Performance Evaluation of **Pulsar LeoBear 500W Hall Effect Thruster** with Krypton Propellant

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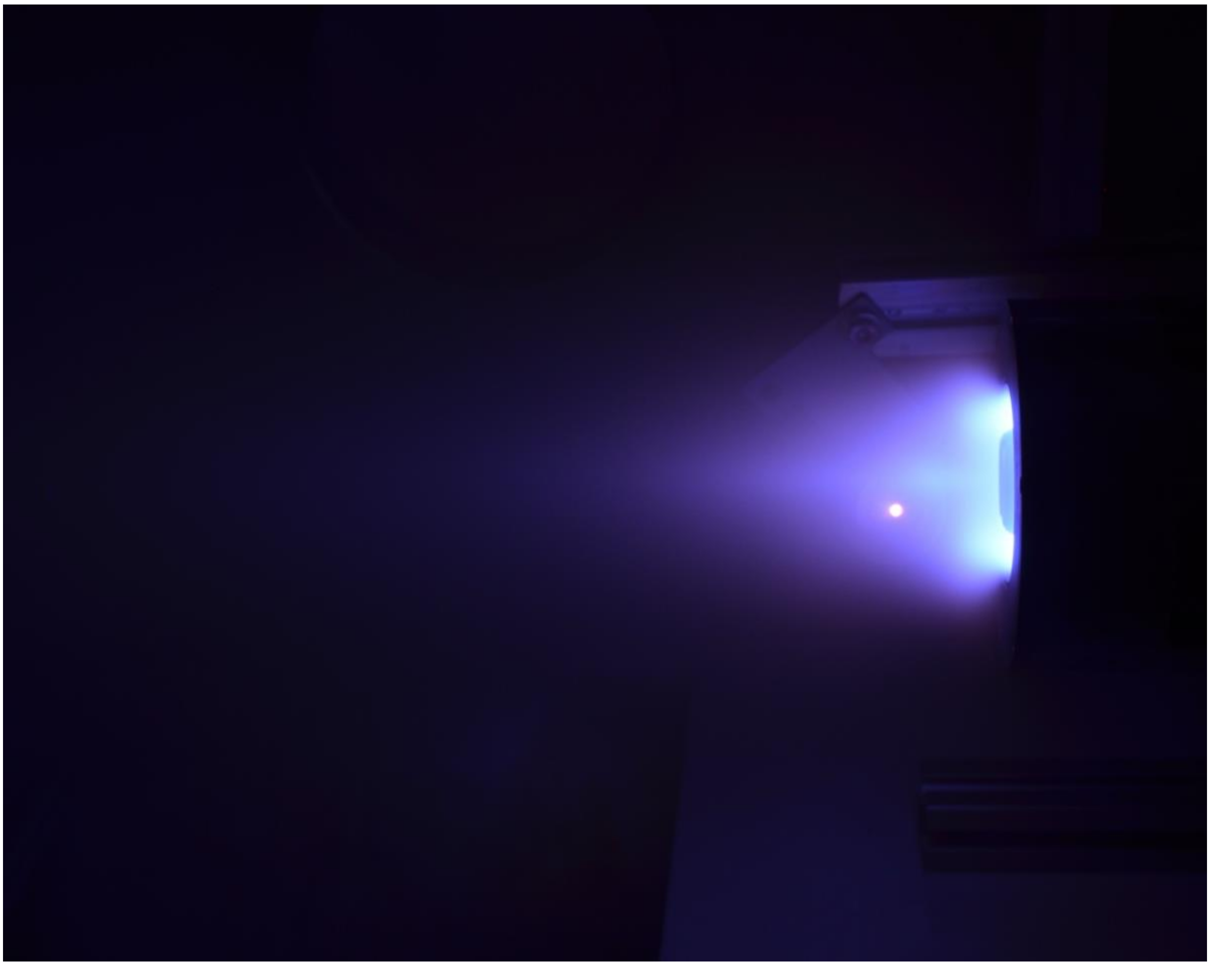

Abstract

This paper presents the results of a test firing campaign for a 500W Hall Effect Thruster (HET) using Krypton (Kr) as the propellant, conducted on 2–3 July 2025. The thruster was evaluated across a range of operating conditions, with discharge voltages from 224.8 V to 299.8 V, discharge currents from 1.54 A to 2.5 A, and Kr anode flow rates of 16, 20, and 24 sccm. Key performance metrics included thrust (13.52–27.46 mN), specific impulse (1382.8–2149.7 s), and anode efficiency (21.68–43.66%). The campaign addressed challenges such as sensor resolution and pressure variations, with upgrades to a confocal displacement sensor improving measurement accuracy. The results demonstrate the thruster's potential for efficient, high-performance electric propulsion in satellite and deep-space applications.

