

Test Campaign on the novel Variable Isp Radio Frequency Mini Ion Engine

IEPC-2019-A-574

*Presented at the 36th International Electric Propulsion Conference
University of Vienna • Vienna, Austria
September 15-20, 2019*

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Abstract: The paper describes the novel approach of Ion Optic System and its realisation to deliver independent regulation of the thrust and Isp among classic Ion Thruster technology when broad range of thrusts and specific impulses are required by the mission. It delivers the results of performance testing of the Variable Isp Ion Optic System on a Mini Ion Engine RIT3.5. The results of two test campaigns performed in Bundeswehr University in Munich with Laboratory Equipment and in ESA/ESTEC EPL where the Engine was coupled with an Engineering Model of Power Processing and Control Unit are summarised. The paper also includes the endurance test results in comparison to those of the classic Ion Optic System.

Nomenclature

<i>EM</i>	=	Engineering Model
<i>GIE</i>	=	Gridded Ion Engine
<i>Isp</i>	=	Specific Impulse
<i>IOS</i>	=	Ion Optic System
<i>NGGM</i>	=	Next Generation Gravity Mission
<i>PPCU</i>	=	Power Processing and Control Unit
<i>RIT</i>	=	Radio Frequency Ion Thruster
<i>TRP</i>	=	Technological Research Program

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I. Introduction

A Variable Isp Ion Optic System approach was proposed to overcome the intrinsic interdependence of Isp and Thrust existing in classical Ion Optic Systems. Whereas for many applications this wouldn't become critical, there are missions where it is required to deliver performances that would be not feasible to reach within classic Ion Engine. For example, for some Earth Observation and Scientific missions, where it is required to obtain fine attitude and orbit control by means of low-noise force actuators, the demand on increase of Specific Impulse in the low thrust region cannot be completely satisfied by the means of classical Ion Optic System. This, together with other very strict requirements on the thrust controllability and lifetime, wouldn't let a big choice of propulsion systems that would be capable to fulfil all mission challenges.

As a result, TransMIT GmbH was awarded an ESA Technological Research Program (TRP) contract to design, construct and test Ion Optic System for Radio Frequency Mini Ion Engine engineering model which comprise full set of requirements for NGGM mission.

A modular extraction system was designed, constructed and tested. This grid system allows an independent regulation of the thrust and Isp in mini Gridded Ion Engines in a very broad thrust range as from 50 microN to 2 mN satisfying also demand on low power at different thrust levels.

Low power consumption is especially important due to the small solar cell arrays on NGGM spacecraft that would also ensure the minimizing of the heat production in the thruster. Designed Ion Optic System was manufactured and tested showing a very good compliancy of the experimental results to the requirements.

II. Variable Isp Radio Frequency Mini Ion Engine

The Specific Impulse and the Thrust of a real thruster with classic Grid System are normally interdependent and no practical variation of the Specific Impulse can be proposed for fixed thrust levels without drop in efficiency or lifetime. Thus, to give an Ion Engine the ability of an independent Thrust and Specific Impulse control, new techniques were to be introduced.

The idea proposed is based on the use of an additional electrode inside of the IOS in order to de-couple the extraction and the acceleration as it has been originally proposed by D. Fearn for its use on Ion Engines. Such method, allow to overcome the limitations of classic IOS and to accelerate the extracted ions to higher velocities, and therefore to increase both thrust and specific impulse levels of the engine.¹

In 2011, Moscow Aviation Institute initiated a study aimed to demonstrate other advantages that a four-grid system could introduce to GIE technology: flexibility of thruster performances optimization and lowering power to thrust ratio by redistributing the potentials and/or optimising the geometry of grid system. A number of experiments were performed and confirmed the multiple assumptions of the researchers. In particular, it was shown that the four grid- system approach is able of providing different ion currents or thrusts by the same Isp which also could be independently chosen.²

The use of an additional fourth electrode in order to be able to redistribute the potentials in the IOS and thus manipulate the extracted current and the energy of ions separately was proposed to fulfil ESA project requirements.

