

Mixed Metal based Hollow Cathode Neutralizer Technology for HEMP based Ion Propulsion Systems

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Abstract: Thales Deutschland - Electron Devices - is currently developing an electric propulsion system for the SmallGEO Hispasat AG1 mission. Main part of the system is a High Efficiency Multistage Plasma Thruster (HEMPT) which self-consistently generates and accelerates xenon ions to provide thrust.

To prevent electrical charging of the satellite the positive ion current has to be compensated with an equal negative electron current. A hollow cathode is used for this purpose as an electron source. For the emissive cathode material a barium impregnated tungsten-osmium sintered body is used. Thales employs this technology since a long period in travelling wave tubes (TWT) and has gathered expansive operating experience with more than 300 millions of hours of flight heritage. The work function of the emissive material amounts to 1.98 eV. The cathode is especially designed to provide a long-term stable Ba reservoir resulting in a stable keeper discharge and stable coupling voltages and in particular in very low ignition voltages of the keeper discharge.

The design of the neutralizer combines robustness and low weight with emphasis on the thermo-mechanical stability of welded and brazed junctions faced with high thermal loads. All temperature critical linkages are successfully tested and verified prior to qualification of the HEMP Thruster Module (HTM). 4800 firing hours in continuous operation are gathered during the ET1 endurance test on HTM level. Environmental verification including mechanical and thermal vacuum loads on qualification level has been performed successfully both on component and on HTM level.

Nomenclature

ET1 = Endurance Test 1
FM = Flight Model

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<i>HCN5000</i>	=	Hollow Cathode Neutralizer 5000*
<i>HEMP</i>	=	High Efficiency Multistage Plasma
<i>HEMPT</i>	=	High Efficiency Multistage Plasma Thruster
<i>HTA</i>	=	HEMP Thruster Assembly
<i>HTM</i>	=	HEMP Thruster Module
<i>MIP</i>	=	Major Investigation Point
<i>PSCU</i>	=	Power Supply and Control Unit
<i>QM</i>	=	Qualification Model
<i>TEDG</i>	=	Thales Electron Devices GmbH, Ulm
<i>TWT</i>	=	Travelling Wave Tube

I. Introduction

Thales is the world's leading supplier for Traveling Wave Tubes (TWTs) for satellites and other spacecrafts. A key component of such devices is the cathode. Thales Deutschland – Electron Devices – employs for this particular purpose tungsten-osmium mixed metal dispenser cathodes. With this particular technology more than 300 millions of hours of flight heritage were gathered up to now. In course of the development of the novel HEMP thruster based electric propulsion system it therefore appeared self-evident for TEDG to develop its own hollow cathode neutralizer. The development activities for the Thales hollow cathode neutralizer HCN5000 started in the year 2003. Important milestones were achieved with the successful coupling tests of the HCN5000 with the RIT-22 ion engine and a demonstrator model of the HEMP 3050.¹ Since 2008 TEDG develops, designs, manufactures, and qualifies an electric propulsion system for north-south as well as east-west station keeping. The in-orbit verification of this novel system is scheduled for the SmallGEO Hispasat AG1 mission.^{2,3}

The present paper covers mainly aspects of the Thales hollow cathode neutralizer HCN5000 as a part of the above outlined ion propulsion system and is organized as follows: In the Chapter II. the basic design and the functional concept of the Thales hollow cathode neutralizer is introduced. Chapter III. is dedicated to the neutralizer ignition and continuous operation parameters gathered during the development and test activities at TEDG in Ulm and the ET1 endurance test of a HEMP Thruster Module (HTM) starting from August 2010 until to March 2011. In this test a HTM was subjected to a life time test for 4000 + 800 hours of continuous operation at the LVTF-1 test facility at AEROSPAZIO Technologie s.r.l., Siena, Italy⁴, and the ULAN test facility at TEDG in Ulm.⁵ In Chapter IV. details about the Qualification status of the Thales hollow cathode neutralizer HCN5000 on sub-assembly-, component-, and sub-system-level will be provided. Finally in Chapter V. the results are summarized and the next steps towards Qualification and production of the Flight Models (FM) for the SmallGEO Hispasat AG1 mission are outlined.

