Performance mapping of new µN-RITs at Giessen

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Some months ago a program has been started at Giessen university to scale down the standard ion thrusters RIT-10. Following recent requirements of EP-microthrusting for attitude control, drag compensation and fleet maneuvers of scientific spacecrafts, RIT-engines with 1 to 4 cm ionizer diameters are under investigation. The R&D work started at Giessen with establishing scaling laws on the base of the larger RF-thrusters with 10cm, 15cm, 22cm, 26cm and 35cm diameters. These theoretical considerations yield the scheduled data of thrust, power and propellant consumption of the RF-microthrusters together with the suggested optimum values of the discharge vessel length, RF-frequency and discharge power. In the mean time a RIT-4 has been constructed and successfully tested in a new 2m^3-vacuum facility, equipped with cryo pumps of 24000 ltr/sec pumping speed. A RIT-2 thruster is just being manufactured. The two engines will cover the thrust range between few µNs and somewhat more than 1 mN. One of the most important requirements of EP-microthrusting for recent scientific missions is the fine controlling of the thrust. For this purpose are some controlling loops and thrust regulation methods under design and evaluation.

I. Introduction

From 1962 till 2001, a family of rf-ion thrusters with 10 cm, 15 cm, 20 cm, and 35 cm of ionizer diameter has been designed, built, optimized, diagnostically investigated, and performance-tested. In addition, a 26-cm diam. thruster "ESA-XX" was successfully tested (1991 - 1998) in the large Giessen vacuum facility "Jumbo", where a 22-cm engine "RIT-22" is now operated by EADS since 2000.

These thrusters cover the thrusting range from 10 mN to 250 mN and have been developed for NSSK and primary propulsion applications.

During the last years, the question arose whether gridded ion thruster could be used in the range of 10 µN to about 300 µN, too. Attractive applications of these microthrusters are e.g. the fine-pointing attitude control, an accurate drag compensation, the controlled formation flying of spacecraft fleets, etc. Some future ESA missions like

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"Darwin", "GAIA", "LISA", etc. would benefit from the stable and precise operation of gridded ion thrusters working with a Xenon gas discharge.

Among this class, the RIT-type seems advantageous, because the ionizer consists of nothing but an isolatiang tube surrounded by a rf-coil.

Therefore, at the beginning of 2004, the 1st Institute of Physics, Giessen University, started a scaling-down program of its standard 10-cm engine "RIT-10".

II. Scaling Laws

At the beginning of the activities, preliminary scaling laws have been established in order to minimize the optimization procedure. Based on the well-known performance data of RIT-10 and on basic plasma physic laws, the optimum discharge parameters (see Fig. 1) and the power and propellant consumption data (see Fig. 2) have been calculated.[1].

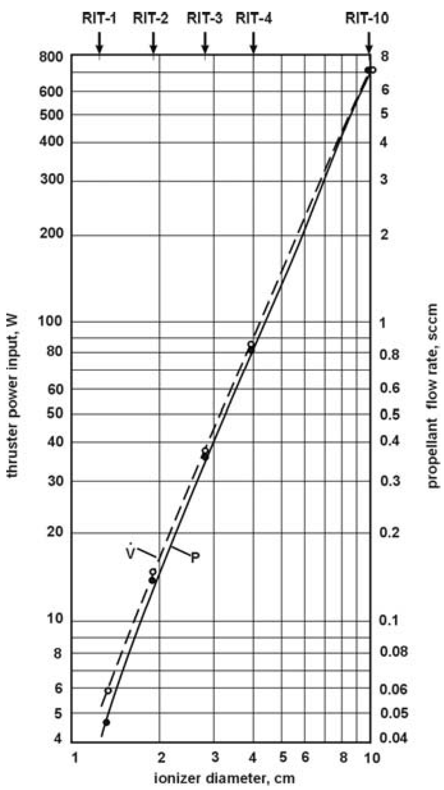


Fig. 1: Optimum rf-discharge parameters as calculated by scaling laws vs. the ionizer diameter.

