

DLR's Electric Propulsion Test Facility – the First Three Years of Thruster Operation

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Abstract: Since the end of 2011 DLR operates the High Vacuum Plume Test Facility Göttingen – Electric Thrusters (STG-ET). This electric propulsion (EP) test facility has now accumulated approximately three years of EP-thruster testing experience. Several special features tailored to electric space propulsion testing like a large vacuum chamber mounted on a low vibration foundation, a beam dump target with low sputtering, and a performant pumping system characterize this facility. The vacuum chamber is 12m long and has a diameter of 5m. With respect to thruster tests, the design focus is on accurate thrust measurement, plume diagnostics, and plume interaction with spacecraft components. Electric propulsion thrusters have to run for thousands of hours, and with this the facility is prepared for long-term experiments. The present paper gives an overview of the facility, and describes the vacuum chamber, pumping system, diagnostics, and experiences with these components. After commissioning of STG-ET, the main focus was put on the testing of gridded ion thrusters of radiofrequency ion thruster (RIT) type.

Nomenclature

EP	=	Electric Propulsion
RIT	=	Radiofrequency Ion Thruster
RPA	=	Retarding Potential Analyzer
STG-ET	=	Simulationsanlage für Treibstrahlen Göttingen - Elektrische Triebwerke
THR	=	Thruster

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I. Introduction

The interest of commercial industries in electric space propulsion experienced a big push with Boeing's all-EP initiative based on its new 702SP platform. Electric propulsion is nowadays used routinely for satellite station keeping but not yet for orbit transfer. All-EP satellites will ultimately perform these manoeuvres, and consequently will need higher thrust engines. Using the actual thrusters may lead to very long transfer times. But there is a strong indication that the all-EP strategy will lead to a total cost reduction of up to 30%^[1].

Electric propulsion is also gaining more interest in the sector of future science missions requesting very low thrust in conjunction with low thrust noise and accurate thrust level control. On the other hand, EP comes with low absolute thrust compared to thruster mass and this requires long runtimes for fulfilling a given mission. This implies special challenges for qualification and on-ground testing, which means that EP testing sets very different boundary conditions to test facilities compared to chemical propulsion.

Based on the above mentioned perspective of EP growth the DLR Göttingen site added to its chemical space propulsion testing capabilities a test facility for electric propulsion - the STG-ET.

The inauguration of the facility took place at the end of 2011, and soon after final commissioning the facility has been used for operating electric thrusters. In parallel additional infrastructure and diagnostics elements have been step by step added. The next sections provide an overview of the vacuum chamber and the installed components.

II. Facility Overview

A. Vacuum Chamber

The central element of the facility is a 12m long and 5m diameter vacuum chamber. Figure 1 shows the facility with its door open. For instrumentation and pumping 169 feedthrough ports are available^[2].

The chamber is mounted on sliding bearings for reduction of stress in case of pump-down and temperature changes. The test object and the diagnostics equipment are positioned on a stand which is decoupled from the metal chamber wall. This decoupling ensures less vibrations and a well-defined space coordinate system origin.

The STG-ET is located in close vicinity to other DLR space vacuum test facilities and shares a common infrastructure of cryogenic media like liquid nitrogen and liquid helium.

B. Pumping System

In order to operate thrusters in a vacuum chamber, powerful pumps are required to keep a low and space-like background pressure. As in other facilities DLR's vacuum chamber uses cryopumps when running EP thrusters. Roughing pumps are rotating vane and Roots pumps, followed with turbo pumps for standby operation. A set of 7 cryopumps is activated when thrusters are running.

Figure 2 shows two of the pumps, and Figure 3 displays a typical pressure plot during tests. The latter shows that a pressure of around $1\text{--}5 \cdot 10^{-5}$ mbar can be maintained during operation of a thruster. Such a pressure limit is a typical requirement for EP thruster operation. The standby pressure is in the 10^{-8} mbar range, and in the plotted case the standby interval is followed by a short regeneration of cryopumps with a raise in pressure.



Figure 1. View into the open vacuum chamber of the STG-ET facility.

