Airbus DS 5kW class electric propulsion system based on radio-frequency ion thrusters

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Abstract: Airbus DS is developing a modular electric propulsion system for the application in current and future telecommunication satellites. The system is based on the flight proven Radio-frequency Ion Thruster (RIT) technology. The current Airbus DS activities in the 5kW class link the heritage from the RIT-22 development with the new RIT 2X development. It addresses both thruster performance and system aspects. The functional principle of the RIT technology is described and the Airbus DS RIT portfolio is presented including the design of the new generation of RIT 2X thrusters. Achievements from recent system tests in different European test facilities with RIT thrusters of the 5kW/200mN class are presented. The tests performed include performance measurements on system level, smooth coupling test with a breadboard high voltage converter, beam diagnostics and direct thrust measurements.

Nomenclature

EBS	=	electron back-streaming
EP	=	electric propulsion
FCU	=	flow control unit
ISP	=	specific impulse
NHV	=	negative high voltage
NSSK	=	north south station keeping
PHV	=	positive high voltage
rf	=	radio-frequency
RIT	=	radio-frequency ion thruster
TMD	=	*technology maturity demonstration*
TPS	=	test power supply

I. Introduction

The economic environment for telecommunication satellites is highly competitive. Focusing on satellite propulsion the employment of highly efficient propulsion systems were an evident goal. Meanwhile electric propulsion (EP) systems have become state of the art for north south station keeping (NSSK). A remarkable reduction of wet mass with the associated cost effect could be realized.

The general growing acceptance of EP together with the highly competitive environment for satellite operators paved the way for full or partial electric orbit transfer. This is presently one of the driving topics for EP development. In contrast to NSSK these transfer maneuvers require more total impulse. To realize acceptable orbit

transfer times higher thrust levels and thus higher power levels are required. Currently, the class of the 5kW thrusters are employed for all EP orbit transfers, here thrust in the range of 150-270mN per engine are typical.
Technically, the need was clear for many years and worldwide the development of adequate thrusters and systems started 10-20 years ago. However, missing acceptance of EP solutions and the lack of electric power delayed the employment of all EP systems. Now that the acceptance is given and power is available all satellite primes are planning there next generation platforms where EP for NSSK, hybrid and full electric solutions are discussed.
Airbus DS started the development of a high power ion thruster around 2000. Under different market circumstances the first 5kW EP system seemed closer to application onboard a scientific probe than on commercial geostationary satellites. In this context the development of the thrusters and the electronics was driven towards maximum specific impulse [1].

Assessing the business case in house emphasized indeed the importance and superiority of high ISP. The outstanding performance of the RIT thrusters with its high ISP, its excellent thruster efficiency and low beam divergence are providing clear advantages for improved satellite capabilities. However, a moderate adaptation sacrificing some of the power towards more thrust instead of ISP seems desirable for the telecommunication market. This is taken into account in the current development, the evolution of the RIT-22 towards the RIT 2X.

The presented paper outlines the development status. As a first hardware related step in the new development program a technology maturity demonstration (TMD) was conducted with the existing RIT-22. The TMD covered primarily two aspects:

1. Demonstrating a wide operational envelop within the 200mN thrust range.
2. Demonstration of several system aspects, i.e.
    a. coupling of the thruster to flight like high voltage converters
    b. simulation of operation with flight flow control unit (FCU)
    c. coupling of the thruster to a flight like FCU
    d. extensive beam diagnostics
    e. assessments of performance and operation in different test environments
    f. direct thrust measurements

The TMD was open for customers and the agencies. TMD can be considered as link between the past RIT-22 development and the new RIT 2X development. The current development status of the RIT 2X will be presented.