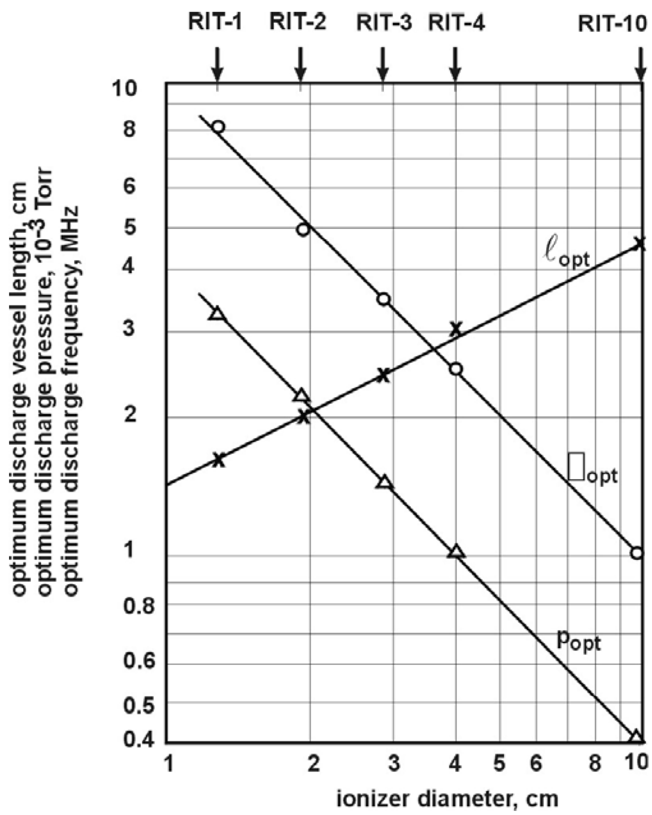


Fig. 2: Thruster power input P and propellant flow rate V̇ (without neutralizer) of 4 rf-microthrusters vs. ionizer diameter as calculated by scaling laws.

III. Laboratory Prototypes RIT-4 and RIT-2

The RIT-concept has been repeatedly described[2] and will be sketched here only briefly:

- The xenon propellant enters the ionizer tube through an isolator and an integrated gas distributor manufactured from Macor.

- The discharge vessel is surrounded by the induction coil of a rf-generator. The induced electric eddy-field accelerates the discharge electrons. The Maxwellian tail of their energy distribution cares for ionization impacts and generates a self-sustaining, electrodeless, annular gas-discharge.

- The plasma ions are extracted, focused, and accelerated by a two-grid system made of molybdenum and graphite. The beamlet hole geometry has been taken from the larger RIT-engines. The number of beamlets can be varied (151, 19, or 7).

- The beam neutralization of the laboratory prototypes is done by a conventional filament electron source. Instead to draw the neutralizer electrons into the ionizer, the discharge ignition could be done easily by a short pressure pulse, too.

Figs. 3 and 4 show drawings true to scale and photos of the 4-cm and the 2-cm Micro-RIT prototypes. Both engines have been built in the mechanical workshop of the institute.

Fig. 3. photo and drawing true to scale and of the 4-cm µNRIT-4 prototype

While the larger prototype has been designed in a conventional way, the smaller one shows some new constructive elements:

- The discharge vessel consists only of a quartz or ceramic cylinder, which enables an easy change for a shorter or longer one during optimization procedure.
- All thruster parts are put together and clamped by three screw rods, which enables not only a non-problematic manufacturing, but also a fast assembly or disassembly.

