A NEW FRENCH FACILITY FOR ION PROPULSION RESEARCH

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Abstract

A new French facility for ion thruster research is under development. The facility will allow basic research to be conducted on the properties of ion thrusters, including the properties of the ion jet and of the ion source. A large vacuum chamber associated to a cryogenic set of pumps is designed in order to optimize the simulation of the flight characteristics of orbital satellites. The chamber will be equipped with various permanent diagnostics, such as electrostatic and ion probes, thrust balance and plasma mass spectrometer. Other diagnostics, mainly laser based, will also be used for particular research needs. The facility will be accessible to many French research laboratories participating to the joint CNES/CNRS/SEP program on ion propulsion, and will permit to develop new studies with the aim of better analysis and prediction of the global performances of the ion thrusters.

Introduction

A new facility for ion propulsion research is under development in France. This research program initiated by the CNES (Centre National d'Etudes Spatiales), is supported by the CNRS (Centre National de la Recherche Scientifique) and the Conseil Régional Centre (the Orléans Region Government, where the facility will be definitively located). This research effort involves three research laboratories: Laboratoire d'Aérothermique where the facility will be installed, this laboratory is presently located at Meudon near Paris, but will move to Orléans in 1997; the two other laboratories are already located at Orléans: the Laboratoire de Combustion et des Systèmes Réactifs (CNRS) and the Groupe de Recherche sur l'Energétique des Milieux Ionisés (CNRS and University of Orléans). The use of the facility will be open to other laboratories involved in the CNES/CNRS/SEP joint research program on ion propulsion.

The studies on ion propulsion to be conducted with this facility will be aimed to investigate the main global characteristics of the investigated thrusters (such as thrust, efficiency, oscillations of the discharge current, erosion and sputtering) and local properties of the jet (such as electron and ion current, electron and ion energy distribution function, relative concentrations of neutral species and ions, characteristics of magnetic fields).
The ultimate aim of the studies is the development of a global model for the prediction of the performances of ion thrusters.

The facility will mainly consist of a large vacuum chamber associated to a cryogenic set of pumps designed to optimize the simulation of the flight characteristics of orbital satellites. The chamber will be equipped with various permanent diagnostics, such as electrostatic and ion probes, thrust balance and mass spectrometer. Other diagnostics, mainly lasers, emission spectroscopy, one- and two-photon laser induced fluorescence, will also be used for particular research needs.

The new facility, which is complementary to the existing facilities of the SEP [2] and of the Laboratoire de Physique des Milieux Ionisés [3], is an essential element of the CNES electric propulsion research program [1], where the main objective is to develop the necessary scientific and technical expertise in order to further the development and the use of ion thrusters by the French space industry. The main characteristics of this facility and of its accompanying permanent diagnostics are described in this paper.

**Description of the Facility**

The future facility named PIVOINE (Propulsion Ionique pour les Vols Orbitaux - Interprétation et Nouvelles Expériences) mainly consists of:

- a cylindrical vacuum chamber with lock chambers
- a group of pumps (primary pumps and cryogenic pumps)
- power supply for the anode, the cathode and magnetic coils
- Xenon mass flow controllers and pressure transducers
- a process control system (PCS)
- various basic diagnostics (electrostatic and ion probes, plasma mass spectrometer, axial thrust balance, spectra analyzer, Hall-effect probe).

**The vacuum chamber**

The cylindrical vacuum chamber is 2.2 m in diameter and 4 m in length and has two parts: a first moving part for the pumping system and a second part for the plasma thruster and the diagnostics. The chamber will be placed horizontally on a rail system. The chamber is made of stainless steel and the inner surface will be treated by polishing. A schematic description of the vacuum chamber is shown on Figure 1.

A lock chamber along the horizontal axis is used to extract the thruster from the chamber to allow modifications on the thruster, while maintaining the vacuum in the chamber. The displacement system of the thruster including the pendulum balance is computer controlled; the displacement velocity is 500 mm.s\(^{-1}\) and the maximum travel is 1.7 m. This displacement system allows an axial exploration of the Xenon jet. The limit position of the displacement system enables to explore the thruster exit section with the plasma mass spectrometer and the electrostatic and ion probes (Fig. 1). A lock chamber is used for the plasma mass spectrometer and the probes. These diagnostics are moving with another computer controlled displacement system. This displacement system is horizontal and perpendicular to the axis vacuum chamber. It allows a radial exploration of the Xenon jet. The displacement velocity and the maximum travel are the same for the thruster and diagnostics. The diagnostic arm will be protected from the energetic Xenon flux by a graphite device.
The lock chambers are connected to the primary pumps. A set of accesses for windows is provided for future optical measurements, such as emission spectroscopy (visible and VUV), and laser induced fluorescence (1 and 2 photons). Other accesses are also available on the vacuum chamber.

