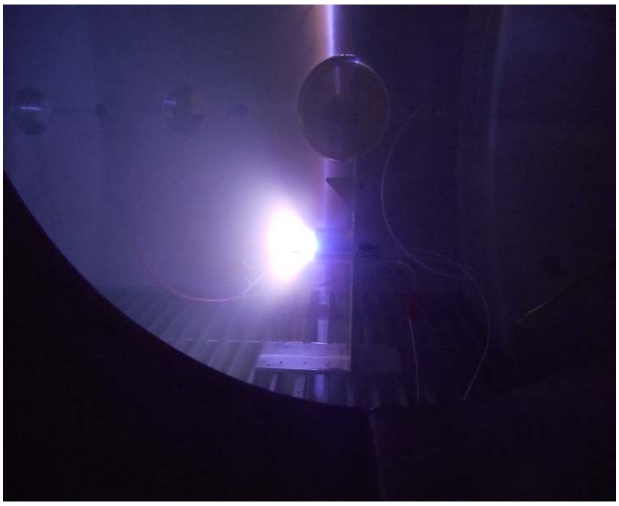

Fig. 9. Picture of the cusped field Hall thruster operating inside the BUSTLab vacuum chamber

at 50 Watts of RF power provided by a 13.56 MHz RF power source. A picture, taken from one of the side optical ports of the vacuum chamber, of the CFHT-40 operating inside the BUSTLab vacuum chamber is shown in Fig. 9.

Preliminary testing of the developed SPT type Hall effect thruster is also conducted inside the BUSTLab vacuum chamber. The thruster was operated at a discharge voltage of 260 V and discharge current of 1.2 A with high purity argon propellant for the initial tests. During Hall effect thruster testing, a cathode made of tantalum wire placed just in front of the thruster is used as the electron source.

V. Conclusion

In this study, the design, acquisition and manufacturing processes, and capabilities of a newly built vacuum facility at the Bogazici University Space Technologies Laboratory (BUSTLab) are presented. Moreover, details regarding the preliminary testing of two different prototype Hall thrusters, designed and assembled at BUSTLab, are also brought to the attention of the research community. To our knowledge, these are the first experimental plasma thrusters designed, built and successfully tested in Turkey. Established vacuum chamber will be used for the simulation of the space environment in order to conduct experiments on electric propulsion systems as well other spacecraft components.

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