The µNRIT-4 Ion Engine: a first step towards a European mini-Ion Engine System development.

IEPC-2007-218

Presented at the 30th International Electric Propulsion Conference, Florence, Italy

September 17-20, 2007

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As a demand for small gas-discharge ion engines with a thrusting range between few Micronewtons and a few Millinewtons appeared, Giessen University started a RIT-scaling-down program, funded by DLR(1). Two µN-engines, µNRIT-4 and µNRIT-2, have been built in the workshop of the institute, a $2m^3$ test facility has been developed and preliminary scaling laws have been established in order to predict the performance data of rf-thrusters with ionizer diameters less than 10cm [2].

Following preliminary tests of the microthrusters at Giessen [3] and a demonstration test campaign of the RIT-4 laboratory prototype at ESTEC/ Noordwijk, ESA/ ESTEC placed a GSTP-contract to ASTRIUM ST (with the University of Giessen as subcontractor) in the beginning of 2007.

In the meantime, the performance of the µN-RIT-4 has been improved remarkably by new design and using new peripheral supply units.

I. Introduction

ESA founded studies based on future Earth Observation and Science Missions have highlighted the advantages of using Electric Propulsion systems to satisfy specific propulsion and control needs using a single design concept able to perform in the milli-Newton and micro-Newton thrust regime.

In particular the EP fuel mass efficiency advantage was considered for application such as drag compensation, orbit control and reconfiguration; the EP high thrust accuracy property was considered for applications such as disturbance cancellation and controlled formation flying.

Small Gridded Ion Engines with rf-ionizers having a thrust range from a few µN up to some mN are candidates for on-coming missions which could benefit from the advantages of this thrusters type, namely the possibility of using an inert gas as propellant, the high specific impulse provided, the simple and precise thrust control, the system reliability and long lifetime as well as the mechanically easy miniaturization (both facts due to the absence of discharge electrodes and magnets). A further advantage could be the small beam divergence which allow for a reduced interaction with the spacecraft.

In order to respond to those specific propulsion and control needs, in 2004 Giessen University started several R&D activities using its cumulated experience on the well known radio-frequency technology commercialized by ASTRIUM (Germany).

Applying the well established scaling laws based on larger RF-thrusters with more than 10cm diameter, a prototype of 4cm diameter, the µNRIT-4 Ion Engine, has been manufactured.

During 2006 the µNRIT-4 Ion Engine has underdone several ESA founded studies based on future Earth Observation and Science Missions test campaigns to establish preliminary performance and to verify compliance with scaling laws predictions. During a test campaign performed in the ESA Propulsion Laboratory at ESTEC, the µNRIT-4 Ion Engine prototype, equipped with two different extraction systems, demonstrated thrust capability in the two mentioned thrust regimes. Data on beam divergence were also obtained for different operational conditions.