II. RIT functional principle

The RIT belongs to the class of gridded ion engines. All gridded ion thrusters generate thrust in two steps (Figure 1). In the first step the propellant is ionized and in the second step the ionized fraction of the propellant is accelerated in an electrostatic field of the grid system. The ion acceleration in a grid system is the common feature of all gridded ion engines. However, different types of ionization are used.
Radio-frequency thrusters ionize the propellant in an inductive plasma generator. An rf-voltage is applied to an antenna structure around an insulating ionization chamber, and the rf-energy is coupled to the electrons. A sketch is shown in Figure 2 where an induction coil is wrapped around an insulating chamber with a gas feed. The chamber can be of different shape and is connected to an ion optics structure with either two or three grids that is used focus and accelerate the ions. Concentric holes in these grids form a large number of single extraction channels. Each of these channels represents a single ion optical system. The ion optical system's properties are determined by the diameters of the holes, the grid spacing and the applied voltages. A positive high voltage (PHV) is applied to the screen grid and a negative high voltage is applied to the acceleration grid. The rf-coil is connected to an rf-power supply that provides the power to generate the plasma. The discharge chamber is enclosed in a metallic housing to suppress electron collection from the surrounding; a neutralizer cathode is connected to provide net charge neutralization of the beam.

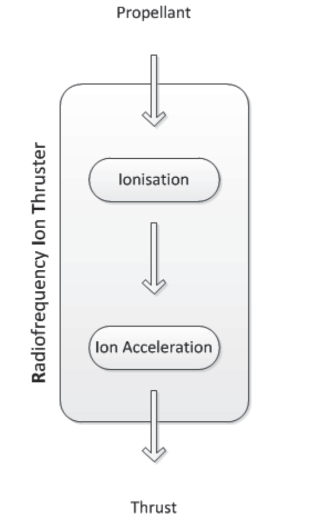

Figure 1 Principle of stepwise thrust generation in a RIT.

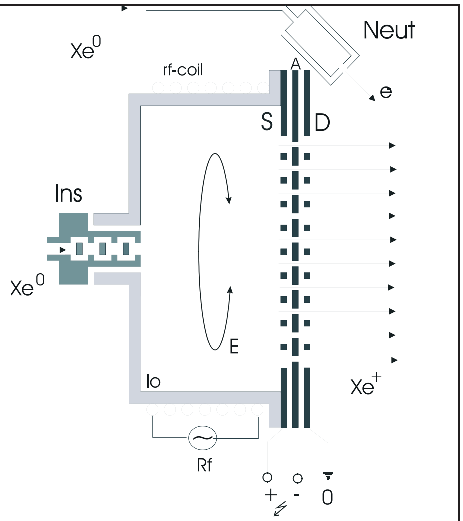

Figure 2 Functional principle of a RIT

Airbus DS has decided to proceed with the development of EP systems based on RIT as the principle provides inherent advantages:

- Robust and reliable thruster
- Simple system design
- Very high specific impulse
- Very good scalability
- Durable due to very long lifetime
- Excellent thrust controllability and high throttle range
- Fast thrust response
- Low thrust noise
- Direct electric feedback of produced thrust
- Working with inert noble gas xenon
- Free of (magnetic) torque

The radio-frequency technology is a flight proven technology: Two missions powered with Airbus DS' RIT-10 [2], [3], [4]engines marked milestones in the history of electric propulsion.

III. Airbus DS radio-frequency ion thruster family

Already at the time when EURECA [2] and ARTEMIS [3], [4] demonstrated the capabilities of electric propulsion based on the RIT technology it was evident that EP systems of higher power rating than the pioneering engines (approx. 0.5kW) would be required for commercial needs. Hence, three years before ARTEMIS reached its GEO orbit, Airbus DS initiated the development of an rf-engine in the 5kW class [1].

The RIT technology is highly scalable and a family of thrusters were developed at Airbus DS [5]. The smallest member is RIT-µX, a miniaturized ion thruster for the micro and low millinewton thrust range. The RIT-10 and its thrust augmented version RIT-10 EVO are intended for north south station keeping of smaller telecom satellites with limited power budget. RIT-15 [6] was developed at Gießen University, a modern elegant breadboard built and tested at Gießen University. Applying Airbus DS' processes and engineering tools, RIT-15 can be made available on a short time scale. The RIT-22 was initially developed to provide highest specific impulse and it has proven its performance and durability in numerous studies [7]. The RIT 2X series is the current evolutionary development based on the heritage of the RIT-22.