A. Mini Ion Engine RIT3.5

An Engineering model of the Radio Frequency Mini Ion Engine RIT3.5 was developed by TransMIT GmbH according to the Propulsion Requirements of the Next Generation Gravity Missions between 2013 and 2015 in the frame of ESA contract "Miniaturised Gridded Ion Engine Breadboarding And Testing For Future Earth Observation Missions". Various aspects of plasma, electromagnetic and thermal models of the thruster for the comprehensive radio frequency gridded ion thruster modelling used to develop RIT3.5 are described in the reference 3. Broad Characterization test campaign confirmed overall compliance of the thruster to the mission profile including also thermal status with some limitations on side of the Specific Impulse. Tests were performed in two different Electric Propulsion (EP) facilities to eliminate facility effects. Details of the project and its achievements are summarized in references 4 and 5.

As the original RIT 3.5 had three grids already, it was comparably easy to implement the Variable Isp approach given that it was only necessary to add an electrode on the thruster output. It has been decided to use an encircling

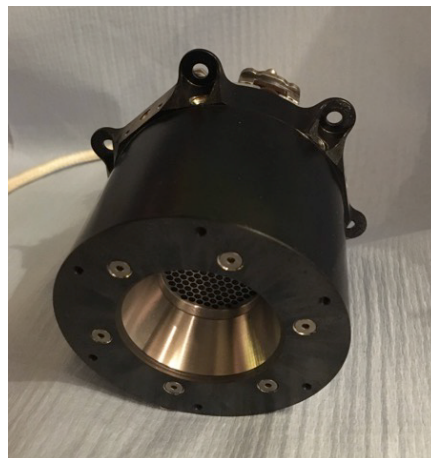


Figure 1. Variable Isp μ NRIT3.5.

ring instead of adding an extra grid to avoid a complex design and given also that it is only necessary to apply a ground potential in order to separate the potentials inside and outside the thruster.

A performance model was developed to predict the behaviour of the thruster with the new IOS. After a preliminary modelling, the design of the new grid system has been carried out. Figure 1 shows integrated the Variable Isp Ion Optic System on the RIT 3.5 EM.

III. Test campaign



Figure 2. R2D2 test facility.

Experimental program was divided in two sequences of functional/performance characterisation and endurance tests.

Characterisation tests included performance mapping of the Variable Isp μ NRIT-3.5 against classic version of this thruster. Performances were tested over the operational envelope of the thruster in the range of NGGM mission thrusts in the extended range of mass flows and high voltages and not only for the pre-set operation points considered to be optimal for the mission. Electrical and flow parameters were monitored to determine thrust range, specific impulse and specific power. The test results were then compared with the results predicted by the thruster performance model.

The Characterisation test campaign was in its turn divided to a larger campaign covering all the tests using laboratory Power Supply and Control Units, that was done in collaboration with Bundeswehr University Munich at Ludwig Bölkow Campus, Munich, and a smaller campaign covering coupling with the Engineering Model Power Processing Unit in comparison to laboratory PSCU, that was done in collaboration with ESA at ESTEC EPL, Noordwijk.

Endurance test included 500 h of direct firing of the thruster with three erosion measurements with the help of microscopy before test kick off, after 300h of firing and at the end of the test.

A. Test set-up

At Ludwig Bölkow Campus test was set-up inside of R2D2 vacuum test facility (depicted in fig. 2). This facility comprises two volumes – main chamber and hatch - with total volume 4.5 m³ and total pumping capacity of 24 000 l/s.

The laboratory Power Supply and Control Unit as well as laboratory Mass Flow Board were both located next to the facility hatch in order to minimise harness to the installed inside of the hatch μ NRIT 3.5 with its Radio Frequency Generator.

At ESTEC EPL test was set-up in Corona vacuum test facility (depicted in fig. 3). This facility as well comprises two volumes divided by a large gate valve with total volume of about 13 m³ and total pumping capacity of over 70 000 l/s.

Both laboratory and engineering model Power Processing Units were used for the performance measurements on μ NRIT3.5. In order for the comparison to be accurate the same harness and same flow control unit were used. The thruster with its Radio Frequency Generator were placed on the trolley of Corona facility hatch.



Figure 3. Corona test facility.

B. Test results

Functional tests demonstrated repeated and smooth start-up, thrust on and standby modes of the thruster.