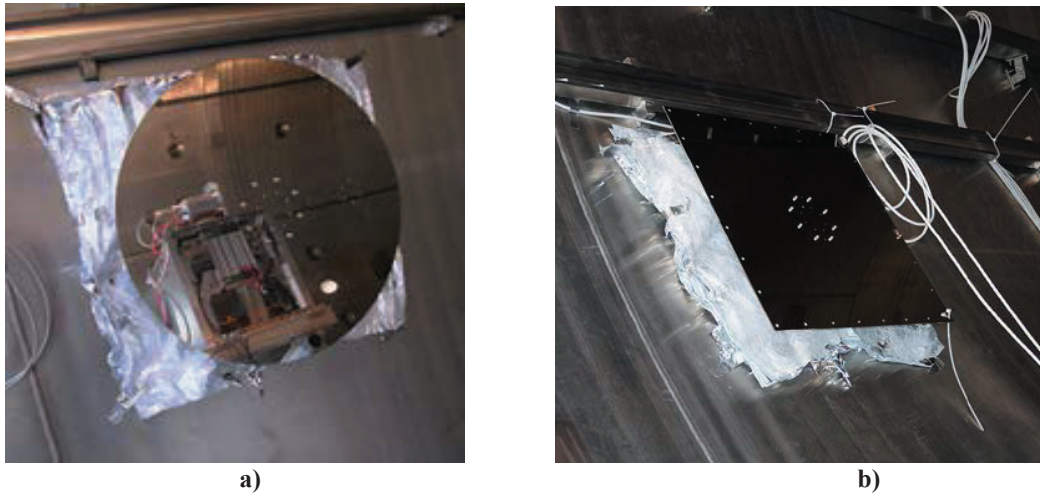


Figure 2. STG-ET cryopumps: a) with circular cold plate, b) with square cold plate.

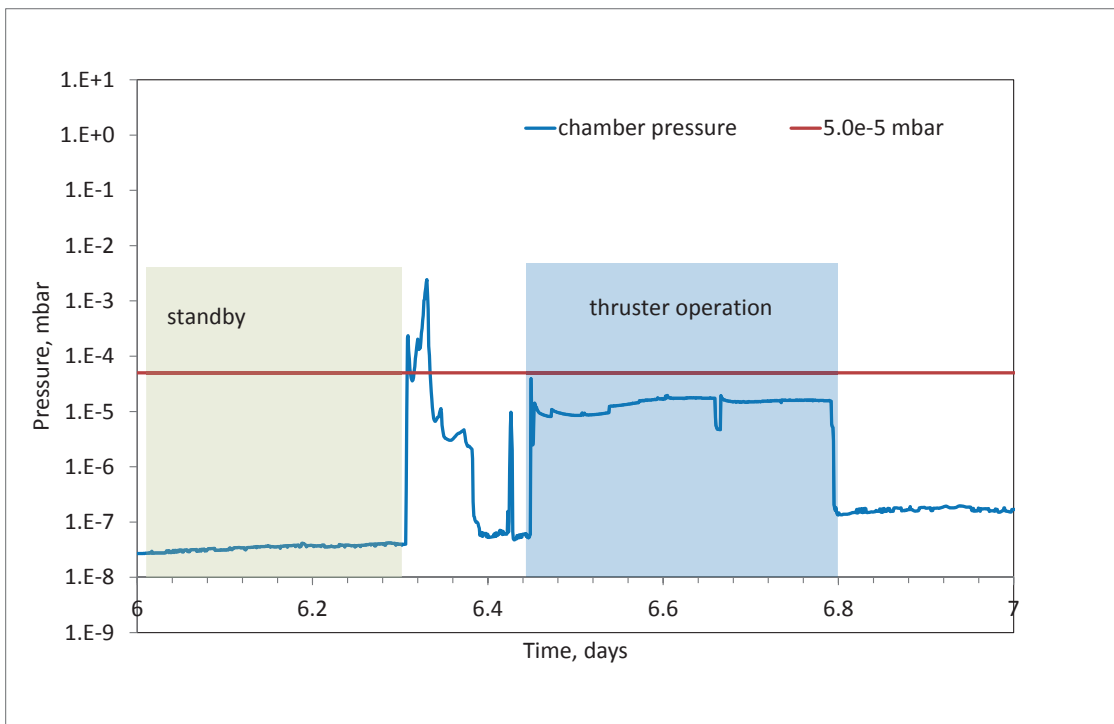


Figure 3. Typical pressure plot during a test. A standby time interval is plotted, followed by a short regeneration of cryopumps with a raise in pressure. After that, a period with thruster in operation follows.

C. Beam Dump Target

Ion thrusters generate beams of fast ions that may interact with the facility walls and equipment. These high velocity ions cause sputtering when hitting the walls of the chamber or all other components located inside the chamber. In ion propulsion test chambers dedicated beam dump targets are used for reduction of sputtering effects. Such a component has also been installed in the DLR facility. The beam dump must successfully minimize the possible sputtering, and must be able to dump the heat flux generated by a range of EP-thrusters including powerful thrusters. Figure 4 shows the STG-ET beam dump target with graphite-coated plates. The windmill-like design was chosen because it leads to a more symmetrical behavior compared to venetian blind designs used in other EP test facilities.

