Neutraliser for FEEP: review on the development status

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Since year 2005 a new neutraliser concept has been developed, to be used for neutralisation of the positive charges in the beam of FEEP thrusters. The unit design is now mature for the flight phases of both the European LISA PF and Microscope programs.

The device is based on a small light and low power consumption Barium impregnated cathode operating without the need of Xenon gas. The neutraliser works in a biased diode configuration allowing the extraction of electrons and their acceleration to be independent processes separately controlled by the Power Supply Unit.

The qualification activities have been successfully completed on both the two mentioned programs. Lifetime tests are presently concluded under the MICROSCOPE program (1000h) and ongoing under the LISA PF one (6000h expected, more than 3500h, presently achieved).

During ground tests these devices have demonstrated the ability to emit the specified current levels asking for a negative bias of few tens of Volts. Then, it is possible to summarise that the key advantage of this neutraliser design is the possibility to efficiently perform the neutralisation of low current ion beams by operating both without the need of a gas feed-line and with a maximum power dissipation less than 5 Watts.

The possibility to scale up the present design to neutralise the beam generated by ion or mini hall effect thrusters as well as to use this technology to alleviate charging problems for GEO (or LEO polar) spacecrafts are to be considered additional possible applications, presently under investigation.

References


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Nomenclature

**E-GUN** = Electron Gun (generator and electron accelerator)
**EQM** = Engineering Qualification Model
**EM** = Engineering Model
**EP** = Electric Propulsion
**ESA** = European Space Agency
**FEEP** = Field Emission Electric Propulsion
**FM** = Flight Model
**GEO** = Geostationary Earth Orbit
**HET** = Hall Effect Thruster
**Ia** = Anode Current
**Ic** = Cathode Current
**Ih** = Heater Current
**LEO** = Low Earth Orbit
**LPF** = Lisa Path Finder, as LISA (Laser Interferometer Space Antenna) precursor mission
**MPS** = Micro Propulsion Sub-system
**NA** = Neutralizer Assembly (containing 2 NU), referred to the LPF application
**NU** = Neutralizer Unit
**PPCU** = Power Processor & Control Unit (part of the EPSA)
**PS** = Power Supply
**QM** = Qualification Model
**SCL** = Space Charge Limitation (referred to a possible cathode emission regime)
**SC** = SpaceCraft
**TAS-I** = Thales Alenia Space Italia
**TL** = Temperature Limited
**Vanode** = Voltage applied to the accelerating electrode of the neutralizer also called anode
**Vtarget** = Voltage applied between the cathode and the target; also called Vbias
**Vheater** = Voltage applied to the heater of the neutralizer

I. Introduction

FEEP (Field Emission Electric Propulsion) is considered an important technology for future European scientific missions, in that it shall be able to provide a very fine tuning of torques and forces for actuating the precise attitude and “drag-free” spacecraft control; during the operational phase. FEEP thrusters would provide a controlled and repeatable thrust level in the range of 1 to 100 µN, with a thrust noise below 0.1 µN and a specific impulse higher than 6000 s.

Currently the FEEP is under evaluation for the Microscope and is embarked on Lisa Path Finder (LPF) ESA supported missions.

The Neutralizer Units (NU) are key components of the FEEP MPS (Micro Propulsion Sub-system) as they are fundamental for the correct FEEP in space operation; they provide electrons for the compensation of positive charge in the ejected ion beam. In this way the build up of electrostatic charge on the spacecraft surfaces can be prevented and the spacecraft neutrality can be kept. This aspect is particularly delicate in missions like Microscope and LPF where any perturbation force (including the electric and magnetic ones) acting on the spacecraft has to be drastically avoided in order to not jeopardize the successful accomplishment of the scientific experiment.

The FEEP NU, built at TAS-I FI, is based on a small “electron gun” design in diode configuration. The electrons are extracted and accelerated, from the thermionic emitter (cathode) through an accelerating electrode, into the ion beam of the FEEP. The emitter is heated up to the electron emission temperature by a heater located very close to the emissive surface.

The FEEP NU main elements/ parts (in diode configuration) are:

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• Electron emitter (cathode subassembly) and its heating provision;
• Thermal Screen;
• Anode (or extraction electrode) used to extract electrons from the cathode and to focus them in a beam profile;
• Electrode Insulation Structures;
• Gun shell or Mechanical/supporting Structure.

II. NU Configuration/architecture

The device is realized by integrating the thermionic cathode and the beam conditioning electrode structure into a suitable mechanical support that will also be in charge of handling thermal issues. The electron gun is configured like an axial-symmetric cylindrical structure. The electrode configuration is planar with a shaped outlet to focus electrons; the cathode emissive surface is shaped as a spherical segment.

The NU electron emitters (cathode) are provided by SPECTRAMAT INC. and are based on a porous Tungsten (W) matrix impregnated with Barium – Calcium – Aluminum oxide chemicals. The kind of chemicals impregnation selected for the FEEP NU is such to allow the best possible trade-off between emitted thermionic current and electrical power necessary to heat up the cathode at the thermionic emission temperature.

