DLR's Test Facility STG-ET

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Abstract

Chemical and cold gas thruster plume flow and plume spacecraft interaction are subject of research and application at the German Aerospace Center, DLR, Germany, since about three decades. DLR is extending these activities in Göttingen to cover electric space propulsion testing and thruster investigation. For this purpose a new high vacuum facility, named STG-ET, has been built especially for electric propulsion testing. The vacuum chamber measures 12.2 m in length and 5 m in diameter. The design focus is on plume interaction with spacecraft components and on long-term tests. The facility will be equipped with advanced measurement methods for plasma analysis and thrust and thrust vector measurement. Inauguration of the facility took place in October 2011. This paper describes the facility, special design features, and first tests performed in the vacuum chamber.

Keywords

vacuum chamber; electric space propulsion; xenon; thruster; cryopump

Introduction

Electric propulsion is a more and more common method for controlling and propelling satellites in space. Developing and testing these electric engines requires different specifications and infrastructure for test facilities compared to chemical or cold gas propulsion.

In 2011 DLR inaugurated its new "High Vacuum Electric Propulsion Test Facility Göttingen", STG-ET. STG-ET is the acronym for its German title „Simulationsanlage für Treibstrahlen in Göttingen - Elektrische Triebwerke". This facility is part of the DLR test facility network COSMIC which will be presented in more detail in a later section in this paper.

Space Propulsion Testing at DLR

Since decades DLR investigates plume flow and plume impingement of chemical and cold gas thrusters in its high vacuum plume test facility STG-CT. This facility has a vacuum chamber of 7.5 m length and 3.3 m diameter (Figure 1). The enormous gas flow pumping capability is provided by a liquid helium-driven cryopump with an area of 30m² at temperatures of 4.3 K [1]. Having such a low temperature enables even hydrogen pumping. At DLR, experiments go hand in hand with numerical simulation as DLR has expertise and tools for modelling rarefied gas flows.

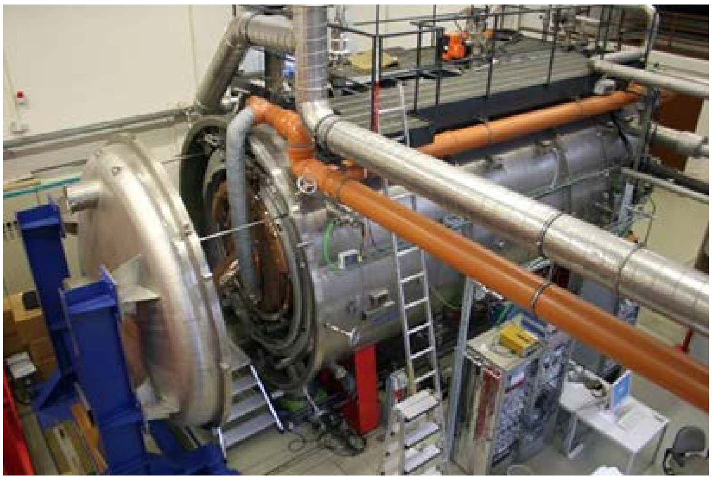

Figure 1 – STG-CT, high vacuum plume test facility

DLR and Its Test Center Cluster COSMIC

There is a worldwide trend towards development of smaller and compact satellites. The satellite size can be classified according to their mass into nano-class satellites with masses up to 50 kg, and pico-class satellites with up to 1kg. These low weight classes emerge from the effort to realize cost effective access to space. Utilizing small satellite platforms leads in special cases to a distributed system configuration, the so-called "formation flying". The requirements for these formations are highly precise and dynamic positioning. This pushes development of new types of propulsion systems.

These developments brought up DLR's interest in extending its activities by establishing the test center cluster COSMIC, the COmpetence Center for Small and MICro propulsion, Niedersachsen. The motivation of COSMIC is based on small scale satellite propulsion and developments around compact satellites as mentioned above. This contains future high precision attitude control demands and a broad range of reaction speeds and thrust levels. It covers chemical propulsion, mainly for pulsed operation in the Newton thrust range, and micro-chemical propulsion in the mN and µN range. Furthermore it contains the electric propulsion with its continuous operation in the thrust range spanning from µN over mN up to 1 N for the most powerful thrusters.

The goal of COSMIC the establishment of a test center for the development, qualification, analysis, and improvement of new small and micro-thrusters based on chemical propulsion, cold gas thrusters, and electric propulsion.

At present, STG-ET and another facility, STG-MT (facility for testing chemical and cold gas micro thrusters) are being completed at DLR Göttingen.

Design Requirements for the New Facility STG-ET

A few years ago DLR decided to add electric propulsion to its portfolio. The first step was to establish a test facility for such propulsion systems. An important specification for a new electric propulsion test facility is the maximum gas flow of thrusters and the resulting background or chamber pressure. Geometrical considerations regarding the inside of the vacuum chamber of STG-ET lead to a maximum continuous pumping speed of 200,000 l/s for Xenon. This limits the thruster mass flow to 100 sccm in order not to exceed background pressures of 10^{-4}-10^{-5} mbar. As the established STG-CT facility has an available liquid helium (LHe) supply infrastructure, the plan was to add for the new STG-ET a LHe boost pump with pumping capability of up to 400,000 l/s. The available helium supply allows a continuous operation for about 24 hours per week. This, on the other hand, allows higher thruster gas flows for this period at the same background pressure or lower pressure with the same mass flow.