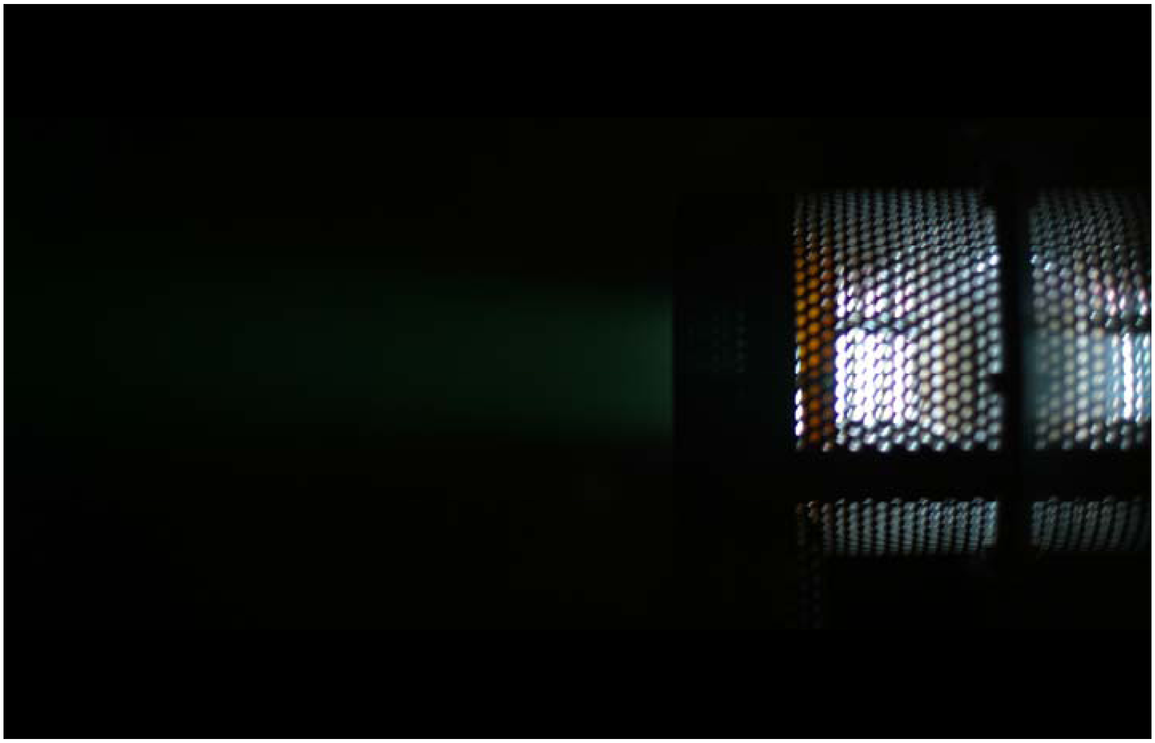

Figure 1: µNRIT- 4/151 in CORONA test facility

II. Test campaign in CORONA vacuum chamber at ESA/ESTEC

II.A.Test Facility

Figure 2: CORONA test facility

The characterization test of the µNRIT-4 Thruster was performed in the Vacuum Facility #4, CORONA located at the ESTEC Test Centre. The CORONA VF is composed of a main chamber of 2m diameter and 4m length and a hatch of 1m diameter and 1m length.

The combined pumping system during previous test allowed obtaining 10000L/s pumping speed in the main Chamber and 7500L/s pumping speed in the hatch (@ 0.05sccm of Xe MFR).From this list the key items of the PSCU are the high voltage power supplies, since they have to convert high power, they need to provide reliable high voltage insulation and they are significant for the thruster performance.

II.B. Test Equipment

The Thruster control unit included:

- A PHV-Us Power Supply (it was changed during the mN-range test)
- A NHV Power Supply
- A RF-Generator Aux
- A RF-Generator Power Supply
- A NTR Power Supply

The Feeding System, including the following valves, was installed outside of CORONA facility: It included Xenon supply, mass flow controller and purge system.

II.C. Plume Diagnostic System

The plume diagnostic system located in the CORONA facility was used to measure charged particle in the beam of the Thruster, in order to provide beam characterisation data and to calculate the beam divergence.

The diagnostic includes a system of 11 Faraday cup probes mounted on a semicircular movable arm and pointing at the central axis of the thruster exit, as shown in the Figure 11. The distance between the thruster and the central probe was 148 cm. A drawing of the plume diagnostic system is shown in figure 3.

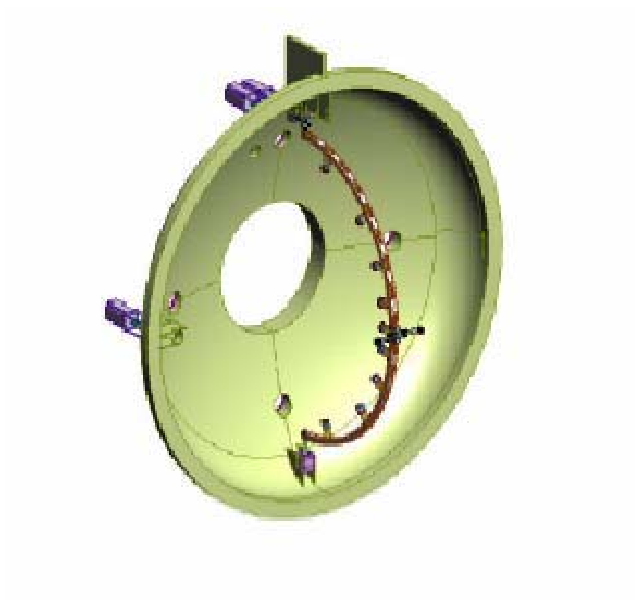

Figure 3: Faraday Cup probes array

III. Results of the test campaign in CORONA

The objective of the µNRIT-4 Thruster Operational/Characterization test was to take a preliminary characterization of the Thruster in order to gather useful information for the future development. These four objectives are chosen:

• Characterization of the µNRIT-4 Thruster performance data in the thrust range 20µN-120µN (mass efficiency test, specific impulse test)

• Mapping of the µNRIT-4 Thruster at 75µN (steady state performance)

• Thrust throttling test (thrust range)

• Beam characterization (divergence measurements)

Moreover a Thruster short-characterisation with a different extraction system has been performed to gather information on operation of the thruster in the mN-thrust range.

III. A. Mass Efficiency Results

Mass efficiency is measured in different thruster operating parameters. Figure 4 shows the mass efficiency of the μNRIT4 with 7 holes as a function of its thrust. This measurement is done by a fixed extraction voltage of 1400v.