The selected impregnation for the cathode is the 6:1:2 (BaO – CaO – Al₂O₃) with small quantity of Scandium added. The use of this advanced chemical mixture in principle is expected to allow a further lowering the cathode work function (from 2.1eV for standard 6:1:2 down to ≈1.8eV). This expected enhancement positively impacts the heating power demand and allows to cope with the very challenging requirements on power budget (for both the Microscope and LPF missions).

These types of cathodes have experimentally demonstrated smooth variation of the current density with temperature at low emission, allowing the control of the emission process by implementing an operational mode based on a mix of Space Charge Limitation (SCL) and Temperature Limitation (TL) regimes.

Before nominal operation, the impregnated cathode has to be “activated”. During the cathode “activation” process the compounds of impregnation diffuse up into the surface. The cathode activation is a slow process within which the heating power is raised progressively during a time span of about 48 hours for achieving the nominal electron emission current density at the cathode surface. After the activation process, the NU can be normally operated following few minutes of heating up and applying the necessary accelerating voltage to the anodic structure:
The main body of the NU is composed by two ceramic supports brazed to 3 cylindrical Molybdenum flanges used, one to interface the cathode sub-assembly, one to sustain the anode structure and the last to interface the external Titanium case; finally cover cases made in Titanium are screwed with the main Molybdenum flange.

III. NU Activities Status

Several devices have been realized and tested in the last years. These are:
- three Qualification model Neutralizer Units (NU) for the Microscope program;
- two Engineering model Neutralizer Assembly (NA) for the LISA PF program;
- one Neutralizer Assembly Engineering Qualification model for the LISA PF program equipped with one NU and a dummy neutralizer.

The qualification tests were successful on both the Microscope and LISA PF programs. The QM and the EQM NA models have performed mechanical thermo-vacuum and functional tests according to requirements of the programs.

The functional and thermal vacuum tests have been performed in a high vacuum facility equipped with an high speed turbo pump operating together with a ionic pump; the system is able to reach vacuum level in the $10^{-9}$ mbar range in static condition. The Neutralizers were controlled with an automatic computerized workstation hosting Labview software, able to simulate the main functionalities of the flight Power Control Unit.
Steady state operation is achieved with the following nominal parameters (data from the EQMmodel for LISA PF): 
- **W heater** = 1.9 Watts;
- **W anode** = 1.5 Watts;
- **W bias (target)** = 1.3 Watts.

The operational temperature of the cathode tip is about 940°C; in this condition, a current emission up to about 10 mA to the target is typically obtained (significantly higher than the required current of 6 mA). The functional scheme used during vacuum tests is shown in the next figure: three PS are used one for heating the cathode (heater), one for the anode (or accelerating electrode) and one to polarize the cathode with respect to the target; by selecting the position of a ground switch (see 11 in the next figure) either a negative cathode bias or a positive target configuration can be tested.

![Functional scheme of the test set-up used for testing the Neutraliser for FEEP](image-url)
In the next figures results from a typical functional test are reported showing the profiles of voltages and current vs. testing time: three bias voltage levels are used during functional tests (200V, 100V, 50V); the cathode is polarized negative with respect to the target; the test allows to verify emission capability varying the external electric field. 

Voltage profiles vs. time as applied during functional test:

Current profiles vs. time as applied during functional test (Ic: cathode current; Ia: anode current; I{EQM: Target Current; Ih: Heater current)

After the qualification test campaign the QM neutralizer model from the Microscope program performed a 1000h lifetime test whereas the LISA EQM one is, nowadays, still performing the lifetime test having already cumulated a life period of more than 3500 hours. In the next table, results of the various functional tests during qualification and lifetime test are reported, showing stable operational parameters through the accumulated life.
Summary of functional test averaged parameters for the LISA EQM model during qualification campaign and lifetime test

Furthermore, the LISA EQM and two QM devices from the Microscope program have been subjected to an air exposition/humidity test to verify the robustness of the cathode against air exposition. The test consisted in holding the neutralizers exposed to a controlled humidity and temperature ambient atmosphere for 50 days; after the exposure, all the cathodes have been retested successfully and the EQM unit was used for the on-going lifetime test as described in the previous section of this paper.

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<td><strong>After vibration</strong></td>
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**Test Set-up arrangement for the Air exposure test at TAS-I**

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IV-Conclusions

The neutralizer for FEEPS technology and programs has, nowadays, reached successfully a mature stage. The device design and manufacturing have been qualified for two ESA programs and a lifetime test is presently on-going very satisfactory.

The demonstrated capability to sustain air exposition for a long period without affecting performances and lifetime is considered a key element for the demonstration of the reliability of such technology.

In view of their very light mass, their capability to operate without the need of an inert gas (as per standard Hollow cathode devices), it is possible to propose additional applications for this type of technology, different than the present one (neutralizer for FEEPS); these are suggested here below:

• neutralizers for other low thrust Ion Engines and/or Hall effect thrusters technology;
• active negative charging compensator for GEO and LEO POLAR Spacecrafts: a feasibility study named ACCS (Active Charging Compensator System) under ESA support is already started at TAS-I;
• very low thrust thrusters based on energetic electron beam emission.