The specifications for measurement and test tasks at the STG-ET facility are:

- Accurate thrust and thrust vector measurement
- Measurement equipment for ion beam profiling also in the thrusters backflow
- Plume and plume impingement investigations on spacecraft components
- EP thruster lifetime tests
- Thruster tests with different gases
- Operation customer oriented with stable/reference conditions

Designing a new test facility dedicated to the above tasks poses several challenges. In the first place, the distance thruster-chamber should be as large as possible in order to minimize the flow of sputtered material and electric interaction with the chamber walls. This means designing the chamber as large as possible.

Electric propulsion engines usually have low thrust values which require sensitive thrust balances. Measuring small forces implies that the instruments are also very sensitive to movements and vibrations which can be caused by vacuum pumps or other mechanical equipment, or transmitted from outside traffic via the floor. For this purpose special design care has been taken for the mechanical decoupling of the STG-ET chamber from vibration sources.

Another issue is that measurement systems which need precise alignment might be disturbed by deformation of the chamber itself. Such deformations might happen due to temperature gradients caused by changing ambient temperature or heating of inner chamber components.

STG-ET Design, Infrastructure and Building

The new STG-ET building is located directly adjacent to the existing nitrogen (LN_2) and liquid helium supply which is used for the STG-CT test chamber (Figure 2). The connecting pipework to the LN_2 and LHe supply has been installed and works so far.

An important infrastructure system is the cooling water supply for facility and thruster under test. The nominal cooling water flow is 20,000 l/h with a maximum of 40,000 l/h. 10 connection points for equipment are available (Figure 5).

Vacuum chamber leak tests and pump down tests have been successfully completed, and the installation of the cryopump compressors has been done.

The chamber deformation effects mentioned above (Figure 4) are reduced by decoupling measurement systems from the chamber structure and by giving some freedom in expansion or contraction to the chamber. In our case the chamber sits mainly on sliding bearings (Figure 5) with only one fixed point. Vibrations from traffic are mitigated by supporting the vacuum chamber by very solid foundation blocks, and placing these well below street level. In our case the floor of the building is about 3 m below the street surface and just above ground water level. Table 1 summarizes the main data of the STG-ET facility.

Figure 2 - The new building which houses the STG-ET vacuum chamber is placed inside the u-shaped laboratory building hosting the STG-CT plume test facility

Figure 3 – Cooling water supply outlets. Left: the pump room, right: vacuum chamber hall

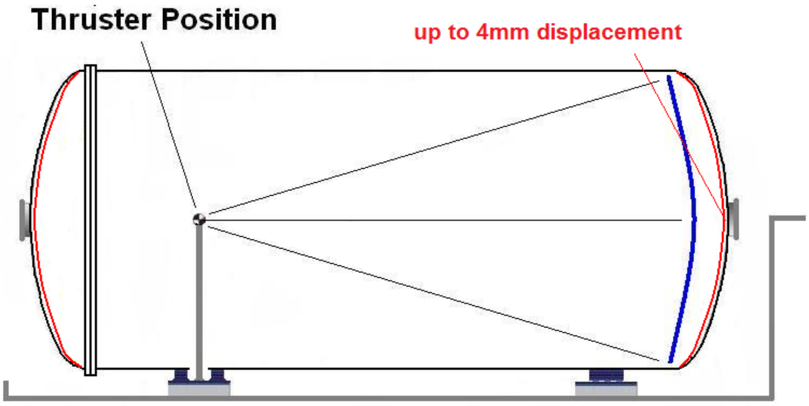

Figure 4 – The vacuum chamber shows a deformation of up to 4mm due to pressure change during evacuation

Figure 5 – View onto one of the sliding bearings on the vacuum chamber foundation

Table 1

STG-ET Features

General Features	• Horizontal axis chamber • Single door design • 169 mounting ports • Engine stand decoupled from chamber wall
Length of vacuum chamber	12.2 m
Diameter of vacuum chamber	5 m
Mass of empty vacuum chamber	25 tons
Volume	226 m³
EP Engine Power Range	≤ 50kW

The major inner components of the STG-ET chamber are actually under development. This refers to the cryopump shrouds and baffles, the liquid helium boost pump, the beam dump targets, and main measurement systems (Figure 6). Concerning the measurement equipment a thrust balance is under development in cooperation with the company Advanced Space Technologies, AST, owned by Dr. Harmann, who also developed the concept of the facility.