II. Design and functional concept of the Thales hollow cathode neutralizer HCN5000

A schematic of the Thales hollow cathode neutralizer HCN5000 is presented in Figure 1. The neutralizer consists of a heater assembly brazed to a cathode assembly - a cylindrical tube containing the emissive cathode material. The applied brazing technology provides an excellent thermal contact between heater and cathode. The refractory materials of both assemblies form a cylindrical cavity representing the hollow cathode. At the rear panel of the hollow cathode xenon is fed through a bore and at the downstream end of the cavity the orifice bore is located.

The hollow cathode assembly is encircled by the keeper electrode. In the center of this electrode a bore larger in diameter than the orifice bore is located. The distance between the orifice plate, i.e. the circular plane containing the orifice bore, and the keeper electrode amounts to a few millimeters.

As emissive material for the cathode a tungsten-osmium porous sinter body impregnated with a mixture of barium, calcium, and alumina is applied. The employment of tungsten-osmium lowers the work function by approximately 0.1 eV compared to pure tungsten to 1.98 eV.

* The number of 5000 indicates the maximum current of 5000 mA which can be drawn from the Thales hollow cathode neutralizer HCN5000.

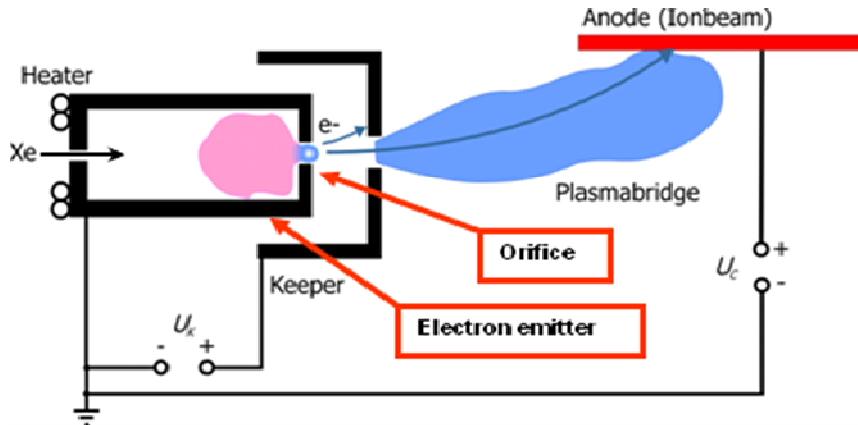


Figure 1 Schematic illustration of the Thales hollow cathode neutralizer HCN5000

The functional concept of the Thales hollow cathode neutralizer HCN5000 is basically the same as for tungsten porous matrix based and barium impregnated dispenser cathodes. Such devices are subject of extensive and ongoing research and their functionality is vastly understood.^{6,7,8} Nevertheless, the Thales hollow cathode concept differs from the tungsten matrix based dispenser hollow cathodes at specific points.

A key feature of the Thales hollow cathode technology is a orifice plate which comprises of impregnated W/Os matrix material. There are several reports in the literature dealing with the ignition mechanism of dispenser hollow cathodes.^{9,10} One outcome of this research is the finding that a monolayer of barium shall cover the channel surface of the orifice bore to allow for reliable ignition of the hollow cathode neutralizer. The Thales concept accommodates this issue by design as shown in Figure 2.