The most challenging part of the thruster requirements for NGGM was the very large dynamic range of the thrust which had to be demonstrated in the frame of the characterisation test campaign. The minimum thrust was required to be around 50 μ N and the maximum not less than 2000 μ N. Figure 4 shows the results of the thrust range achieved

by the Variable Isp μ NRIT3.5 in the frame of such tests in comparison to the predicted values and classic mode operation as well as the power consumption of the thruster for the different thrust levels.

No disruption in thruster operation at any thrust level of the range was observed, lower than minimum required and higher than maximum required thrusts levels were achieved during the test campaign.

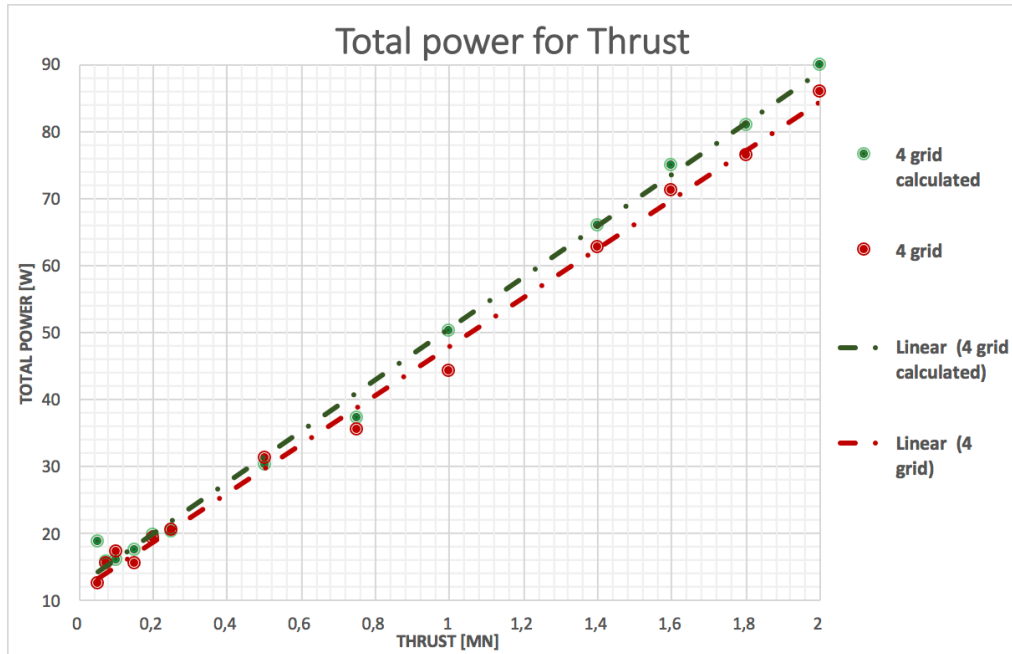


Figure 4. The power consumption of the thruster for different thrust levels between $50\mu\text{N}$ - $2000\mu\text{N}$.

Figure 5 shows the thruster Isp for different thrusts in comparison to predicted ones. Certain deviations between calculated and experimentally derived values at low thrust levels were confirmed to arise from the limitations on the plasma discharge side and not from any IOS related processes.

