Ariane Group 5A Neutralizer qualification status

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Abstract: At ArianeGroup a hollow cathode type neutralizer is under development since 2015. This paper gives an overview about the actual qualification status. Starting with an overall description of the neutralizer design the paper provides a closer insight into the used test facilities, qualification approach and qualification status. A special focus is set on the qualification of the neutralizer heater as the used heater technology is a new approach compared to heaters used in state-of-the-art hollow cathode neutralizers.

Nomenclature

BOL	=	begin of life
CVD	=	Chemical Vapor Deposition
LaB6	=	Lanthanum Hexaboride
NTR	=	neutralizer
PBN	=	pyrolytic boron nitride
PG	=	pyrolytic graphite
RIT	=	Radio frequency Ion Thruster

I. Introduction

ARIANE Group GmbH in Lampoldshausen has developed and qualifies now a RIT2X called gridded ion engine system[1]. This system is designed to provide a wide thrust range from 70mN to 260mN. One key component of the system is the neutralizer. The neutralizer is one of the smallest components of the system, however it has a significant impact on the overall system performance and lifetime. Moreover, it is an integral part of the thruster and system qualification. Consequently, ArianeGroup decided for an own neutralizer development and production.

The hollow cathode type neutralizer has to cover an extraction current from 1A to 5A. The decision to use a new heater concept is based on the well-known issues with the commonly used swaged wire heaters. To ensure a fast and efficient development and qualification ArianeGroup Lampoldshausen build up test facilities for the neutralizer stand-alone testing and the heater qualification on-site. In the following an overview over the Lampoldshausen test facilities for the Neutralizer testing will be given. The qualification of the neutralizer stand-alone units is actually ongoing according to the qualification plan. This paper presents an insight into the actual qualification status. As a

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significant part of the overall neutralizer qualification, the heater qualification can be seen. Due the fact that the used novel heater had no flight heritage in hollow cathode neutralizers ArianeGroup decided to perform a dedicated heater qualification. The comprehensive qualification campaign includes five heaters which went through several thousand hours of hot testing verifying heater lifetime requirements including qualification margin.

Figure 1. ArianeGroup 2X5 Neutralizer.

II. Neutralizer description

In Figure 1 the so called 2X5 neutralizer is shown. The hollow cathode type neutralizer was designed for the use on the RIT 2X Thruster. Basing on the knowledge of the RIT 2X operation parameters the main requirements for the neutralizer were defined. The neutralizer has to provide the electron current for counterbalancing the electrical potential of the propulsion system. Therefore it needs to provide the equivalent electron current for the extracted ion current of the ion thruster. Additionally to this it provides electrons for the thruster ignition. The new concept is introduced to overcome these issues.

A. Neutralizer function and operation

The electrical setup of the neutralizer is shown in Figure 2 . The neutralizer has four electrical contacts which are required for operation. Two electrical contacts are used for the heater, one heater+ and one heater-. One connects the insert inner tube and insert to the thruster grid return lines and one for the keeper supply. Three main different operation modes define the neutralizer. The first one is the ignition mode. In this the heater heats up the neutralizer emitter the ignition xenon flow but without voltage applied to the keeper until it reaches the ignition temperature after a defined time. When this time is reached, the keeper voltage is applied and a discharge between the keeper and thin insert ignites. After this ignition the heater is switched off. This procedure defines the ignition of the Neutralizer. The second mode is the standby mode. In this the keeper current flows, but no electrons get extracted towards the thruster beam or anode. In the third mode the neutralizer extracts electrons towards the beam or anode. This is the nominal operation mode which gets used to counterbalance the system electrical potential.

