# JAXA 1-KW CLASS LONG-LIFE HALL THRUSTER SYSTEM ν800 EMPLOYING A NOVEL IGNITION MECHANISM

**SPACE PROPULSION 2024**
GLASGOW, SCOTLAND | 20 – 23 MAY 2024

**Shinatora CHO[(1)], Yoshiki MATSUNAGA[(1)], Hiroki WATANABE[(1)], Hiroaki KUSAWAKE[(1)], Yasushi OHKAWA[(1)], Shuichi NAKAMURA[(2)], Kazuyuki HIGASHINO[(2)], Toru TAKAHASHI[(3)]**

*[(1)]Research and Development Directorate, Japan Aerospace Exploration Agency, Kanagawa, Japan, Email: choh.shinatora@jaxa.jp*
*[(2)]NETS, Saitama, Japan, Email: s-nakamura@nets-co.jp*
*[(3)]TDS, Fukushima, Japan, Email: toru_takahashi@tds-i.co.jp*

**KEYWORDS:** In-space propulsion, electric propulsion, Hall thruster, Ignitor

**ABSTRACT:**

JAXA is continuing research and development of a 1-kW class long-life Hall thruster system called ν800 for future JAXA missions, for example, active debris removal, low orbit observation, and deep space exploration. One of the most important features of ν800 is that it employs a novel ignition mechanism, replacing the complex keeper/ignitor power supply in PPU with a simple passive ignitor circuit utilizing the high voltage of anode power supply, achieving substantial weight loss and simplification of failure modes. The outline of the ignition mechanism, typical ignition waveform, and qualification status of the ν800 system is presented.

## 1. Introduction

JAXA is utilizing in-space electric propulsion (EP) systems for different space missions. Hayabusa1&2 sample return mission[1] and Super Low Altitude Test Satellite (SLATS)[2] had successfully completed their missions using domestically developed gridded ion thruster systems. In addition, a 6-kW high power Hall thruster is under development for geostationary missions[3], awaiting its in-space demonstration on Engineering Test Satellite-9 (ETS-9). For future JAXA missions, e.g., active debris removal[4], low orbit observation, deep space exploration, there are growing demand for middle/low power Hall thruster. Accordingly, JAXA initiated a research and development program of a low cost, long life, high performance 1-kW class Hall thruster system called ν800, which consists of thruster head unit with internally-mounted cathode (THU), power processing unit (PPU), and flow controller unit (FCU)[5]. The lifetime capacity target of ν800 is >20,000 hrs (>4.4 MNs total impulse) and > 20,000 ON cycles, which is challenging for Hall thruster system of this class. To meet the high lifetime requirement, low-erosion thruster design and internally-mounted cathode configuration are adopted. In addition, a novel ignition mechanism is employed for system simplification to accomplish both successful downsizing and cost-cut.

As reported in Space Propulsion 2022[6], breadboard-model thruster performance of >1,500 sec of total-Isp, and >65 mN/kW of thrust-to-power ratio was achieved at >800W Xe operation in a <5×10-4 Pa high vacuum test facility; The coupling test with breadboard-model power supply, radiated emission measurement in a glass sub-chamber, mechanical environmental test, and lifetest of 2,000 hrs with 2,000 ON cycles was successfully demonstrated[6]. The qualification test of the ν800 system engineering-model is completed in March 2024 and the lifetest is ongoing.

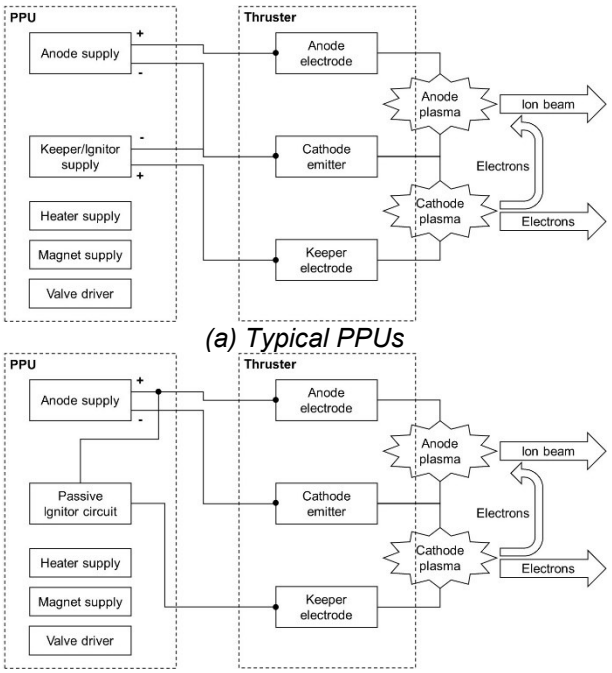
In this paper, we report the overview of the patented novel ignition mechanism and how it works, as well as the qualification status of the ν800 system.