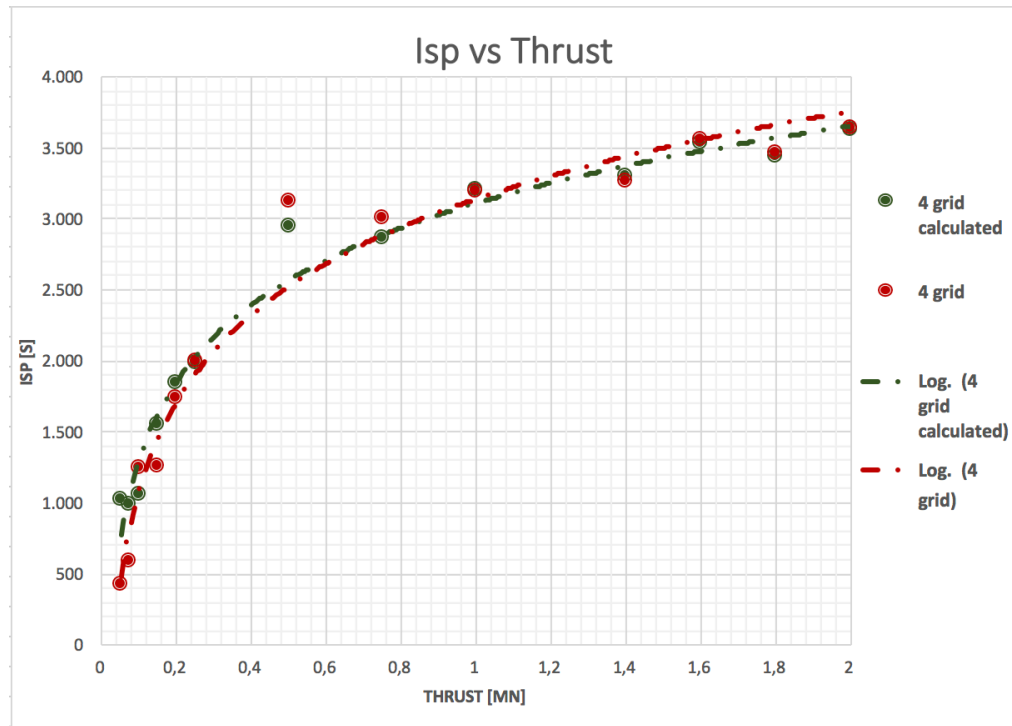


Figure 5. Isp of the thruster for different thrust levels between 50 μ N-2000 μ N.

No major differences have been observed in the power consumption of the thruster on a system level (as no measurable value can be derived for laboratory PPU “bus” level) between laboratory and engineering model formats PPU’s which can be seen at fig. 6.

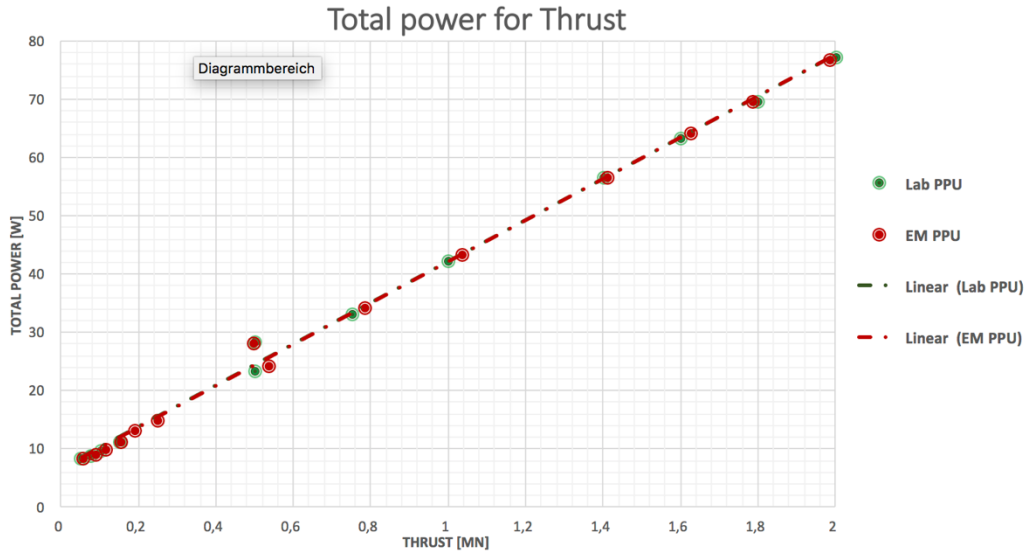


Figure 6. Power consumption of the thruster for different thrust levels between 50 μ N-2000 μ N with laboratory and EM PPU.

Figure 6 shows the variation of the thruster Isp for different thrust levels experimentally derived for the RIT 3.5 with Variable Isp IOS (green) and the original RIT 3.5 EM assembly.