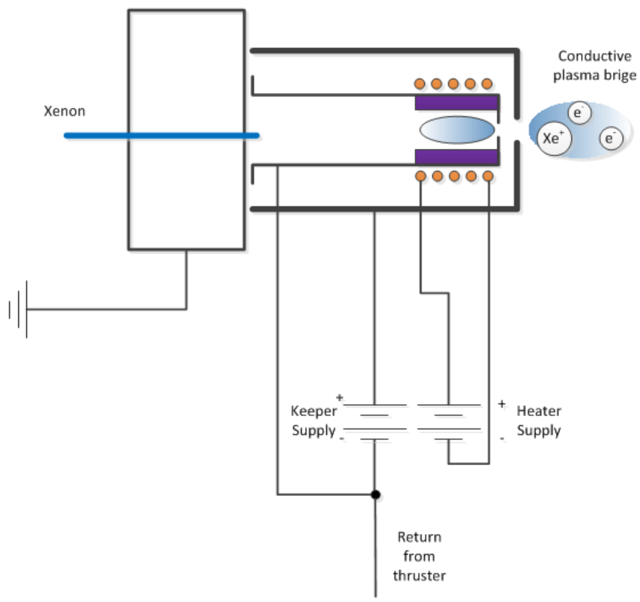

Figure 2. Electrical Setup NTR

B. Main Requirements

The specification requests 18,000 cycles including a qualification margin foreseen. This is a driving factor for the neutralizer design and leads to total heater on-time of 3,000h, which need to be qualified. Additionally to this active heater on-time the heater gets exposed to elevated temperatures during the extraction of electrons, where the heater is switched off, but the neutralizer heats up by the total extracted current. This passive heating duration is defined by the total thruster on time. The total thrust time defines the requirements for the neutralizer operation and the heater passive heating and is >25,000h. This 25,000h are divided into different electron extraction modes which are related to the different thrust levels. Within the qualification ~4.5A of extraction current in the high current mode and ~1.3A in the low current mode are under validation.

C. Neutralizer design

As mentioned above, a typical hollow cathode neutralizer design was chosen. The main parts of this kind of neutralizers are:

1) Keeper
2) Emitter
3) Heater

The keeper is held on a positive potential vs. the cathode tube, it protects the cathode from outside ion bombardment and initiates the plasma discharge during the ignition process. In addition, the current flow between cathode and keeper contributes to maintain the required emitter temperature when the neutralizer is operated in plasma mode. Due to the constant ion bombardment a material with a high sputter yield needs to be chosen ArianeGroup decided to use a graphite keeper to achieve minimal keeper erosion and maximum lifetime.

Within ArianeGroup's baseline configuration, a state-of-the art "barium calcium aluminate" BaO emitter impregnated into a tungsten sponge is used, which is the standard configuration of most cathodes used in flight today. Its main advantage is the moderate operating temperature of 1200°C and the fact that is does not change its shape during life. The tungsten emitter acts as a reservoir for the emitting material which is constantly transported by means of diffusion through the tungsten sponge to the emitter surface as soon as the material on the surface is consumed by evaporation. The tungsten matrix material itself will not be consumed LaB6 emitters on the contrary to the embedding matrix are subject to constant evaporation of LaB6 material which results in a change of the emitter geometry over life.

The heater must provide sufficient temperature to activate the emitter for first use and to bring it prior to every ignition to working temperature. The heater to be used in ArianeGroup's design must withstand during the 25,000h / 18,000 the full thermal cycles without performance degradation. With the knowledge of the difficulties swaged wire heaters, which are used in current flight neutralizer designs, ArianeGroup decided to use a different technology. The ArianeGroup heater is made out of pyrolytic boron nitride (PBN). These heaters have the following main advantages:

- material is not prone to embrittlement
- Very similar CTEs of allow high temperatures and number of thermal cycles
- High flexibility in the heater design due to the nature of the CVD process

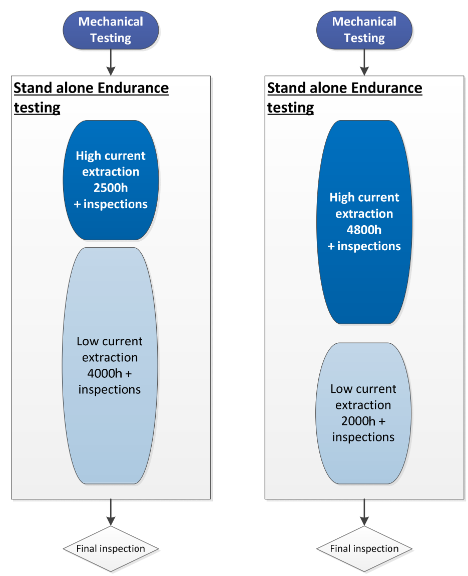

Figure 3. Neutralizer qualification overview

III. Neutralizer stand-alone qualification activities

A. Qualification logic

The qualification of the neutralizer in stand-alone configuration is performed to verify the component requirements, which are derived from mission and system requirements. It was decided to perform the qualification with two units. This approach allows on the one hand some redundancy in case of failure which is not directly related to the test units and on the other hand this approach allows to set the focus for the first unit on the high current mode and for the second one on the low current mode. After the mechanical vibration and shock testing of the units both started in a high current mode which gets followed by a low current mode for the rest of the mission. The test sequence (Figure 3) is divided into several dedicated test blocks. Each test block consists of the nominal endurance operation at the given extraction current and gets followed by an orifice measurement. This approach shall ensure that enough intermediate data are available for a validation of the erosion model.