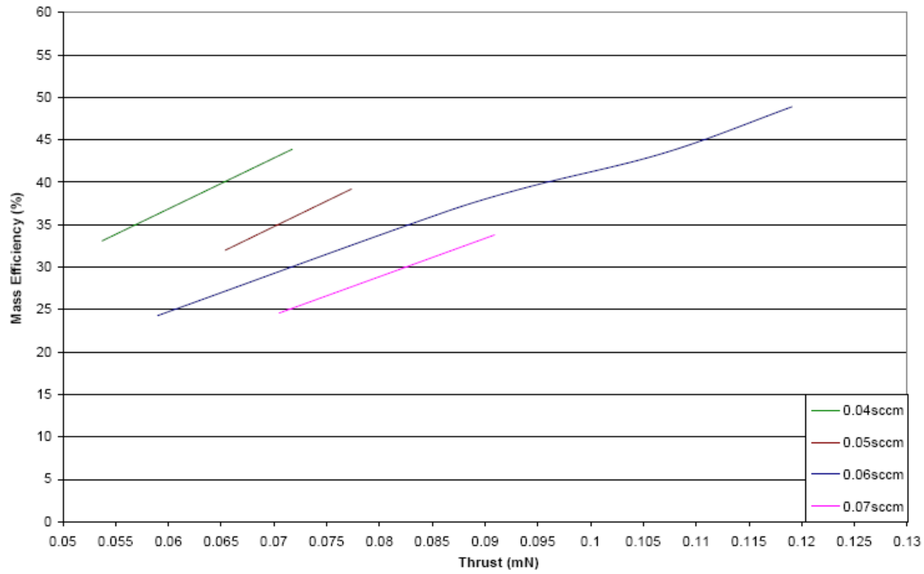

Figure 4: Mass Efficiency Test Results. Mass Efficiency vs. Thrust @ constant MFR

III. B. Beam Divergence Results

Assuming that the beam is cylindrically symmetric, the divergence is defined as the half-cone angle subtended from the centre of the grids that includes a specified percentage of the high-energy ions leaving the thruster. A typical value of 95% is used for the inclusion percentage when considering the divergence of ion engines.

All the beam scans were performed during the steady-state operation of the thruster at 75μN.

Since the rotation axis of the arm on which the probes were mounted and the exhaust plane of the thruster were not coincident, a correction was applied both on the angles acquired during the scan and on the acquired probe current. A typical beam profiles, given by the scan with the central probe, is shown in Figure 5.

The divergence value for the shown in figure 5 is 15.2°.

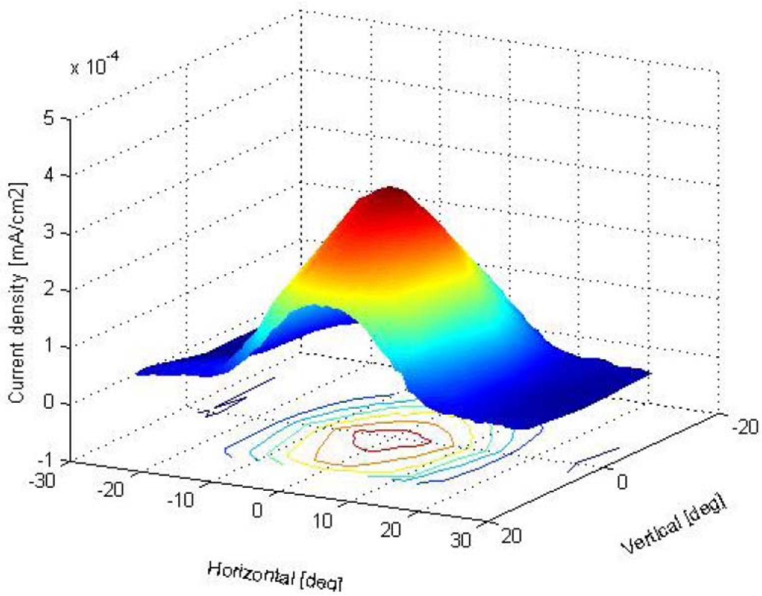

Figure 5: 3-D plot of beam current density vs. angular position at Us=1700V for 75uN

III.C. Thrust Throttling Test (Thrust Range)

Figure 6 demonstrates the test results of the thruster operation over a thrust range from 25µN to 112 µN. Thrust stepping is done by changing the RF power. Alternatively the extraction voltage can be changed for thrust regulation. Thrust steps of 0.44µN are achieved. Thrust rise time was under 20 mSec.