Figure 5 shows an infrared image of the water cooled beam dump target in vacuum conditions. This test was done to confirm the uniformity of coolant water flow.

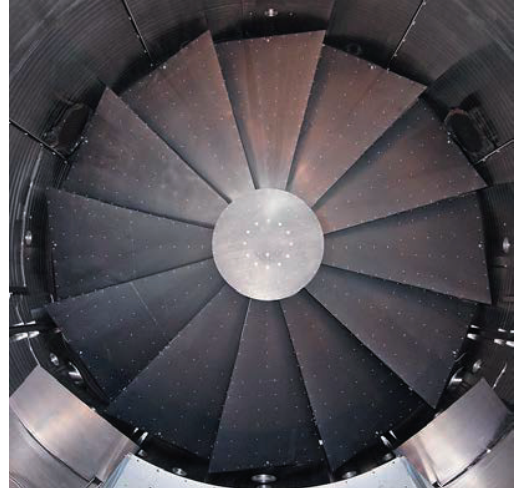


Figure 4. STG-ET beam dump target installed at the vacuum chamber end wall.

D. Thrust Balance

Thrust measurement is a basic task to be performed on all types of thrusters. The challenge in electric propulsion is that thrust values are very small compared to the weight of the thruster itself. In case of ion thruster the thrust-to-mass ratio is in the order of 0.001, or even less if adding weight of ancillaries. Requesting a thrust resolution of 0.1% will lead to a maximum balance load capability of several kg's, to be measured with a resolution well below 1mN.

DLR's thrust balance is an actively compensated inverted double pendulum because this design has proven to be very sensitive^[3]. An appropriate counterweight is placed on the lower platform and compensates the weight of the thruster assembly located on the upper parallel platform (Figure 6).

The STG-ET with its large vacuum chamber was designed such that thruster with high thrust, up to several hundred mN can be tested. A future upgrade for thrusters generating thrust up to 1N is foreseen. Accordingly, the thrust balance must be able to measure these values, while being able to carry the weight of large and heavy thrusters.

Figure 7 shows the thrust balance and a gridded ion thruster mounted on it. The balance can carry a single thruster or arrays with a mass of up to 40kg. To minimize hysteresis or other unwanted effects, cables and tubes feeding the thruster are routed in a holder configuration called 'cable harp'. Herein the length of cables and tubes are adjusted so that the distance between their bending points is the same as between the corresponding balance bearings.

Calibration is crucial and the thrust balance has two independent methods for performing a calibration:

- voice coil calibration
- gravimetric calibration

The voice coil method uses an electrically calibrated coil to apply a known force to the balance platform.

The gravimetric method is based on accurately measured masses for a direct calibration. The balance includes a device that uses small weights that can be lifted from a holder. Their weight force is applied to the thruster table by a thin wire guided over a pulley. While the voice coil method is faster, shows smaller variances and allows a larger number of measurement points compared to the weight calibrator, systematic errors might occur. The gravimetric method verifies the calibration to an absolute standard.

E. Beam Profiling

Besides thrust measurements the monitoring of the ion beam distribution is an important task for EP diagnostics. Figure 8 shows the two rotational diagnostics arms (single plane arm and multi-sensor arm) that enable recording of ion current distributions at a distance of 0.5-1.5m from thruster exit. The maximum scanning speed is 2deg/s for the single plane arm, and up to 10deg/s for the multi-sensor arm.

The multi-sensor arm is permanently equipped with 15 Faraday cups, while the single plane arm has the capability of carrying different sensor types^[4]. The standard setup for the single plane arm uses two Faraday cups and one retarding field energy analyzer (RPA).

F. Sputter Targets

Operating an ion source causes sputtering which is an unwanted effect in a test facility. Deposits on the chamber wall, instrumentation, and on the thruster itself have an impact on measurements and test results. For STG-ET a program has been started in cooperation with the Justus Liebig University Giessen, Germany, that will define a set of standard samples for monitoring sputtering. This activity was triggered by the RITSAT project^[5]. These samples will be placed routinely in the chamber and recovered for analysis.

Figure 9 shows an example of a sputter target based on a standard 2 inch wafer. The wafer is coated with a regular pattern that enables surface profiles to be investigated. The rate of change of these patterns gives an indication of the ion beam etching or deposition of sputter material.

III. Thruster Operation

EP testing activities are another area of cooperation with the Justus Liebig University Giessen. This cooperation is based on joint research projects and access to test facilities^[5]. After the inauguration of the STG-ET, testing began in 2012. DLR's standard test thruster is a RIT10 radiofrequency engine with small diameter exit grids with 37 holes. The grid setup of this so-called RIT10/37 produces a narrow, low divergence beam (Figure 10). A control system for this thruster was developed by DLR, and the thruster has been used for qualification of the above mentioned beam diagnostics and for the investigation of facility modifications.