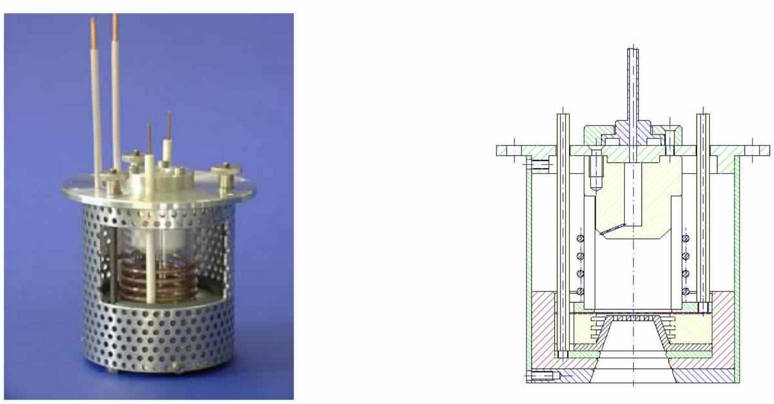


Fig. 4. photo and drawing true to scale and of the 2-cm µNRIT-2 prototype

IV. Test Facility "Big Mac"

For investigation of the laboratory prototype rf-microthrusters, a new vacuum test facility as been built and put in operation in 2004. Due to its shape (see Fig. 5) it is called "Big Mac".

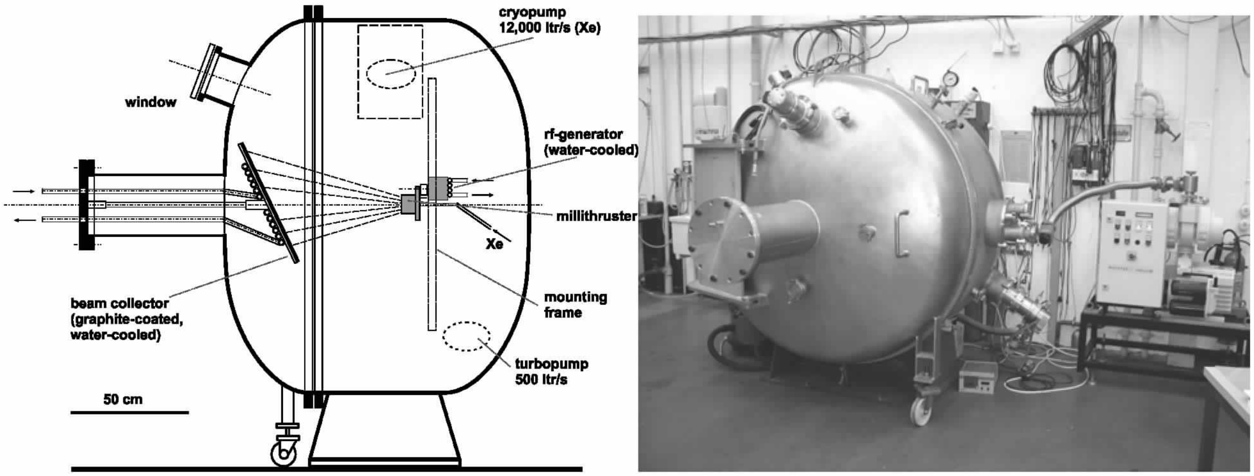


Fig. 5: Drawing true to scale of the new 2.2 m^3 EP-test facility "Big Mac" of Giessen University. Photo of the new 2.2 m^3 EP-test facility "Big Mac" of Giessen University.

The vacuum vessel has a volume of 2.2 m^3. The pumping system consists of two cryogenic pumps with 12,000 ltr/s for Xenon, each, and of two 500 ltr/s-turbo pumps. At full-power operation of RIT-4, a background vacuum of $1\cdot10^{-6}$ Torr is maintained.

The thruster and its rf-generator are mounted on a frame of structural bars. There is enough space to install later a thrust balance and a rotating diagnostic beam scanner.

The beam collector is made of copper sheet. It is water-cooled and covered with a carbon mat. The collector surface is inclined with respect to the beam axis in order to reflect the Xenon particles towards the cryogenic pump and to reduce the deposition of sputtered target material on the thruster.