## 2. IGNITION MECHANISM

Figure 1 shows a block diagram of a Hall thruster and a PPU. Typical PPUs have two plasma supplying DC/DC converters: anode and keeper/ignitor. While the anode converter provides the Hall thruster main discharge, the keeper/ignitor converter is responsible for initiating the cathode plasma needed to ignite and sustain the main discharge of the anode plasma as well as neutralizing the ion beam. Keeper/ignitor supply are generally required to have both high voltage output for ignition breakdown and current capacity to sustain the cathode plasma until at least the ignition of the anode plasma, therefore, relatively complex circuits such as flyback topology are typically used[7]. It is also to noted that the keeper/ignitor supply must have sufficient immunity to the plasma rush current and noise during the ignition

breakdown, which makes the design of the keeper/ignitor supply less easy.

In order to drastically simplify the design and failure modes, ν800 PPU employs a patented ignition mechanism which has a passive ignitor circuit branches from the anode supply HOT line. The functions of this passive ignitor circuit are to pass through the high voltage output of the anode supply to the keeper electrode to ignite the cathode plasma; sustain the cathode plasma until the ignition of the anode plasma; and cutoff the current pass from the keeper electrode to the cathode emitter to prevent excessive energy consumption by the cathode plasma. These functions can be achieved with an extremely simply configuration, requiring only a single resistor or a single capacitor in minimum. Practically, the passive ignitor circuit also can be constructed with a network of LCR electronic elements depending on the plasma ignition behaviour and noise suppression requirements.




*(a) Typical PPUs*




*(b) ν800 PPU*

*Figure 1. block diagram of a Hall thruster and a PPU*

Figure 2 denotes the typical ignition waveform of ν800 THU using the passive ignitor circuit. The keeper-to-cathode voltage rises equally with the anode-to-cathode voltage until the breakdown of the cathode and anode plasma occurs at approximately 37 Volts. Both keeper and anode current jump up simultaneously at the instance of the plasma breakdown, and the keeper current supplied by the passive ignitor circuit was about 0.7 Amperes. After the anode plasma transitioning to the steady-state high voltage operation, the keeper-to-cathode voltage is kept to low value and the keeper current is essentially zero.

Although ν800 THU employs internally-mounted cathode configuration, the passive ignitor circuit was also found to work effectively for externally-mounted cathode configuration without any differences. It is speculated that this ignition mechanism is valid for Hall thrusters adopts heater-less cathode, however, the limit of anode converter output might impose restrictions on the ignition capability because heater-less cathodes generally require higher voltage for plasma breakdown.

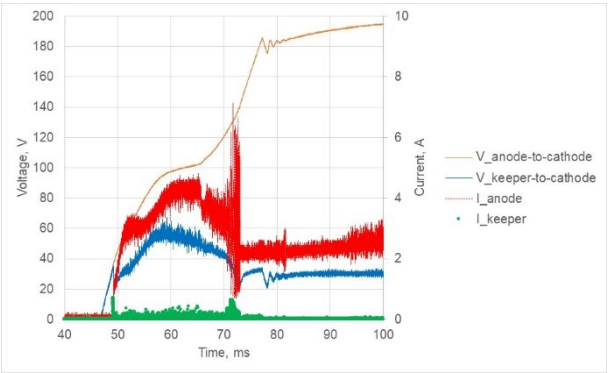



*Figure 2. Typical ignition waveform of ν800 THU using the passive ignitor circuit.*

