Journal of large-scale research facilities

Journal of large-scale research facilities, 3, A108 (2017) http://dx.doi.org/10.17815/jlsrf-3-156

Published: 07.04.2017

STG-ET: DLR electric propulsion test facility

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Abstract: DLR operates the High Vacuum Plume Test Facility Göttingen – Electric Thrusters (STG-ET). This electric propulsion test facility has now accumulated several years of EP-thruster testing experience. Special features tailored to electric space propulsion testing like a large vacuum chamber mounted on a low vibration foundation, a beam dump target made of low sputtering material, and a performant pumping system characterize this facility. The vacuum chamber is 12.2m long and has a diameter of 5m. With respect to accurate thruster testing, 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. This paper gives an overview of the facility, and shows some details of the vacuum chamber, pumping system, diagnostics, and experiences with these components.

1 Nomenclature

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

2 Introduction

For performing maneuvers in space, satellites and spacecraft need propulsion systems. Besides chemical or cold gas thrusters, nowadays electric propulsion devices are often employed for attitude control

[*]**Cite article as:** DLR Institute of Aerodynamics and Technology. (2017). STG-ET: DLR electric propulsion test facility. *Journal of large-scale research facilities, 3*, A108. http://dx.doi.org/10.17815/jlsrf-3-156

and station keeping. Furthermore, the actual developments in electric propulsion for commercial application aim at orbit transfer with electric thrusters, and with this the development goes into the direction of more powerful engines. As the absolute thrust values of electric thrusters, especially of ion propulsion systems, are rather low these thrusters have to run for much longer times for fulfilling missions, i.e. thousands of hours. With respect to ground testing for these thrusters, a dedicated test facility has to be prepared for such long-term experiments.

3 DLR Electric Propulsion Test Facility

Since the end of 2011 DLR operates a space propulsion test facility specifically designed for EP, the High Vacuum Plume Test Facility Göttingen – Electric Thrusters (STG-ET). Several special features tailored to electric propulsion testing have been implemented. This includes a large vacuum chamber mounted on a low vibration foundation, a low sputtering plasma beam dump target, a performant pumping system, and comprehensive plasma diagnostics. With respect to thruster testing, the design focus was on accurate thrust measurement, plume diagnostics, and on the possibility of performing investigations of plume interaction with spacecraft components like e.g. solar arrays.

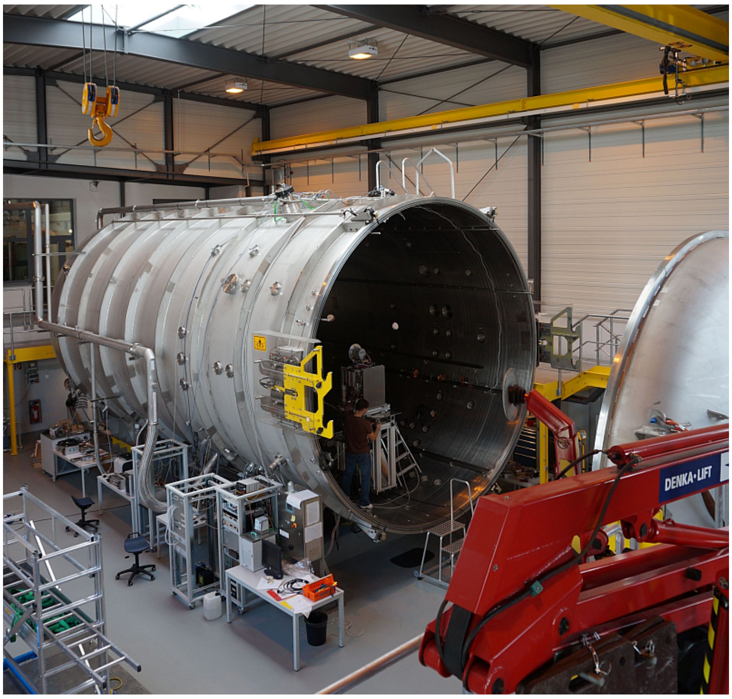

Figure 1: View into the open vacuum chamber of the STG-ET facility.

4 Facility Details

4.1 Vacuum Chamber

The central element of the facility is a 12m long and 5m diameter vacuum chamber (Neumann et al., 2015). Figure 1 shows the facility with its door open. For instrumentation and pumping 169 feedthrough ports are available (Neumann et al., 2011). The chamber is mounted on sliding bearings for reduction of stress in the chamber walls in case of pump-down and temperature changes which otherwise would deform the vacuum chamber metal cylinder and warp coordinate systems which are connected to the chamber wall. Test object and diagnostics equipment are positioned on a stand which is decoupled from the chamber wall. This decoupling ensures less vibration transmission 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, e.g. liquid nitrogen and liquid helium. Both media may be used during thruster testing.