V. Test Description

The thrusters used are the μNRIT-4 equipped with a 19 and 7 hole grid system, as well as the μNRIT-2 equipped with 7 hole extraction system. The hole tests are done using an 1 MHz rf-generator. The purpose of this test was to investigate the stability and the thrust controllability. To operate the thruster we used a Test Power Supply (TPS) that was built to operate the ARTEMIS RIT-10 at 5 to 15 mN. Consequently it was not optimized for the operation in the μN regime.

Therefore the data described below are showing some fluctuations. During this preliminary test, the ignition was done by a pressure impulse, which caused the peaks in the chart. A filament neutralizer, to be used also for discharge ignition, is prepared to run together with the thruster. Controlling of the thrust is done using a beam current controller. Fig.6 shows a sketch diagram of this closed loop system. The extracted ion current from the thruster is measured on a high precision resistor. It will be comparison with the desired value coming from a computer and a DAC converter. The comparison signal functions as input for a PID controller, which changes the feeded radio frequency power in the thruster.

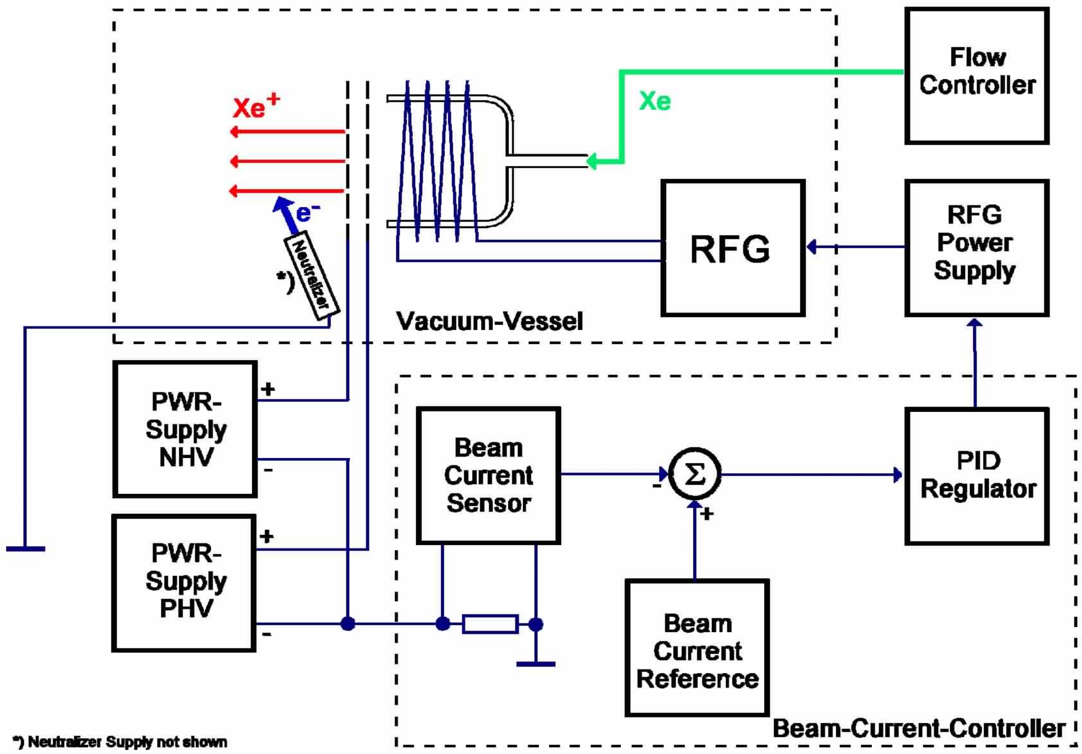


Fig. 6 . Beam current controller system.

VI. Test Results

Figures 7 and 8 show the dependency of the extracted ion current to extraction voltage and the power of the radio frequency generator. The thrust is directly proportional to the extracted ion current. It shows two independent electric parameters, which can change the thrust. We decided to use power of the rf-generator as the main control parameter of the thrust.