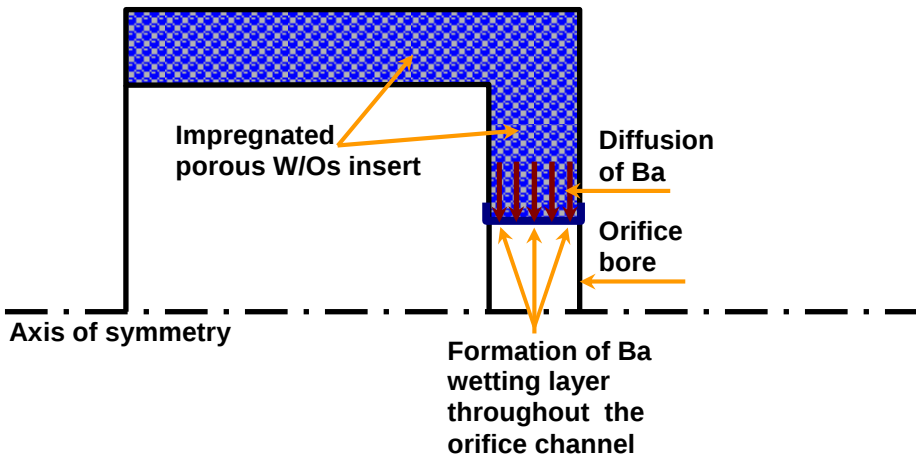


Figure 2 Schematic of the Ba wetting of the orifice channel

Emissive barium is continuously available from the impregnated tungsten-osmium orifice plate. During heating of the neutralizer barium diffuses out of the orifice plate and the formation of a barium monolayer throughout the orifice bore channel is assured. Therefore, reliable neutralizer ignition at low ignition voltages over life time is guaranteed.

A cross section of the current design of the HCN5000 as it is foreseen in the HEMP thruster assembly (HTA) for the SmallGEO Hispasat AG1 mission is given in Figure 3. The present design combines robustness and low weight. It is worthwhile to emphasize that any manufacturing- and process step during the complete production of the neutralizer is kept in-house at TEDG. This enables the full control of the product at any step. This presents a unique feature of the development-, design-, and production facilities at TEDG.

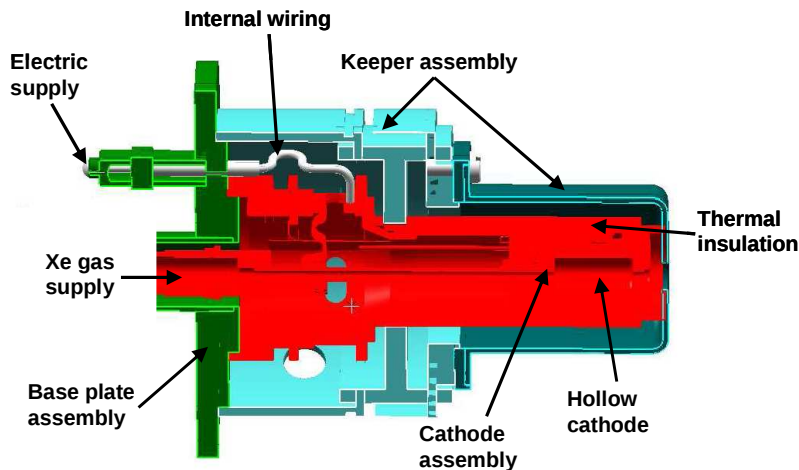


Figure 3 Crosse section of the Thales neutralizer HCN5000

Particular care is taken for the thermal decoupling of the cathode and heater assembly from its environment. This includes both conducted and radiated power losses as this parameter has an essential impact on the cathode sheath potential: Low thermal losses of the hollow cathode lead to a low cathode sheath potential which in turn shifts the power balance for the insert heating from the ionic contribution toward the electronic contribution.⁸ As a result the reduced ion impingement on the cathode insert surface leads to low sputtering of barium at the cathode surface.

The operational concept of the Thales hollow cathode neutralizer HCN5000 is basically composed of three consecutive phases, i.e. heating, ignition, and self-sustained hollow cathode plasma discharge. Prior to neutralizer ignition the hollow cathode is heated up. The continuously available barium at the channel of the orifice bore starts with thermionic emission of electrons. Having reached a certain temperature propellant is fed to the neutralizer. After switching off the heater supply the keeper supply is switched on and the neutralizer ignition takes place. With a pre-defined current drawn by the keeper electrode the hollow cathode plasma remains self-sustained. This approach greatly reduces the complexity on the power supply side. In fact the power supply and control unit (PSCU) of the HTA provides only one power supply branch for both heater and keeper.