IV. RIT-22 technology maturity demonstration (TMD)

The technology Maturity Demonstration consists of several campaigns (illustrated in Figure 4):

- TMD-A: This first campaign was devoted to mapping the thruster performance. Compared to RIT-22 tests performed before the thruster was changed by implementing a smaller footprint of the thruster, it is the most compact housing of a 5kW class gridded ion engine and its interface is compatible to the European QinetiQ T6 and SNECMA PPS5000 engines. TMD was the first activity verifying the design approach. In addition, during TMD-A a new technique simulating the behavior of typical flight standard flow control units was demonstrated.
- TMD-B: In the second campaign the thruster was operated with a new high performance, high voltage, module developed by Airbus DS Friedrichshafen (Germany).
- TMD-Advanced: This campaign again was split in several parts and was devoted to investigations in detailed design aspects. Furthermore, a coupled test with a miniaturized flow control unit that is pre-qualified on unit level, the "µFCU" of AST [8], [9] was performed. All tests described also served as a reference for a follow up test activity performed in the new test facility STG-ET of the German Space Agency (DLR) [10]. All these successful tests represent the first operation of a 5kW ion engine in the new facility. Furthermore, during this test also direct thrust measurements were and beam profile measurements were performed.

Customer days were held during the TMD campaign, where representatives of the German and European Space Agency and Airbus DS customers were invited to the tests.

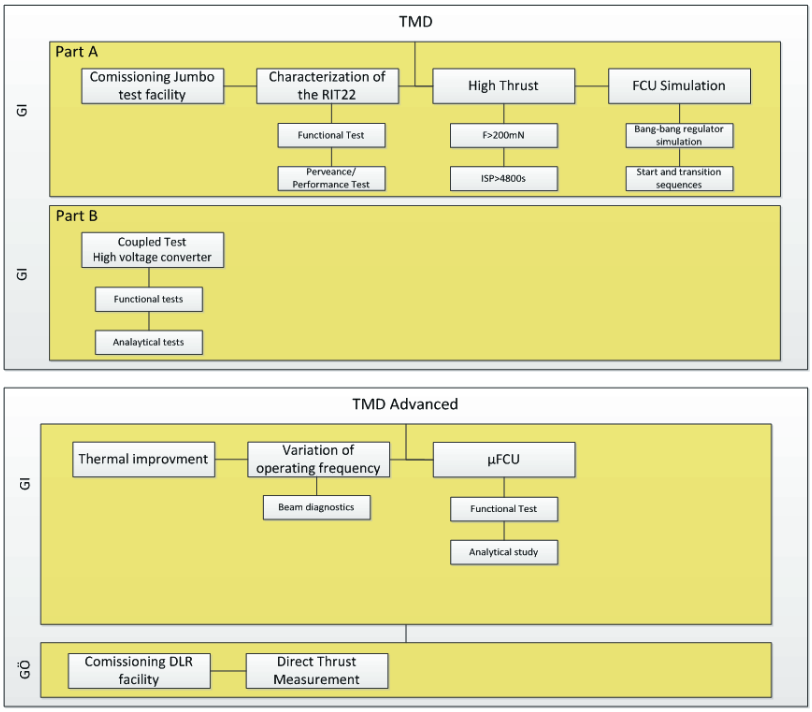

Figure 3 - Project logic of TMD campaign

V. Results

TMD-A

The thruster's perveance limit and the EBS threshold were determined, respectively. A nominal operation envelop could be confirmed as well as the ion optics simulations. As expected, the shape of the thruster housing had no impact on the grid system performance.

Performance mappings were conducted to create a data set that can be referred to as a performance envelop of the thruster and compared to expectations. During performance mappings the thruster is operated at different thrust levels. At each current level the thruster is operated at 5 different ISP levels, i.e. different levels of plasma discharge mass efficiency. During the performance mappings slightly higher rf-power consumption was observed and the reason could be identified in a higher operational temperature. For TMD-B this was mitigated by applying a suitable thermal coating to the thruster housing.

Perveance and performance measurements provide all necessary information for establishing a variety of recommendable operating points. Based on the verification through the TMD-A tests the design of the RIT 2X ion optics was finalized. For RIT 2X the operational acceleration voltages will most likely be significantly lower than for the RIT-22 and thus the designed grid spacing was reduced.