B. Test facilities

ArianeGroup uses two different test facilities for the neutralizer endurance testing. One of these facilities is located at the ArianeGroup site in Lampoldshausen, the second one is the NEMO Facility of the JLU Gießen University. Both test facilities have a vacuum system basing on turbo pumps, with a pumping speed of 4,300l/s (ArianeGroup Lampoldshausen) and 2000l/s (JLU Gießen). Both facilities are equipped with residual gas analyzers and industrial pyrometers to measure the tip temperature continuously during the complete neutralizer operation.

C. Test setup

Both units under test are arranged in the same electrical test setup. The neutralizers are placed 7.5cm with its exit plain away from the graphite perforated anode representing the plasma potential of a thruster The neutralizer gets operated in floating configuration.

D. Current Test status

Both stand-alone tests are ongoing at the time writing this paper. Both units were initially hot fired for ~100h as an acceptance hot firing. This should ensure the correct initial performance. The acceptance hot firing included a run in which is followed by a performance mapping. During this performance mapping the neutralizers operate at their nominal operation parameter and additionally with at least 10% reduced mass flow. After this acceptance hot firing the mechanical vibration and shock tests were performed successfully. Finally the acceptance hot firing was repeated to show that the mechanical loads did not cause any degradation. After passing this test the endurance test was started with a 500h continuous operation. Both units passed the first inspection point after 500h and are now in the continuously running block. Up to now the first inspection has been completed. In the future these inspection results are used for verification of the simulated orifice erosion model.

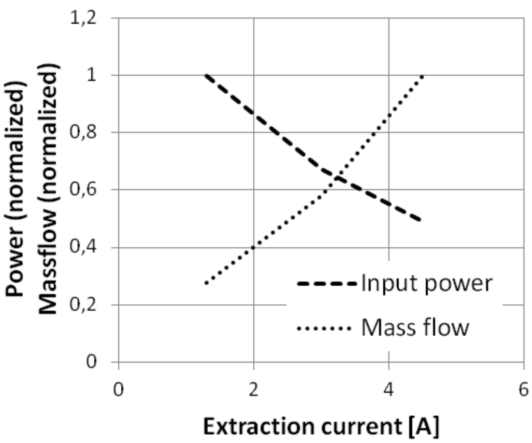

Figure 4. Performance overview

E. Neutralizer performance overview

Part of the neutralizer endurance test is a performance mapping. The performance mapping is performed to acquire the operational parameters for the three extraction currents 1.3A, 3A and 4.5A. The challenge during the neutralizer development was to achieve stable operation over this wide range of extraction current, which guaranties a huge flexibility in the system and mission design. This flexibility has the draw back that especially in the low current operation modes higher power consumptions are required compared to designs for only one operation point or just a small range of different operation points. In Figure 4 the performance overview is shown. This includes the neutralizer input power (Keeper power) and the required Xenon mass flows for the extraction currents between 1.3A and 4.5A.

IV. Heater qualification status

A. Heater qualification approach

Except from mechanical forces only one realistic harming factor for this type of heaters is known. Related to the atmosphere in which the heater gets operated the PBN decomposes under high temperature to solid elementary boron and nitrogen gas. This effect is known but was not quantified. To avoid a test campaign over several years a decomposition model was required. ArianeGroup developed this decomposition model of PBN for the specific heater design[1]. This model provides a decomposition rate of the PBN as a function of the heater temperature.

B. Heater test facility

The qualification tests are conducted at ArianeGroup test facility. In Figure 5 a frontal view of the four heaters, inside the neutralizers, is shown. All four heaters are thermally shielded to reduce cross talk between them. The shown setup is placed inside a vacuum facility which maintains a chamber presser below 1E-5 mbar. The two unites on the left side performed the endurance testing and the units on the right side perform the cycling test. Additionally to these four heaters, one heater was operated at an elevated temperature with the goal to drive it to a failure within acceptable time. This should validate the model and gain new knowledge about the failure mechanisms of the heaters as before no heater failed during operation in its nominal environment.