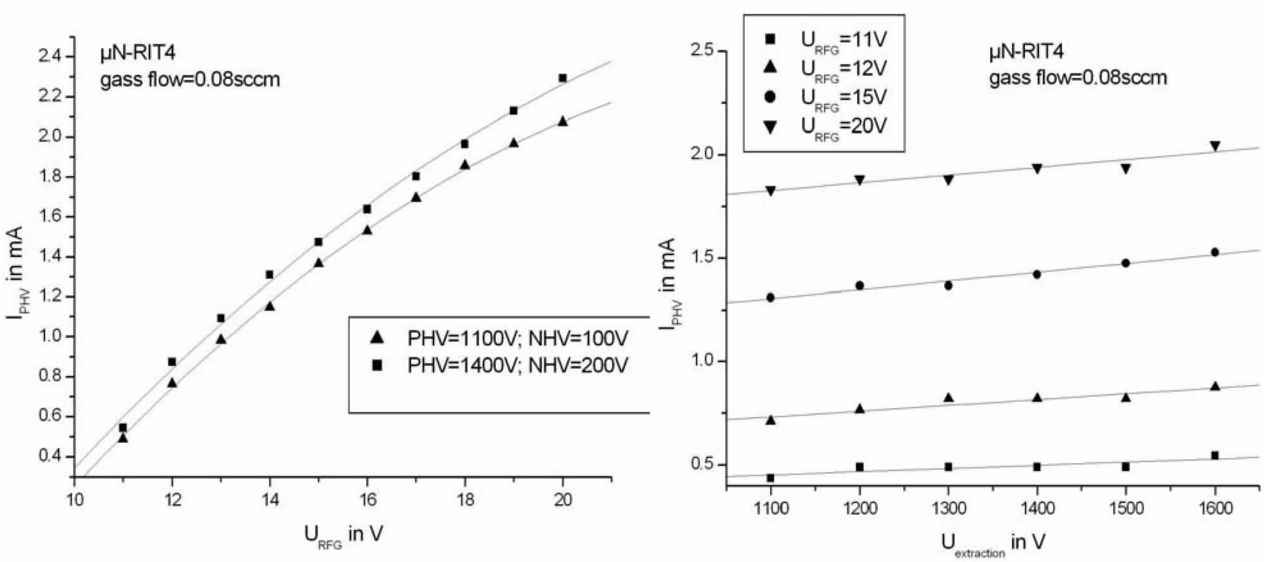
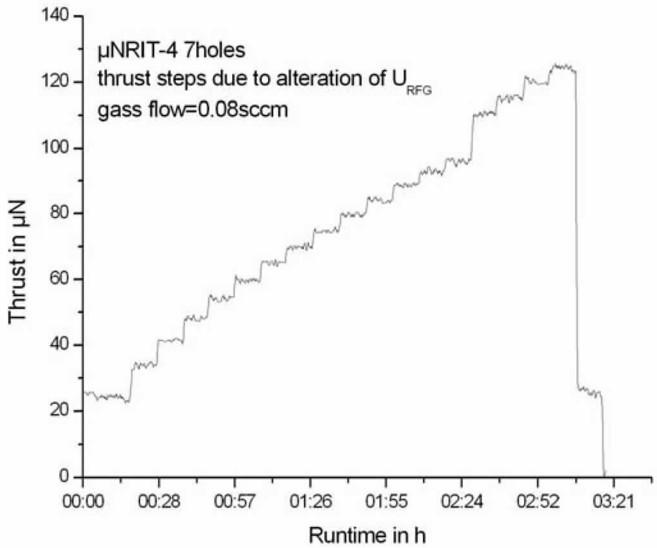


Fig. 7& 8 . Dependency of extracted beam current on rf power and extraction voltage

Figures 9 shows the thrust achieved during the test of µNRIT-4, calculated from beam current and beam voltage. The thrust level is changed by varying the voltage of the power supply for the RF generator. Variations were done manually in this preliminary test. The lowest thrust level achieved (20 µN) was limited by the capability of the test equipment i.e. the power supply for the RF generator. To achieve lower thrusts and higher controllability, an automated beam current control unit with an integrated high precision power supply is manufactured in our electronic workshop. During the entire test the flow rate was kept constant at 0.008 mg/s. This was the lowest flow rate that could be achieved with the available 5-sccm flow controller.