RIT thrusters can be operated over a broad range of mass flows. With a simple control loop between measured ion current and applied rf-power the extracted beam current and thus the thrust can be controlled an held constant. The wide acceptance of mass flows levels relax the requirements for the stability of the mass flow rate and it is possible to operate the engine with a simple FCU based on bang-bang type pressure regulator and flow orifices. When the mass flow decreases during one cycle of the bang-bang cycle, the resulting variation in beam current can be compensated by varying the rf-power and thus keep the beam current and thrust constant.

During TMD-A the behavior of an FCU consisting of bang-bang type pressure regulator and flow orifices was simulated using laboratory flow controllers. This architecture was successfully implemented in the RIT-10 system on ARTEMIS and the tests confirmed its validity for RIT-22. Other FCU simulation tests were devoted to the typical ramp-up effects of FCUs during the thruster start. Overall it was concluded that simulation of FCU behavior by using commercial flow controllers is a valuable tool to investigate system aspects.

TMD-B

TMD-A was conducted using the highly flexible Airbus DS test power supply (TPS). These instruments simulate the behavior of a flight PPU. The TPS with its commercial high voltage modules enable flexible operation in a large window of operational parameter. However, it is known from other thruster technologies that coupling tests of thruster and PPU components mark important milestones in the EP system development as sometimes (severe) interaction between thrusters and power processing units can occur and need to be addressed at an early stage to mitigate devilment risks. In this context a representative high voltage module for the new RIT 2X system was tested together with the RIT-22. The module has been developed by the Airbus DS electronics group in Friedrichshafen, where a flight PPU based on a modular design is developed based on highly efficient high voltage converters.

The first test of the new module together with the RIT-22 showed excellent results. The thruster ignition and thrust on behavior for several operating points were demonstrated. In addition a successful continuous operation of the PHVS-BB with the RIT-22 was conducted as well as analytical measurements. No undesired interactions or instabilities within the thruster system were observed. Additionally, all measurements were also acquired with the TPS system for a direct comparison and showed no deviations.

TMD-Advanced

The TMD-Advanced campaign was conducted in two test facilities:

1. At the "Jumbo" facility at Gießen University [11]
2. At the new test facility STG-ET of the German Space Agency (DLR) in Göttingen [10]

The tests in Gießen focused on detailed thruster improvements and systematic studies including beam diagnostics. Furthermore, a coupled test with the AST built µFCU was performed with the RIT-22 . The µFCU was installed outside the vacuum chamber in parallel to the normally used commercial flow controller. The AST unit tester equipment was integrated into the Airbus DS TPS setup, mass flow set values were commanded by the TPS and the AST equipment controlled the µFCU a commercial mass flow meter was implemented inline and the measured values was returned to the TPS. An initial parameterization of the thruster gas supply was performed with commercial mass flow controllers and then the xenon supply was switched to the µFCU. The RIT-22 was operated at all relevant working points (covering a mass flow range of 0-4mg/s) again to identify potential differences. As smooth operation of the RIT-22 in conjunction with the µFCU was observed. Ignition, standby and thrust operation of the RIT-22 could be demonstrated. The operation was nominal and no abnormal ripple or other effects were detected. During the test the µFCU has been operated in open-loop as well as in a closed loop.

All tests performed at the Gießen facility also served as a reference for the follow up test activity performed in the new DLR test facility STG-ET.

Thruster integration and operation at the STG-ET facility were successful and the RIT-22 operation represents the first operation of a 5kW-class ion engine in the new facility, the thruster was operated for approximately 75hours. During the campaign the test facility and its equipment was assessed and a typical performance mapping of the RIT-22 thruster was performed to provide a facility to facility comparison between campaigns in both test facilities. Furthermore, during this test also direct thrust measurements were performed. A thrust balance [12] is mounted inside the Göttingen test facility. Figure 5 shows a part of the performed direct thrust measurements. Overall a good agreement between measured and calculated thrust was observed. In the framework of this campaign systematic studies of influences of support equipment on the thrust balance were performed.