It is important to note that the maximum temperature of the cathode is reached during the heating phase. In nominal operation (cf. Chapter III.) the cathode temperature is far below this value. Nevertheless, the dimension of the tungsten-osmium matrix, and, therefore its capability for providing emissive material over the neutralizer life time, is chosen that way to guarantee a cathode life for more than 20000 hours of operation at the highest cathode temperature during heating.¹¹

III. Typical ignition- and operational parameters of the HCN5000

A key feature of the Thales hollow cathode neutralizer is its emissive orifice plate allowing for low ignition voltages of the device. In Figure 4 a typical ignition transient of the keeper voltage and the keeper current is presented.

For ignition xenon gas is fed to the neutralizer and a DC voltage is applied to the keeper electrode. Immediately after the voltage is applied the ignition of the neutralizer starts.

In course of the ET1 endurance test⁴ numerous neutralizer ignitions were conducted. Typically the peak keeper voltage during ignition was below 20 V as shown in Figure 5. As an example, for the ignition shown in Figure 4 the maximum keeper ignition voltage amounts to 16.4 V. A value of typically less than 20 V is far below the maximal PSCU keeper ignition voltage of 35 V. Unlike as for LaB6 hollow cathodes no high voltage pulse sequence for the ignition is required.

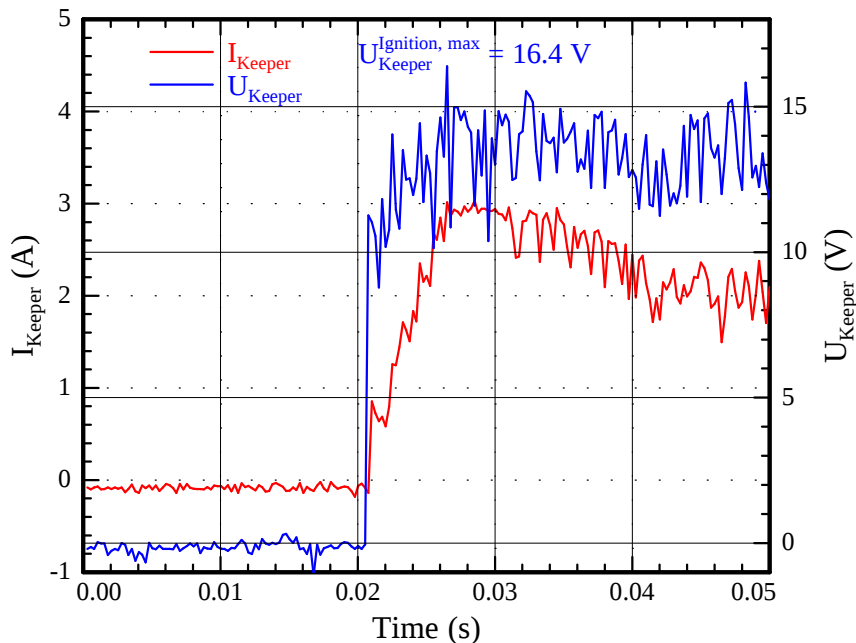


Figure 4 Typical ignition transient of keeper current and keeper voltage of the HCN5000. The presented data were recorded in course of ET1.

Prior to this ignitions the emissivity of the neutralizer was routinely monitored. For this reason a DC voltage was applied to the keeper electrode without supplying the neutralizer with xenon. The resulting emission current is shown in Figure 5. It turned out that this quantity is sensitive to chamber induced effects such as facility regenerations.

Nevertheless, during nominal operation the hollow cathode neutralizer operates in a healthy parameter range. The typical keeper voltage amounts to 9 V...12 V and the EP-ground-to-facility-ground voltage (i.e. the so-called coupling voltage) amounts to -14V...-12V and is shown in Figure 6. The neutralizer performance does not change significantly even during long term operation. The above mentioned facility induced effects hardly influence the neutralizer performance. If once a facility induced event occurs the corresponding effects, i.e. slightly increased keeper- and coupling voltages, disappear within some operational hours. This behavior clearly shows that the Thales hollow cathode neutralizer is able to cope with slight poisoning which may occur if oxygen and/or water are released from the cryogenic panels of the xenon pumping system of a ground test facility during regeneration.