## 3. OVERVIEW OF THRUSTER SYSTEM

Figure 3 shows the image of ν800 system, which consists of THU, FCU, PPU, harness and connectors. The specifications of the system are tabulated in table 1. In comparison with our publication in 2022[5], approximately 5 kg of weight reduction was achieved, and the presented ignition mechanism presented is one of the major reasons. PPU input voltage is primary 50 V unregulated for anode main discharge and secondary 28 V unregulated for other auxiliary power supplies, while it is optional to choose both primary and secondary 28 V to be unregulated. FCU inlet pressure is up to 18.6 MPa with the intention of direct tank pressure input. Capillary-tube type flow control valve[8] is adopted in FCU and used by PPU to control the THU anode discharge current. THU total power range, which is defined by the PPU capability, is 600~1050 W including the anode supply and all auxiliary power supplies. The typical thrust performance is thrust 65 mN and total specific impulse 1550 sec for THU total power 1000W, while the detailed performance depends on the anode voltage and power. The internal cathode of THU is equipped with a heater, whose necessary heating time before ignition is 150~300 sec. PPU utilize digital control technology achieves total efficiency of 92%, which contributes to the reduction of the PPU heat dissipation. The designed lifetime is 20000 hrs / 20000 cycles, which is under verification through qualification lifetest. ν800 system is compatible with Xe, Kr, or other noble gas propellant, whereas ongoing research and development is based on Xe.

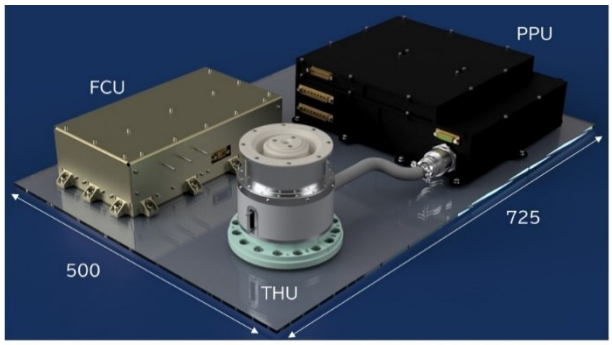



*Figure 3. Image of ν800 system*

*Table 1. Specifications of ν800 system*

| Item | Value | Notes |
|---|---|---|
| Mass | <=10 kg | Includes THU, PPU, FCU, Harness & connectors |
| PPU input voltage | Primary: 50 V unregulated Secondary: 28 V unregulated | Optional: Primary/Secondary: 28 V unregulated |
| FCU inlet pressure | Up to 18.6 MPa | |
| THU total power | 600~1050 W | |
| Typical Thrust | 65 mN | |
| Typical total Isp | 1550 sec | |
| PPU total efficiency | >=92% | |
| Life duration | >=20,000 hrs | >1,000 hrs EM demonstrated so far |
| ON cycles | >=20,000 | >1,900 EM demonstrated so far |
| Propellant | Xe | Kr to be lifetested |

## 4. QUALIFICATION STATUS

All engineering model (EM) of THU, FCU, PPU completed qualification-level test including pressure, shock, sine and random vibration, EMC, thermal vacuum. Through the system coupling tests, it was confirmed that the PPU can successfully control and operate the FCU and THU in an automatic sequence, and that the PPU's command & telemetry and various protection functions are valid. Figure 4 shows a sample data of ν800 system coupling test, whose data sampling rate is 0.1 Hz, demonstrating the end-to-end sequence of cathode heating, valve opening, ignition, constant power control for several target powers through FCU, and turn-off.

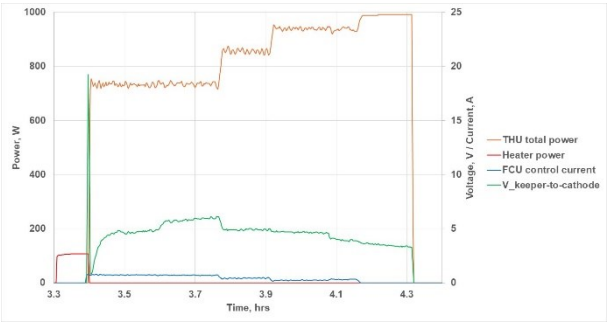



*Figure 4. Sample data of ν800 system coupling test*

After the series of qualification tests, lifetest of the THU engineering model was initiated at the end of 2023. As for the test facility, Chofu electric propulsion test facility was used. The ϕ3m X 5m vacuum chamber has effective pumping speed of 200 kl/s, and chamber pressure was kept below 5×10-4 Pa during the thruster performance test. Test conditions of lifetest are selected from the operational envelop shown by fig.5 according to the priority of mission requirement assumptions. The lifetest procedure is conducted in a manner consistent with actual operations in Low-Earth-Orbit, that is, 30~60 minutes of thruster operation and 30 minutes of shutdown were repeated alternately. A sample data of lifetest procedure is shown by fig. 6.

The cathode heating time was basically set to 150 sec to simulate low-temperature worst-case ignition conditions, since the plasma-induced erosion and contamination is likely to be more severe in low-temperature cases. It is to be noted that the cyclic thermal stress in high temperature cases is verified by another test campaign, more than 10,000 cycles of heating had been already demonstrated in high-temperature worst-case conditions.