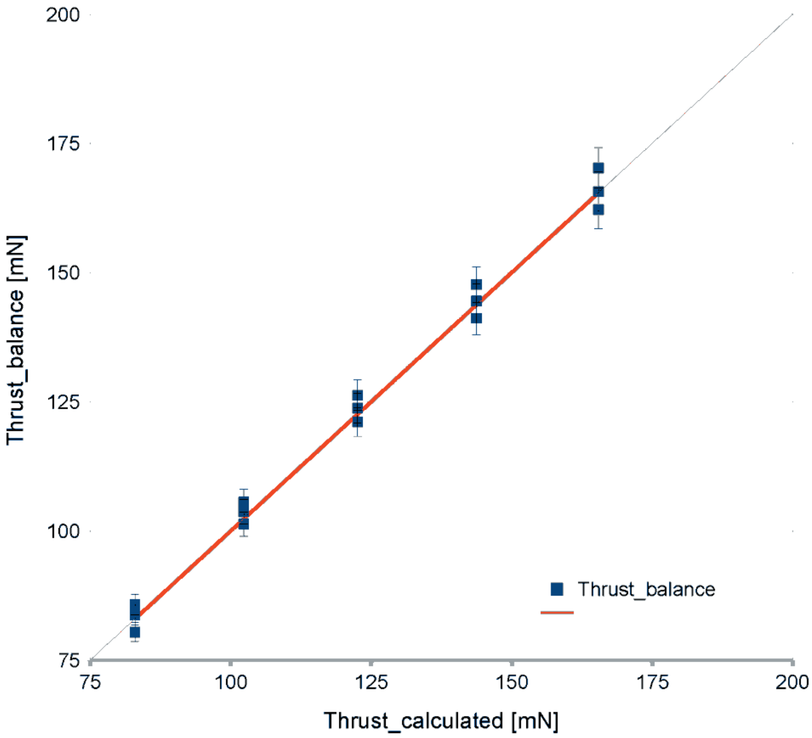

Figure 4 Results of direct thrust measurements compared to calculated thrust values.

VI. RIT 2X Development

RIT 2X is the current evolutionary development based on the heritage of the RIT-22. Although the need for highest ISP remains for science missions, the customers' requirements for orbit transfer and orbit topping shifts the focus for commercial satellites towards lower power-to-thrust ratios in order to minimize transfer times in a given power budget. This is reflected in the evolution towards the RIT 2X thruster. As further increase of available electric power onboard telecommunication platforms can be expected in the future, the RIT 2X is designed to offer the potential to utilize additional power and thus extends the RIT family towards high power EP systems

An increase of available electric power onboard telecommunication platforms can be expected in the future. Based on the heritage of the RIT-22 and the results from the TMD campaign the RIT 2X thruster series was designed to respond to the market's need. The RIT 2X series was designed to offer a certain level of customization. The RIT 2X thrusters are flexible to be operated in a highly efficient high ISP mode offering specific impulse of greater than 4500s, but they can also be tuned to operate at low power to thrust ratio and operate in a high thrust mode to generate up to 200 mN at thruster power levels lower than 5kW. Extensive lifetime studies were performed with Airbus DS partners to ensure standard lifetime requirements can be fulfilled.

A 3d rendering of a RIT 2X thruster is shown in Figure 6. The thruster design was completed in 2014. Integration of the first engineering model is ongoing. The first run-in and performance test of the engine is scheduled for July 2015.

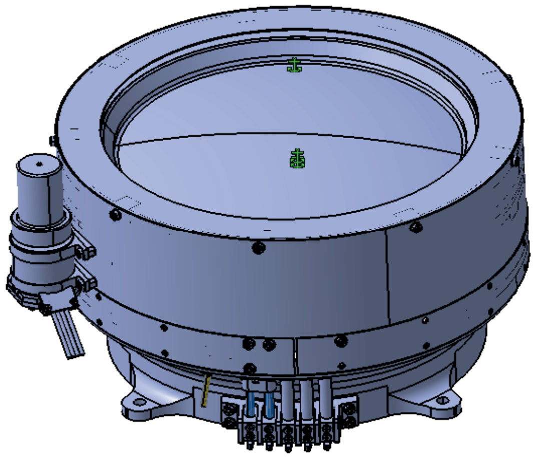

Figure 5 3d rendering of a RIT 2X series thruster.

VII. Conclusion

An extended development test campaign has been performed with the RIT-22. A variety of aspects could be demonstrated as described in this paper. In parallel the development program for the new RIT 2X is on schedule and the design phase is completed. The engineering model RIT 2X hardware will be available for tests scheduled for summer 2015.

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