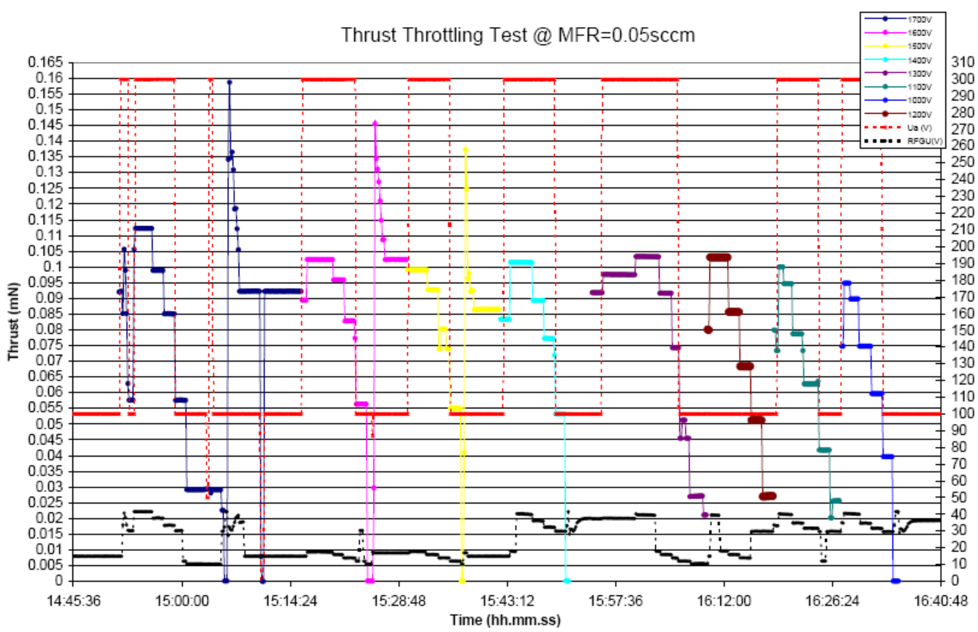

Figure 6: thrust range and regulation test.

IV. Test campaign in Giessen test facility BIGMAC

In February/March 2007, after innovative modifications done in collaboration with ASTRIUM ST and IOM GmbH three small µNRIT-models have been manufactured and performance mapped at Giessen University, namely:

- The µNRIT-4/151 Ion Engine with a 151 holes extraction system (thrust range from 150 µN to 3.5 mN)
- The µNRIT-4/7 Ion Engine with a 7 holes extraction system (thrust range from less than 10 µN to 200 µN)
- The µNRIT-2/7 with a 7 holes extraction system (with an analogous thrust range of the µNRIT-4/7).

During the test activities the propellant flow controller has been calibrated and the optimum positive high voltage and discharge frequency values have been determined, obtaining a confirmation of the theoretical prediction.

The obtained specific data of µNRIT-4/151 Ion Engine were (in agreement with theory) somewhat inferior to those of the larger RIT-10 or RIT-22 thrusters, but still very satisfactory. At 3.5mN of thrust, the propellant efficiency was 80%, the power efficiency 60%, and the power-to-thrust ratio 40W/mN. The specific impulse exceeded 3700s. The discharge pressure has been calculated to be about $4 \cdot 10^{-4}$ Torr, which gives a thrust of the neutral particles efflux of 0.1 % of the ion thrust maximum.

The µNRIT-4/7 Ion Engine showed approximately the same discharge characteristics, but 151/7 times smaller ion currents and thrust levels together with the related smaller power efficiency compared with the µNRIT-4/151 model. The µNRIT-2/7 showed less power demand than the µNRIT-4/7 one, but an increased demand of flow rate. A 1 cm µNRIT-thruster with very small holes is currently under construction.

The results of the previous test activities have recently been used as reference during the execution of the ESA's GSTP contract aiming to the development of a mini ion engine system for Fine Pointing and Attitude Control, controlled Formation Flying and Drag Compensation managed by electric propulsion.

A team composed of ASTRIUM, Giessen University and the IOM GmbH is currently working on the development of the new RIT-µX, an Engineering Model mini Ion Engine capable to answer to the above mentioned mission requirements(4). Successful µ-propulsion technology is closely related to a complete and efficient overall approach for the complete propulsion system including the PSCU Power Supply and Control Unit. For this purpose, funded by the German Space Agency DLR, ASTRIUM in Friedrichshafen is working on a PSCU for mini ion engines. A concept for a complex Power Supply and Control Unit serving up to 12 µN-RITs with a high thrust setting resolution has already been designed. Suitable variations of the concepts for different mission scenarios are currently under trade-off (5).

V. CONCLUSIONS

After the first theoretical works on scaling down of the ion thrusters of RIT type and the first steps to demonstrate the ability of these type of mini thrusters to meet the requirements of ESA future Earth Observation and Science Missions, the mini ion engines of RIT type are reaching the stage of engineering/qualification models. The physics behind their scaling down is meanwhile well known, which helps to design a system specially fitted to specific mission requirements.

VI. REFERENCES

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VII. ACKNOWLEDGEMENT

A significant part of the described work has been funded by the German Space Agency DLR, Entwicklung, Optimierung und Charakterisierung von µN-Triebwerken vom RIT-Typ (µN-RITs).