Important information concerning the hollow cathode condition is obtained by measuring the corresponding cathode temperature. During ET1 the cathode temperature was recorded. It turned out that in nominal operation the hollow cathode temperature is below 1000 °C as shown in Figure 6. This finding allows to extend the expected cathode life time up to 100000 hours.¹¹

The visual post inspection of the neutralizer after ET1 revealed that no significant erosion of the orifice plate, the orifice bore, and the keeper electrode occurred. The stable operational parameters of the neutralizer imply that also at the cathode insert no degradation had occurred. For this reason it was decided to enhance the ET1 at the ULAN test facility without the removal or any kind of refurbishment of the existing neutralizer.

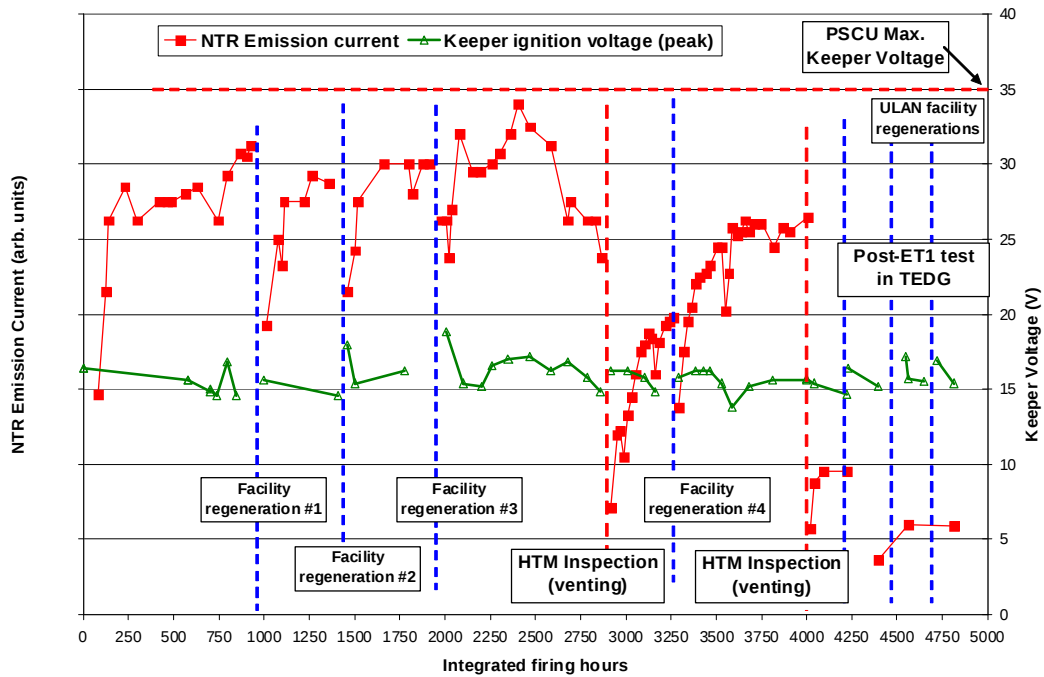


Figure 5 Emission current and keeper ignition voltage during ET1 and post test

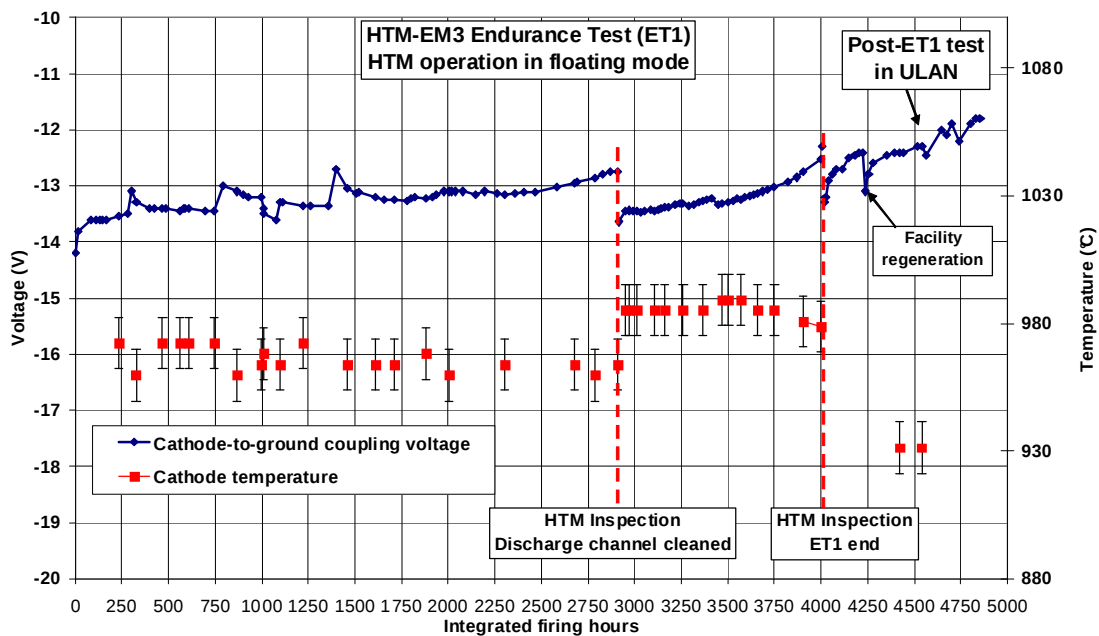


Figure 6 Coupling voltage and cathode temperature during ET1 and post test

IV. Qualification status of the Thales hollow cathode neutralizer HCN5000

The manufacturing of a neutralizer for space applications is a challenging task especially in terms of reproducibility, reliability, and constant meeting of high quality criteria. TEDG continuously makes an effort to cope with such requirements. Any piece part, sub-assembly, assembly, and finally the completed component is routinely controlled by non-destructive analysis means, i.e. measurement of geometrical dimensions, visual inspections, and leakage testing. Furthermore, at particular process steps major investigation points (MIPs) are introduced. To enable endurance testing on assembly- and component level and destructive analysis for screening purposes of neutralizer assemblies TEDG strictly follows a batch philosophy.

For the Qualification of the neutralizer extensive testing of sub-assemblies, assemblies, and the complete component are conducted:

- All brazed metal-ceramic assemblies are subjected to temperature cycling tests. The number of cycles results from the specification of the SmallGEO Hispasat AG1 mission. The temperature swing covers the full range appearing during the mission including sufficient margin.