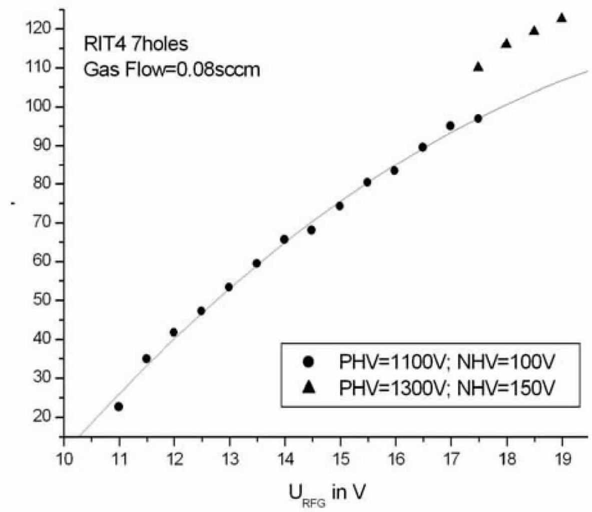
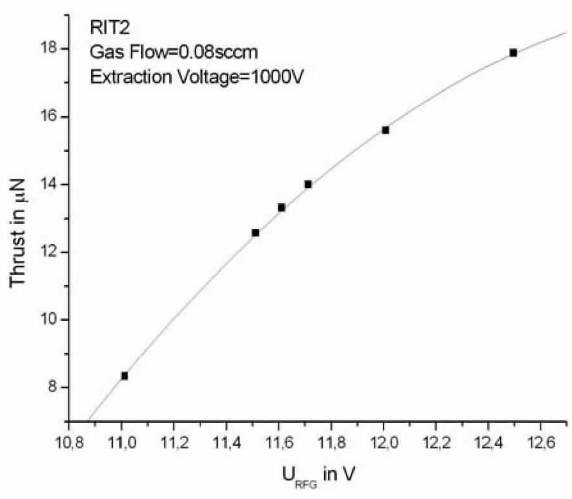


Fig. 9 & 10. Thrust Steps due to the variation of U_{RFG} Test on µNRIT-4 with 7 hole extraction system.