4.2 Pumping System

In order to operate thrusters in a vacuum chamber, powerful pumps are required to keep a low and space-like background pressure. Typical background pressures for EP thruster operation are in the range of 10^{-4} to 10^{-5}mbar. As roughing pumps rotating vane and Roots pumps are used, followed by turbo pumps for standby operation. Like in other EP facilities the DLR vacuum chamber uses cryo pumps when running EP thrusters. Up to 10 cryo pumps can be activated when thrusters are running. The standby pressure without thruster running is in the high 10^{-8}mbar range.

4.3 Beam Dump Target

Ion and plasma thrusters generate beams of fast ions that may interact with the facility walls and equipment. These high velocity ions cause sputtering when hitting a target. 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 pollution of components, and must be able to dump the heat flux generated by a wide range of EP thrusters including most powerful thrusters. Figure 2 shows the STG-ET beam dump target with graphite-coated plates. The windmill-like design with adjustable angles was chosen because it leads to a more symmetrical behavior compared to venetian blind designs used in other EP facilities. The beam dump target is water cooled and it can dump up to 25-50kW of heat flux.

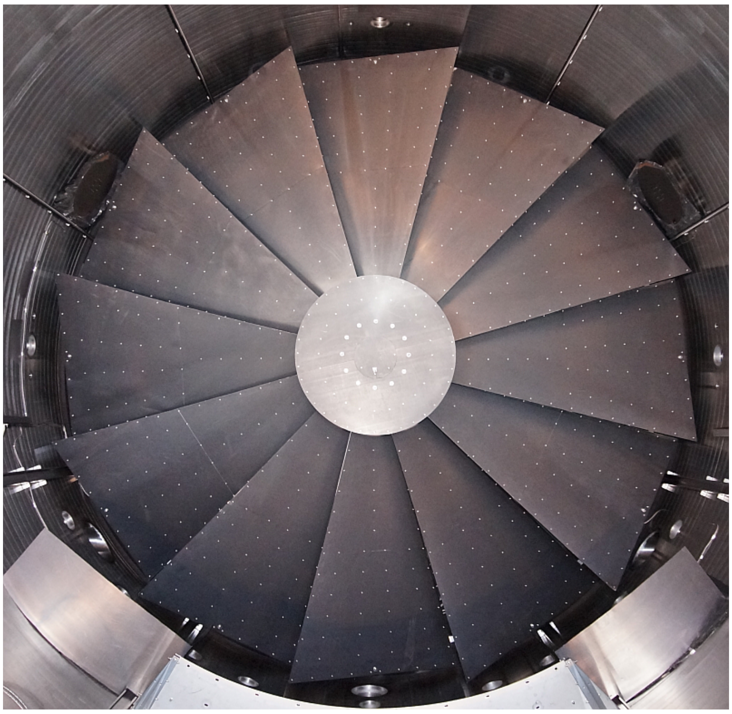

Figure 2: STG-ET beam dump target installed at the vacuum chamber end wall.

4.4 Thrust Balance

Direct 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 thrusters the thrust-to-mass ratio is in the order of 0.001, or even less if adding the mass of

ancillaries. Requesting a maximum thrust of the order of 250mN measured with a resolution of 0.1% will lead to a resolution well below 1mN. As such thrusters weigh roughly 10 of kg the thrust balance must have a maximum load capability of at least these kg's. DLR acquired a thrust balance that is an actively compensated inverted double pendulum because this design has proven to be very sensitive (Neumann et al., 2013). For reaching this high sensitivity an appropriate counterweight is placed on the lower pendulum platform and compensates the weight of the thruster assembly located on the upper parallel platform.
The STG-ET large vacuum chamber was designed such that thrusters 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 single thrusters or thruster arrays. Figure 3 shows the thrust balance and a gridded ion thruster mounted on it. The balance can carry a single thrusters 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 the distance between corresponding balance bearings.
Calibration is crucial and the DLR thrust balance has two independent methods for performing this task. One method uses an electromagnetic voice coil calibration, the other is a direct weight 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 has small weights which can be lifted from a holder. Their weight force is applied to the thruster platform 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 may occur. The gravimetric method permits to trace the calibration back to an absolute standard.

Figure 3: Thrust balance with open lid on one side. A gridded ion thruster is mounted on the balance.