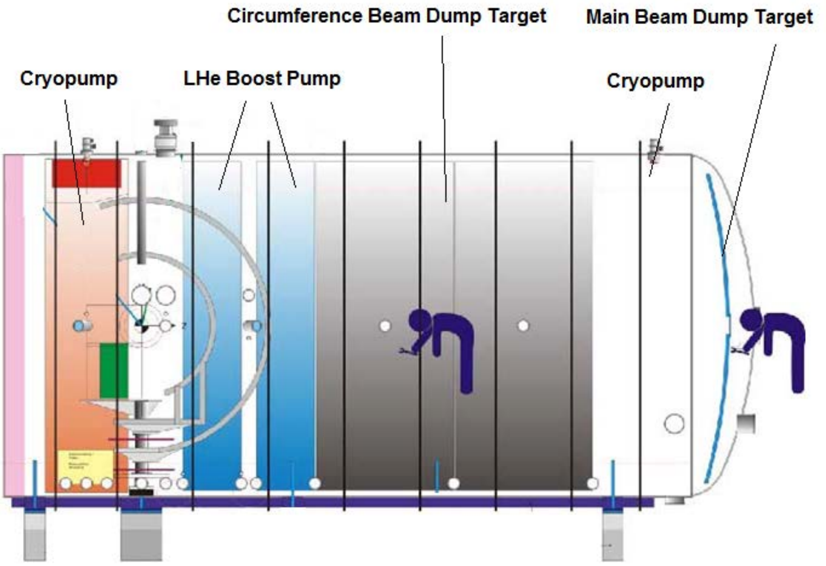

Figure 6 – Sketch of the inner components (see legend)

STG-ET Work in Progress

First Test Runs

In order to demonstrate and inaugurate the STG-ET facility a RIT thruster (Radiofrequency Ion Thruster) provided by the University of Giessen has been installed in the vacuum chamber. Figure 7 displays this type of engine and the installation setup in the vacuum chamber. Finally, Figure 8 shows the first operation of the thruster in DLR's STG-ET facility. For these tests the thruster was operated with argon. As a result, it turned out that a background pressure of less than 10^{-4}mbar could be maintained using mechanical pumps only.

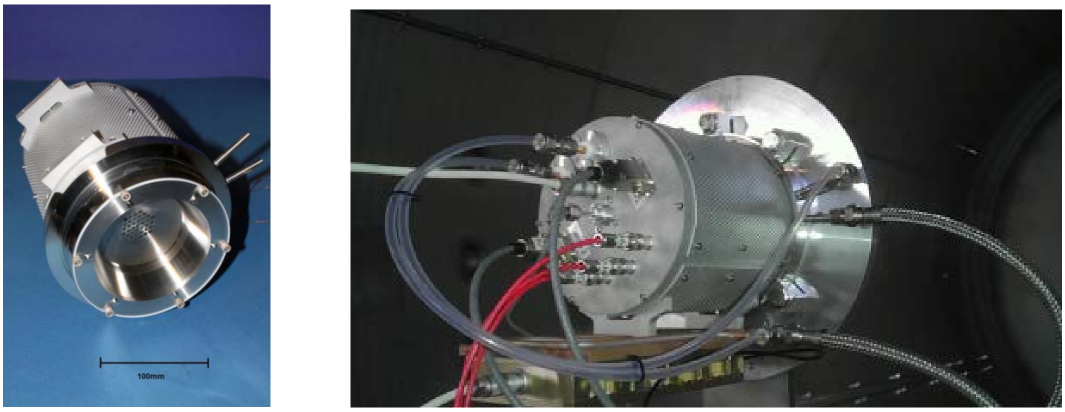

Figure 7 – Left: the RIT ion engine. Right: connected engine in the STG-ET vacuum chamber

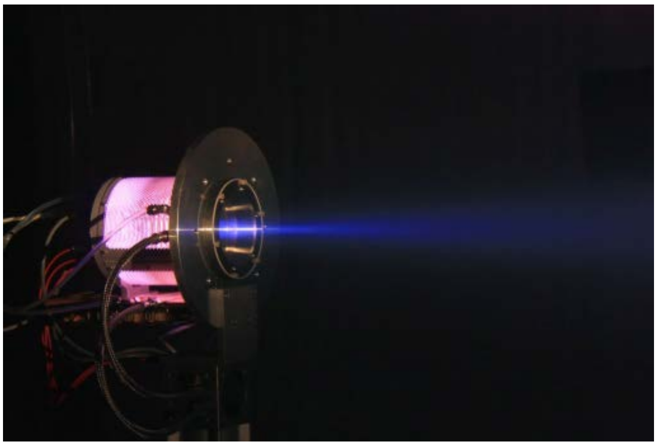

Figure 8 – RIT engine in operation in the STG-ET vacuum chamber. With this type of thruster, the beam is well focussed

Summary and Outlook

The vacuum chamber of the STG-ET facility was completed in 2011, and the inauguration took place in October 2011. The beam dump target and the cryopump design and installation are under way. The facility had a first radiofrequency ion thruster installed and operated. The completion of STG-ET is scheduled for the first half of 2013.

Concerning its activities with respect to electric propulsion DLR is cooperating in the first place with the University of Giessen within the project LOEWE RITSAT, with the IOM Leipzig and with the IRS Stuttgart. Cooperation and dialogue with industrial companies give fruitful information about needs and future developments within the frame of electric propulsion. These hints can directly be taken into account when performing the next steps in completing the STG-ET chamber and its peripheral components.

References

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