So far, >1000hrs and >1900 cycles of EM thruster operation were demonstrated. The measured begin-of-life (after qualification test) representative thrust performance is 63 mN in thrust and 1756 sec in total specific impulse at THU total power 1031 W. As already been demonstrated in 2000 hrs / 2000 cycles BBM thruster lifetest[6], no degradation of thrust performance or discharge characteristics observed so far. The employed novel ignition mechanism is working properly over the demonstrated cycles that no misfire nor degradation of ignition characteristics observed. The lifetest campaign is scheduled until at least March 2025, but can be extended according to the requests of upcoming flight missions.

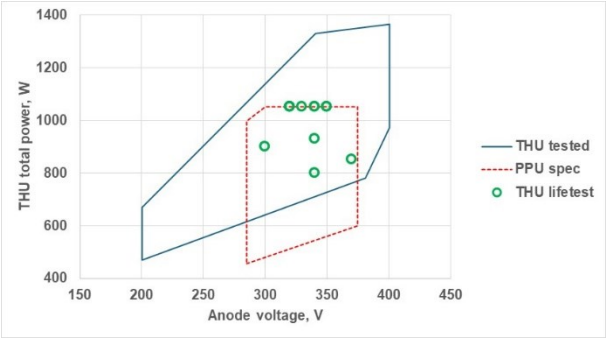



*Figure 5. Operational envelop and lifetest conditions of ν800*

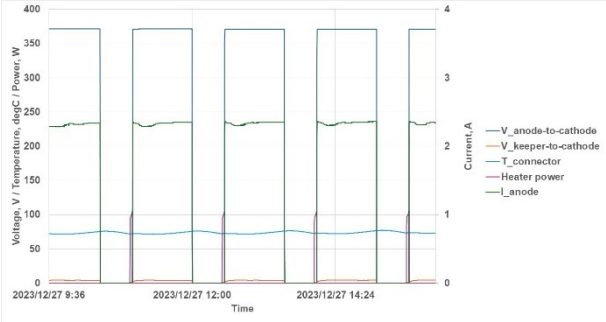



*Figure 6. Sample data of THU lifetest procedure*

## 5. SUMMARY

A novel ignition mechanism, achieving substantial weight loss and simplification of failure modes, utilizing the high voltage output of anode power supply is employed in JAXA 1-kW class long-life Hall thruster system ν800. After the completion of qualification test of each engineering model components and system coupling test, the lifetest campaign was initiated at the end of 2023, and >1000hrs and >1800 cycles of successful operation were demonstrated so far. The employed novel ignition mechanism is working properly over the demonstrated cycles that no misfire nor degradation of ignition characteristics observed.

## 6. REFERENCES

1. T. Yada, et.al.,: Preliminary analysis of the Hayabusa2 samples returned from C-type asteroid Ryugu, Nature Astronomy, (2021), doi: 10.1038/s41550-021-01550-6

2. S. Imamura,: On-orbit operation results of Super Low Altitude Test Satellite (SLATS), SpaceOps 2020

3. I. Funaki, S. Cho, T. Sano, T. Fukatsu, Y. Tashiro, T. Shiiki, Y. Nakamura, H. Watanabe, K. Kubota, Y. Matsunaga, K. Fuchigami,: Development of a 6-kW-class Hall thruster for geostationary missions, Acta Astronautica, Volume 170, May 2020, Pages 163-171

4. S. H. Okamoto, T. Yamamoto, A Novel Concept of Cost-Effective Active Debris Removal Spacecraft System, 1st International Orbital Debris Conference, Houston USA, December 2019

5. S. Cho, et.al., R&D status of JAXA 1-kW Hall Thruster System for Active Debris Removal, The 9th Space Debris Workshop, February 24-26, 2021. Chofu, Japan, doi/10.20637/00047782

6. S. Cho, et.al.,: Research and Development of a 1-kW Class Long-Life Hall Thruster System for JAXA Missions, Space Propulsion 2022, Estoril, Portugal, May 2022

7. S. Savvas, et.al.,: Discrete Cathode Power Supplies for Low Power Hall Effect Thrusters, 2019 European Space Power Conference, Juan-les-Pins, France, September 2019, DOI: 10.1109/ESPC.2019.8932079

8. K. Kinefuchi, et.al.,: Characterization of a Capillary Flow Controller for Electric Propulsion, Journal of Propulsion and Power, vol.36, No.4, 2020, DOI: 10.2514/1.B37726