5 Beam Profiling

Besides measurement of thrust monitoring of the ion beam distribution is an important assignment in EP thruster qualification. The STG-ET mainly uses three systems for ion current measurement in the EP plume. Closest to the thruster exit at a distance of 0.7m a two-dimensional rotational scanner with 15 Faraday cups is located. At 1.5m a single plane rotational scanner is able to host different instruments. A retarding potential analyzer (RPA), a Faraday cup or Langmuir probes can be mounted and can sweep part of a circle down into the backflow. The third system is a flat field scanner with two Faraday cups able to scan an area of 3m in horizontal and 1m in vertical direction. Figure 4 shows the two rotational diagnostics arms, i.e. the single plane arm and the multi-sensor arm located behind the thrust balance. The maximum scanning speed is 2deg/s for the single plane arm, and up to 10deg/s for the multi-sensor arm.

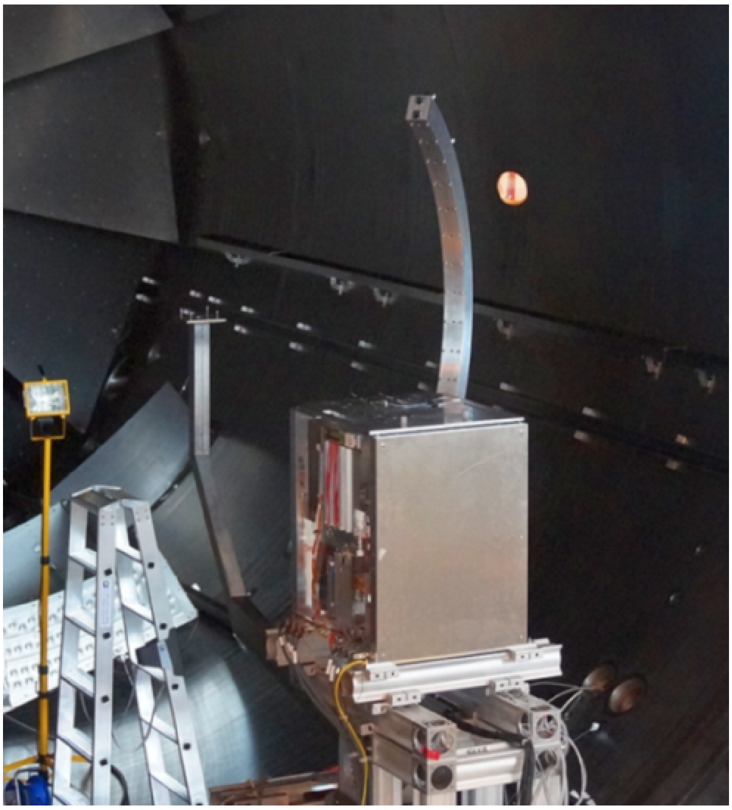

Figure 4: Beam diagnostics systems. On the left the single plane arm, and in the middle of the photo, the multi-sensor arm can be seen.

6 Thruster Operation

For their own testing activities DLR uses an ion thruster. This standard test thruster for facility calibration and diagnostics is a RIT10 radiofrequency ion source provided by the Justus Liebig University Giessen. This thruster has reduced diameter exit grids with 37 holes. The grid setup of this so-called RIT10/37 produces a narrow, low divergence beam as shown in Figure 5. 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.

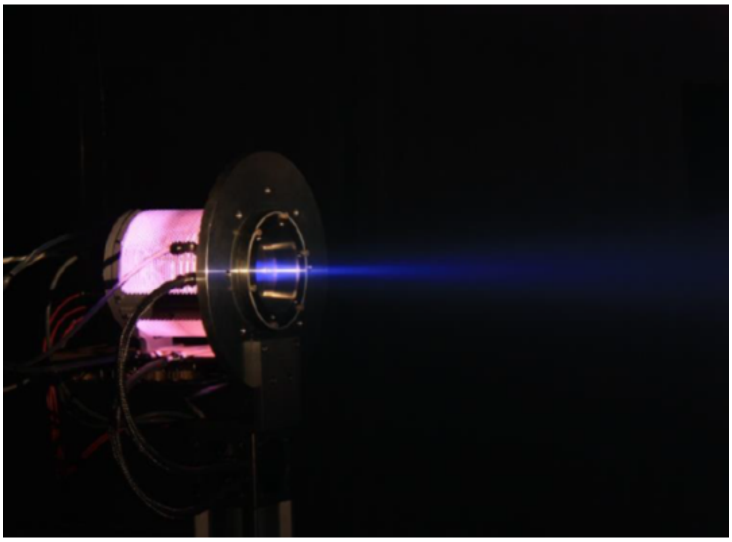

Figure 5: RIT10/37 thruster in operation in the STG-ET.

7 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 was upgraded and the beam dump target was installed. The diagnostics system has been adapted to test requirements given by users, and nowadays three beam scanners are available.

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