The pumping system

The pumping system (Air Liquide-Balzers) is located in the moving part of the vacuum chamber (left part on the Fig.1). The pumping system has two stages. A primary group, (consisting of a primary dry pump with a flow rate of 80 m$^3$.h$^{-1}$, and a Roots pump with a flow rate of 1195 m$^3$.h$^{-1}$, will lower the pressure down to $10^{-2}$ mbar, permitting to start the cryogenic pumping system to reach the operating pressure of $10^{-5}$ mbar. The cryogenic pumping system is organized in four parts. The atmosphere residual gases is absorbed by a cylindrical flat disk coupled to a cryopump with a power of 15 W at a temperature of 20 K. The Xenon is absorbed by a second disk with three cryopumps with a power of 70 W at a temperature of 40-50 K. The flow rate is 30,000 l.s$^{-1}$ for residual gases and 70,000 l.s$^{-1}$ for Xenon. To protect the absorbing disk, a device with a liquid nitrogen cooling circuit is placed between the Xenon jet and the disks; this device also condenses the water vapour contained in the chamber. Annealed graphite plates protect the baffle blades against the sputtering due to Xenon ions. Tests will be conducted in a reactor at the DERTS/ONERA facilities in Toulouse in order to select the more suitable graphite type. A cylindrical piece inserted in the inner part of the chamber insulates the pumping system from the radiative energy coming from the inner surface chamber. The characteristics of the pumping are defined to produce a vacuum of less than $2 \times 10^{-5}$ mbar with a Xenon mass flow rate of 5.3 mg.s$^{-1}$. A schematic view of the pumping system is presented on Fig.2.
The pumping is monitored and controlled by the PCS with two Pirani gauges (up to $7 \times 10^{-4}$ mbar) and two Pennings gauges ($10^2$ to $10^{11}$ mbar). A set of two gauges is placed at each parts of the chamber to evaluate the gradient of pressure. Pirani gauges are located on the thruster lock chamber and the diagnostic lock chamber.

![Diagram of pumping systems](image)

**Figure 2. Primary and cryogenic pumping systems.**

**Diagnostics**

The instrumentation described below will permanently equip the facility. However, the facility is designed to receive other diagnostics, mainly laser based and spectrophotometer to be used in the framework of the French electric propulsion program.

**Thrust balance**

A thrust balance will be used to measure the axial thrust. A pendulum type balance (three metallic wires) will be mounted at the end of the moving arm. The thrust measurement is obtained by a strain gauge. The balance will be developed to measure the thrust in the range 50-200 mN with a precision of 3%. The balance will be fixed at the extremity of the thruster displacement system and will be locked during the displacement. The calibration will be performed with the balance placed in the chamber with its connections and with applied weights. A thermal probe will permanently measure the temperature of the gauge in order to correct the thrust measurement.

**Residual gas analyser**

A mass spectrometer (Balzers 064) will be permanently inserted in the right moving part (Fig.1) of the vacuum chamber for the analysis of the residual gases with a selection of mass between 1 and 64 amu. The total pressure and the partial pressures of species $\text{H}_2$, $\text{He}$, $\text{H}_2\text{O}$, $\text{N}_2+\text{CO}_2$, $\text{O}_2$ and, $\text{Ar}+\text{CO}_2$ are recorded by eight analog channels connected to the PCS. The choice of the selected mass can be varied in the range of 1 to 64.
Plasma mass spectrometer

The relative concentrations of ions and neutral species will be measured by a plasma mass spectrometer. The energy distribution function of ions will also be determined. The plasma mass spectrometer will be developed by CETP (Centre d'étude des environnement terrestre et planétaires) which has expertise in the design of spectrometers used in space probes. The plasma mass spectrometer is of type Mattauch-Herzog with permanent magnet. It will analyze mass ranges 1-200 amu with 1 amu resolution, and ions energy up to 600 eV with a 0.05 eV resolution. This mass analyser will be protected from the energetic Xenon flux by a graphite device and fixed on the radial displacement system.

Electrostatic probes

Single and double electrostatic probes will be used to determine the current-voltage characteristics and the electron energy distribution function (EEDF). The tungsten wires of the electrostatic probes will be inserted in an aluminium oxide tube. The electrostatic probes are polarized by a voltage generator delivering periodic potentials with adjustable characteristics and fixed on the radial displacement system. The EEDF will be obtained by the second harmonic method using a modulation of the probe voltage. Two phase locking amplifier will detect the second harmonic and will improve the ratio of the signal to the noise. A VXI system will be used for the polarization and for the four channel acquisition system with a maximum sampling rate of 20 Mhz and 12 bits resolution.

Ion probe

Ion probe will be employed to determine the mass integrated ion energy distribution function (MIIEDF). These probes use a set of four polarized grids and can be used also to measure the EEDF. The order of the resolution is around 1 eV.

Frequency analyser

The frequency analysis of the discharge current fluctuations will be obtained by a high frequency acquisition VXI system connected to a computer.

Hall-effect gaussmeter

The magnetic field without plasma will be measured by a three-axis Hall Effect probe combined with a multi-channel gaussmeter. The gaussmeter can display readings from all axis simultaneously with different displays for each channel. The probe will be chosen to work in a range 30 mG-3 kG with a resolution up to 10 μG and an accuracy of 0.05%.

Conclusion

A new French facility (PIVOINE) will allow basic research to be conducted on the properties of ion thrusters, including the integral performances, the properties of the output plume and of the ion source. The research and test possibilities offered by the PIVOINE facility will be open to several French laboratories in the framework of the CNES/CNRS/SEP joint research
program on ion propulsion. The ultimate objective of this program is to closely combine the basic analysis and the development of ion propulsion thrusters for orbital satellites.

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References