Figure 5. Qualification heater test setup

C. Qualification endurance test

Based on the degradation model, developed by ArianeGroup, the qualification endurance test was divided in two parts; the passive heating equivalent time and the active heating time. Both factors give us the endurance testing time.

The passive heating time is calculated on the basis of the maximum tip temperature at the different NTR operation points and the total time of operation at the mentioned modes. The maximum tip temperatures were obtained through NTR measurements at BOL; these temperatures are higher than the heater temperatures, but they were chosen to give the calculation a worst case character.

The duration of the active heating qualification was taken directly from the real in space on time including a qualification margin and an additional margin on the defined heating duration. Thus 3,000h of constant operation to qualify the active heating mode are required. In this 3,000h the heaters were operated with the nominal heater current plus additional margin to demonstrate additional robustness.

Another difference between active and passive heating testing is the test temperature; the passive heating temperature is around 50°C colder that the one for active heating. Altogether, the testing time sums up to 7500h, which are already completed successfully.

D. Heater Qualification cycles test

Additionally to the continuous operation of the heaters a heater cycling was included in the qualification program. This was conducted to exclude any issues due to thermally induced stresses. The total test cycles include a margin of 50% of the planned ignitions, coming to a total of 18000 cycles with 10 minutes "on-time" for each cycle.

The test is divided in 3 different cycled periods. The first block is conducted with an "off-time" of 170 minutes, coming down to a temperature below 100 °C. The second block of the test consists of 6000 cycles with 30 minutes off; in this configuration the cold temperatures reached around 200 °C. For the last block of this test an accelerated cycling with 10 minutes off,; requires more than 11000 cycles. At the moment, 80% of this test has been accomplished.

E. Heater elevated temperature test

As mentioned above one heater was tested at an elevated temperature with the goal to drive it to a failure. The test was performed in separated test chamber. The heater was installed inside neutralizer assembly but without an insert inside the inner tube. A special preparation of the neutralizer was required to allow a direct measurement of the heater temperature during the operation. A hole was drilled inside the keeper and heat shield holding structure. Also the heat shield was prepared with a hole inside to realize the direct view on the heater. This setup allowed the temperature measurement of the heater and the orifice plate with the use of an infrared camera.

During the first part of the test the heater input power was stepped up to characterize the heater temperature at different input powers. This was taken as a base line performance to compare it from time to time during the test. It also provided the absolute difference between the nominal operation temperature and the temperature during this test, which is important for the calculation of the expected acceleration factor between the nominal operation duration and the expected degradation rate during the elevated temperature.
During the test phase of the constant heater input power the heater ran about 200°C hotter than during the maximum temperature at the ignition heat up. Objective was to run the test until heater fail.
After more than 1,200h the heater failed. The first signs for an off nominal operation started around 950h at this elevated temperature. Putting this result inside the decomposition model, showed a well fit with the expected end of life of the heater. This result confirmed the approach and margins of the heater qualification. The combination of a demonstrating the full on time at the most demanding temperature plus validation of the mission duration at lower temperature by use of the decomposition model including several margins in the model and the testing durations is a robust approach for this type of heaters.

V. Conclusion and outlook

ArianeGroup GmbH in Lampoldshausen developed a Neutralizer in the 5A extraction current class suitable for modern high power electric propulsion system with multiple operation points like the RIT 2X system. A well-known heater technology outside space business was chosen as baseline and adapted for the use in the neutralizer. Due to the fact that with the heater one of the key parts inside the neutralizer is new for this application the qualification was done for the neutralizer and additionally for the heater itself in parallel. The qualification of this neutralizer and the heater is at the time writing this paper still under completion. An approach of extensive testing combined with modelling and correlation was chosen to qualify the neutralizer within a reasonable time.

While the heater qualification is nearly completed the qualification of the complete neutralizer will continue. It is expected to be completed by mid of 2020.

VI. References

[1] Altmann, C. et al, *Aspects of advanced Neutralizer development for the RIT-2x family of gridded ion engines,* SP2018_00471