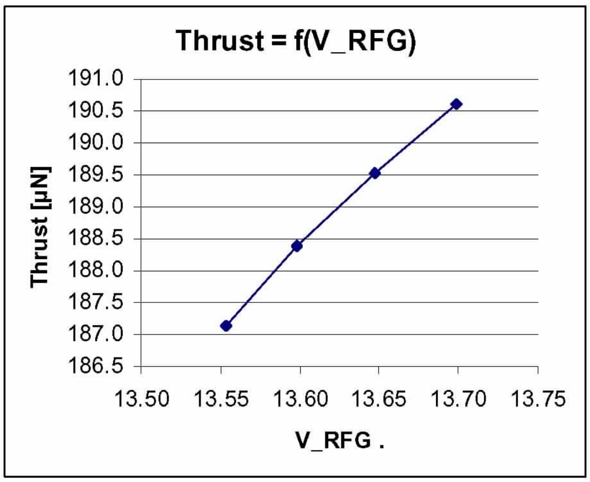


Fig.11. Thrust stepping with µN-RIT-

Fig. 12. One-µN Thrust Stepping of µNRIT-4

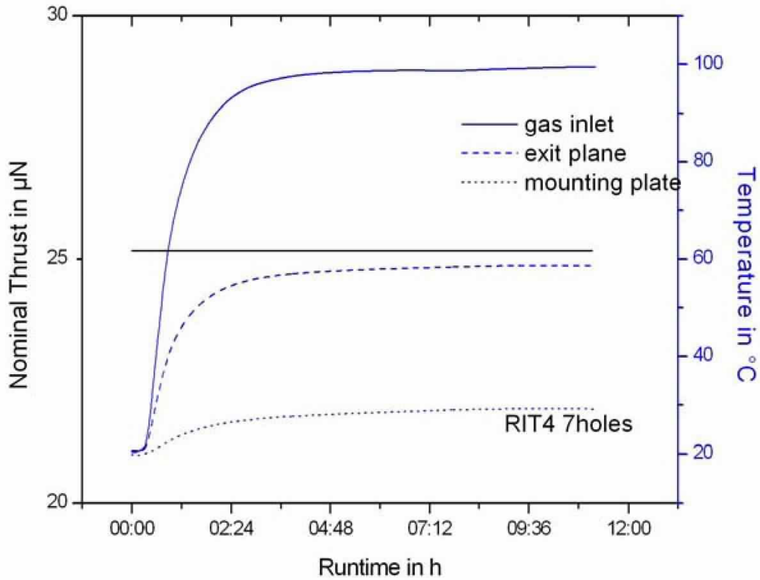


Fig. 13. temperature build up in µNRIT-4

The accel drain current was measured to get first information on the life capability. (Note: The accel drain current (INHV) results from ions impinging on the acceleration grid. To achieve a good life time of e.g. 30.000h, the INHV shall be lower than 1.5%). The INHV was hard to determine, as the resolution of the test equipment was 0.05 mA and the measured value was toggling around zero. Using a maximum approach, i.e. adding a bias that was defined as the minimum value at no thrust, the INHV was < 0.08 mA at a beam current of 2.3 mA. This corresponds to a relative INHV of < 3.5%, which under the described circumstances can be considered as an excellent value. Figures 10 and 12 show the results of thrust regulation performed by varying the RF input voltage. As can be seen, a step width of under 1 µN could be achieved, even with non optimized power supplies.

The beam voltages between 1000 V to 1400 V was applied during the test, which enabled specific impulse up to 3850s by 230 µN thrust and the minimum achievable gas flow, restricted by the gas flow controller. A controlling of specific impulse for lower thrusts would be possible using a GFC for gas flows under 0.008 mg/s. So a better specific impulse especially by lower thrusts is achievable. An earlier test showed also the ability of the thrusters to work with beam voltages up to 1800V, which provides higher Isp.

The achieved mass efficiency was up to 84%. As the gas flow could not be turned down under 0.006 mg/s, the mass efficiency went down to 26% by lowest thrust levels. Due to the low accuracy of the gas flow controller in this range of gas flow, these results are to be regarded cautiously.

Fig. 13 shows the temperature building in the µNRIT-4 thruster, during a 12 hours test of the thruster. The low level of temperature shows a good matching of the rf power in the plasma. As one can see in this figure, there was no single beam out of the thruster during the 12 hour test. A 100 hour test is in planning, and will be carried out as soon the automatization system is accomplished.

The tests on µNRIT-2 show even better thrust controllability and thermal behavior. Fig. 11 shows the thrust stepping test on this thruster. The tests on µNRIT-2 are continuing and the results will be published soon.

A direct measurement of the thrust is to be done by Electric Propulsion Group in European Space Technology Center (ESTEC).

The results of the preliminary rf-µN-thruster testing show its inherent potential in µN region. As soon as high precision supply equipments(beam current control unit, high voltage unit, flow controller for very small flow rates) are available, the overall performance will be mapped, and the results will be distributed.

Acknowledgments

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References

[1]Horst W. Loeb, K.-H. Schartner, St. Weis, D. Feili and B. K. Meyer,: "DEVELOPMENT OF RIT-MICROTRHUSTERS"," *IAC-04-s.4.04, Vancouver 2004*

[2]See e.g. :H.W. Loeb, J. Freisinger, K.H. Groh, and A. Scharmann: "State-of-the-Art of the RIT-Ion Thrusters and Their Spin-Offs", IAF-88-258, Bangalore 1988.