The much more powerful Airbus Defence and Space thruster RIT22 was also under test in the STG-ET (Figure 11), and showed that the facility is able to handle more powerful thrusters.

IV. Conclusion

DLR's EP test facility was inaugurated in October 2011, and started operation in 2012. Since then, in the years 2012-2014, the facility infrastructure and pumping system has been upgraded and a beam dump target was installed. The diagnostics system has been adapted to test requirements given by users.



Figure 5. Infrared image of the water cooled beam dump target in vacuum.

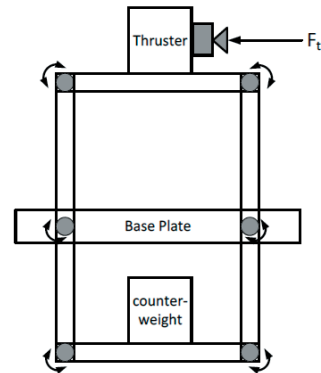


Figure 6. Thrust balance principle: actively compensated inverted double pendulum.

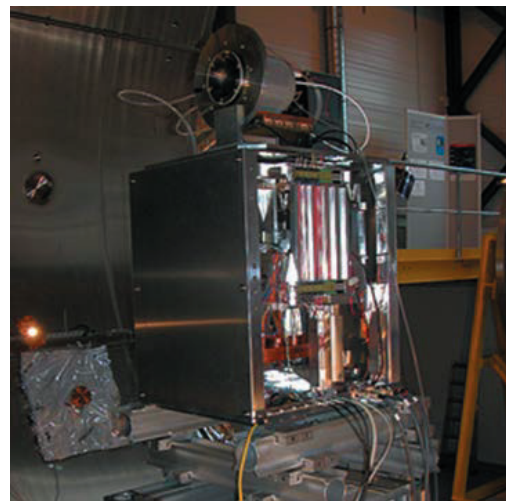


Figure 7. Thrust balance with open lid on one side. A gridded ion thruster is mounted on the balance.

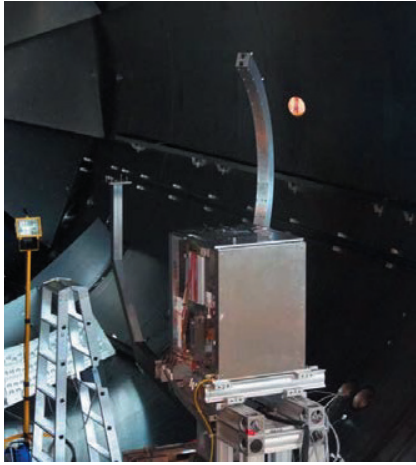


Figure 8. Beam diagnostics systems. On the left the single plane arm, and in the middle of the photo, the multi-sensor arm can be seen.



Figure 9. Sputter target based on a 2-inch wafer with regular pattern.

Acknowledgments

Some of the thruster diagnostic systems have been designed and built in cooperation with the Justus Liebig University Gießen within the project LOEWE RITSAT, which was funded by the Hessen State Ministry of Higher Education, Research and the Arts, Germany.

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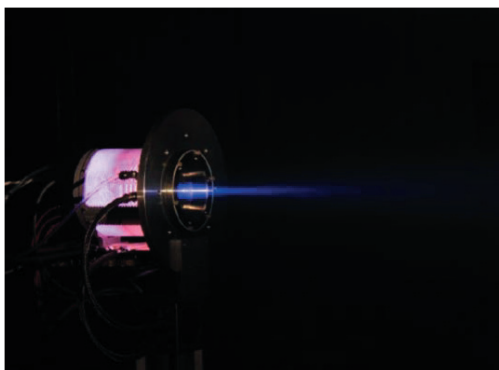


Figure 10. RIT10/37 thruster in operation in the STG-ET.

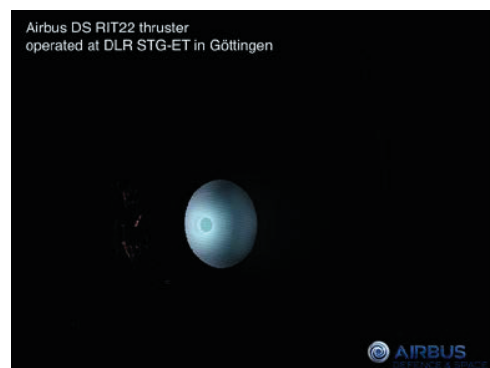


Figure 11. Airbus Defence &Space RIT22 thruster in operation in the STG-ET (courtesy Airbus D&S).