- A certain portion of heater sub-assemblies out of any production batch is subjected to a cyclic switching test. In course of this test the heater is supplied with electrical power and the resulting temperature of a representative cathode dummy assembly is monitored. The slope of the heating-up sequence and the maximal introduced heater power is representative to the SmallGEO mission including sufficient margin.
- To gather statistical relevant data any neutralizer out of a production batch is activated and operated according a precisely defined procedure in a glass bulb at the end of the manufacturing process. As important parameters this test delivers precisely the demanded heater power and the emitted activation current (without plasma load). Both parameters carry essential information needed at HTA system level as well as for monitoring of dedicated production steps.
- The function and capability of the HCN5000 neutralizer is also routinely tested under plasma conditions in TEDG's neutralizer test facility. The evaluation of the test results shall deliver criteria for a final production batch release for the QMs and FMs.

The mechanical verification of the HCN5000 neutralizer was accomplished on both component and sub-system level. To discover a potential mechanical weakness of the design a neutralizer without gas line and electrical wiring was integrated into a structural (and thermal) representative model (STM) and subjected to a mechanical test. The introduced levels were the same as for the SmallGEO Hispasat AG1 mission. The vibration test did not disclose any mechanical deficiencies of the HCN5000 neutralizer design.

For the design verification on sub-system (HTM) level another HCN5000 neutralizer was applied. This time the electrical wiring and gas tubing of the neutralizer was fully representative to the upcoming Qualification- and Flight Models. The HTM also endured the mechanical as well as the shock test sequence at the levels specified for the SmallGEO mission.^{2,3} The accurate function of the neutralizer was afterwards verified in a subsequent thermal vacuum test sequence.