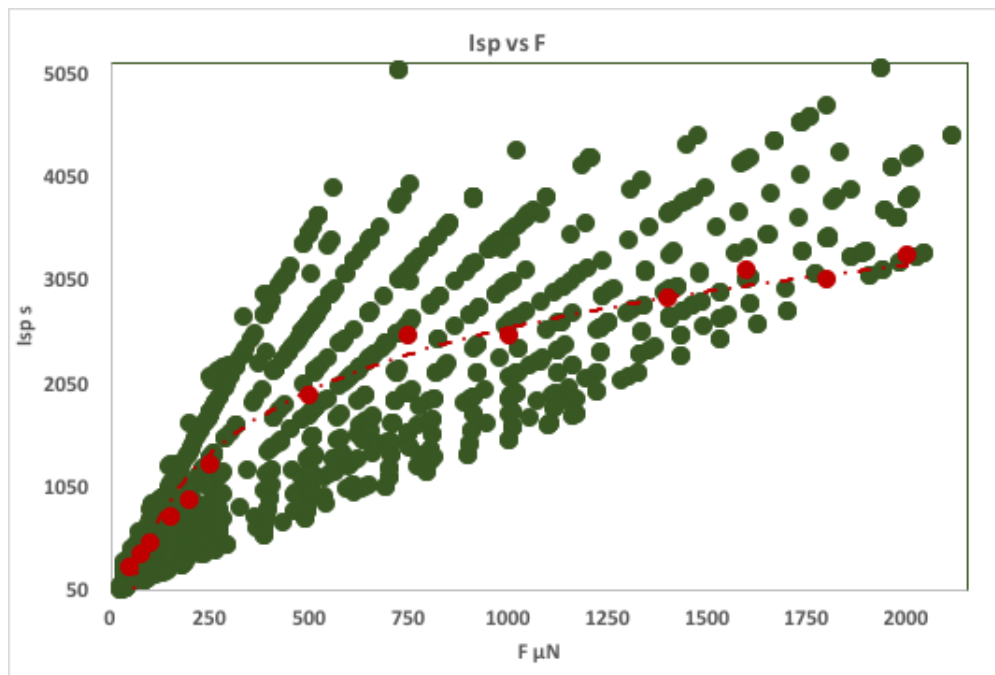


Figure 7. The Isp variation of the thruster for different thrust levels between 45 μ N-2500 μ N. Green – Variable Isp IOS; red – Original IOS.

As can be seen, the Isp variability has been achieved with the help of the newly built IOS that allows expand thruster performances.

The power consumption at the thrust level of 2 mN differed between 75 and 100 Watts, which allowed a power to thrust ratio below 40W/mN at bus level. Specific Impulses variation shown for 2 mN was between 3000 s and 5000 s.

The power consumption at the thrust level of 50 microN differed between 6 and 25 Watts, while Specific Impulse variation shown was between 100 s and 500 s.

An extended firing test was successfully carried out with a total impulse accumulated of 3,6 kNs. The operational point for the extended firing was selected in order to have an accelerated erosion rate for a better comparison with the software. Even given that erosion rate of the acceleration grid was demonstrated to be not more than that of classic IOS operating on RIT3.5 at a nominal conditions for the same thrust level.

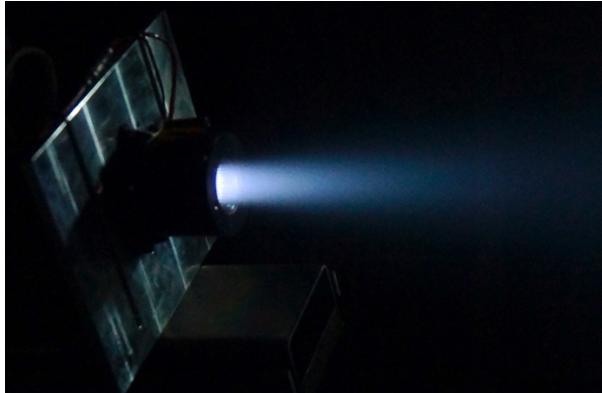


Figure N. Variable Isp μNRIT3.5 running in ESTEC EPL.

IV. Conclusion

A modular extraction system was designed, constructed and tested. This grid system allows relatively independent regulation of the thrust and Isp in mini Gridded Ion Engines in a very broad thrust range as from 50 microN to 2 mN satisfying also demand on low power at different thrust levels.

Acknowledgments

This work has been funded by European Space Agency under the Contract: 4000118817/16/NL/PS/md Variable Isp Grid System for Low-Power Ion Thrusters.

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