V. Conclusion and outlook

The Thales hollow cathode neutralizer HCN5000 exhibits stable performance in a healthy parameter range. This calm characteristics of the neutralizer is advantageous for the simultaneous operation of the HTA and the payload on a spacecraft. The orifice front plate comprising of impregnated W/Os matrix material is a unique feature of the HCN5000 neutralizer and turned out to assure neutralizer ignition at low keeper voltages. The dimensions, and, therefore the capacity of the emissive cathode material, and the considerably low cathode temperatures during nominal operation suggest a total life time in the range of 100000 hours. Environmental tests such as vibration and shock verified the HCN5000 neutralizer on component- as well as on sub-system level. A subsequent thermal vacuum test on HTM level confirmed the full functionality of the device.

The Qualification of the neutralizer on piece part, sub-assembly, assembly, and component level is vastly accomplished. Currently the storage capability of the neutralizer in the launch vehicle fairing environment is under test. For this purpose the neutralizer is stored in an atmosphere containing a certain amount of humidity for a defined time span. Up to now no anomaly occurred.

In the next steps the QM production will be finalized and the FM production is already under way.

Acknowledgments

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References

- ¹N. Koch, H.-P. Harmann, G. Kornfeld, *Status of the THALES Tungsten/Osmium Mixed-Metal Hollow Cathode Neutralizer Development, Proceedings of the 30th International Electric Propulsion Conference*, IEPC-2007-117 (2007)
- ²N. Koch, S. Weis, M. Schirra, A. Lazurenko, B. van Reijen, J. Haderspeck, A. Genovese, P. Holtmann, K. Ruf, N. Püttmann, H. Lübberstedt, *Proceedings of the 47th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit*, AIAA 2011-6086 (2011)
- ³N. Koch, S. Weis, M. Schirra, A. Lazurenko, B. van Reijen, J. Haderspeck, A. Genovese, K. Ruf, N. Püttmann, *Development, Qualification, and Delivery Status of the HEMPT based Ion Propulsion System for SmallGEO*, Proceedings of the 32th International Electric Propulsion Conference, IEPC-2011-148 (2011)
- ⁴A. Genovese, A. Lazurenko, N. Koch, S. Weis, M. Schirra, B. van Reijen, J. Haderspeck, *Endurance Testing of HEMPT-based Ion Propulsion Modules for SmallGEO*, Proceedings of the 32th International Electric Propulsion Conference, IEPC-2011-141 (2011)
- ⁵A. Lazurenko, B. van Reijen, N. Koch, S. Weis, A. Genovese, J. Haderspeck, M. Schirra, S. Scaranzin, F. Scortecci *Overview on Testing Infrastructures and Diagnostic Tools for HEMPT based Ion Propulsion Systems*, Proceedings of the 32th International Electric Propulsion Conference, IEPC-2011-146 (2011)
- ⁶D.M. Goebel, K.K. Jameson, R.M. Watkins, I. Katz, I.G. Mikellides, *Hollow cathode theory and experiment. I. Plasma characterization using fast miniature scanning probes*, J. Appl. Phys 98, 113302 (2005)
- ⁷I.G. Mikellides, I. Katz, D.M. Goebel, J.E. Polk, *Hollow cathode theory and experiment. II. A two-dimensional theoretical model of the emitter region*, J. Appl. Phys 98, 113303 (2005)
- ⁸D.M. Goebel, I. Katz, *Fundamentals of Electric Propulsion*, Wiley, Hoboken, New Jersey (2008)
- ⁹W.G. Tighe, K.-R. Chien, D.M. Goebel, R.T. Longo, *Hollow Cathode Ignition Studies and Model Development*, Proceedings of the 29th International Electric Propulsion Conference, IEPC-2005-314 (2005)
- ¹⁰W.G. Tighe, K.-R. Chien, D.M. Goebel, R.T. Longo, *Hollow Cathode Emission and Ignition Studies at L-3 ETI*, IEPC-2007-023 (2007)
- ¹¹G. Kornfeld, N. Koch, H.-P. Harmann, *Development & Test Status of the Thales W/Os Mixed Metal Matrix Hollow Cathode Neutraliser HKN5000*, IEPC-2005-298 (2005)