Keywords: *Hall Effect Thruster, Krypton, Electric Propulsion, Thrust, Specific Impulse, Anode Efficiency*

1. Introduction

Hall Effect Thrusters (HETs) are a cornerstone of electric propulsion, offering high specific impulse and efficiency for applications ranging from satellite station-keeping to interplanetary missions. Traditionally, Xenon (Xe) has been the propellant of choice due to its high atomic mass and low ionization energy. However, Krypton (Kr) is gaining attention as a cost-effective alternative, despite its lower performance due to higher ionization energy. This study evaluates the performance of a 500W HET developed by Pulsar Fusion, using Kr as the propellant. The test campaign, conducted on 2–3 July 2025, aimed to characterize thrust, specific impulse (Isp), and anode efficiency across various operating conditions, addressing challenges such as sensor accuracy and operational stability.

2. Methodology

2.1 Experimental Setup

The HET was tested in a vacuum chamber at pressures in the low to high 10^{-4} mbar range. The thruster operated at discharge voltages of 224.8–299.8 V, discharge currents of 1.54–2.5 A, and Kr anode flow rates of 16, 20, and 24 sccm (0.996–1.495 mg/s). Thrust was measured using a laser displacement sensor, initially with low resolution, replaced on 3 July with a confocal sensor (0.25 µm resolution) for improved accuracy. Calibration coefficients (0.000984–0.001044 mm/mN) and offsets (0.001113–0.001527 mm) were determined experimentally. Discharge power, thrust, Isp, and anode efficiency were calculated using Excel formulas based on measured data.

2.2 Data Collection

Data were collected over two days (2–3 July 2025, Excel date code 45840–45841). Each test point included displacement (mm), discharge voltage (V), discharge current (A), Kr flow rate (sccm and mg/s), and calculated metrics. Cathode data were excluded, as the focus was on anode performance, with plans to integrate proprietary cathode data for total efficiency calculations. Tests on 3 July were conducted at higher pressures (high 10^{-4} mbar) than typical (low 10^{-4} mbar), and efforts were made to mitigate drift issues.

2.3 Performance Metrics

- Thrust (mN): Calculated from displacement, calibration coefficient, and offset.
- Specific Impulse (Isp, s): Derived from thrust and propellant mass flow rate, indicating propellant efficiency.
- Anode Efficiency (%): Calculated as the ratio of jet power to anode electrical power, reflecting energy conversion efficiency.

3. Results

The test campaign yielded 15 data points, summarized in Table 1. Key findings are presented below, with performance metrics plotted in Figures 1–3.

Table 1: Summary of 500W HET Performance Data

Date (Excel)	Voltage (V)	Current (A)	Kr Flow (sccm)	Thrust (mN)	Isp (s)	Anode Efficiency (%)	Power (W)
45840	224.8	1.71	16	15.14	1548.1	29.91	384.4
45840	249.8	1.55	16	14.47	1479.7	27.13	387.2
45840	274.8	1.54	16	13.52	1382.8	21.68	423.2
45840	299.8	1.6	16	17.89	1829.4	33.47	479.7
45840	224.8	2.01	20	19.96	1632.7	35.38	451.8
45840	249.8	1.91	20	20.14	1647.1	34.10	477.1
45840	274.8	1.85	20	19.96	1632.4	31.43	508.4
45840	299.8	2.1	20	24.94	2040.0	39.64	629.6
45840	299.8	2.1	20	24.29	1986.9	37.60	629.6
45841	299.8	2.24	20	23.36	1910.7	32.60	671.6
45841	299.8	2.5	20	26.28	2149.7	36.97	749.5
45840	249.8	2.29	24	27.33	1863.0	43.66	572.0
45840	274.8	2.24	24	25.98	1770.9	36.66	615.6
45840	299.8	2.31	24	27.46	1872.0	36.41	692.5

3.1 Thrust Performance

Thrust ranged from 13.52 mN (274.8 V, 1.54 A, 16 sccm) to 27.46 mN (299.8 V, 2.31 A, 24 sccm). Higher flow rates and currents generally increased thrust, with the maximum observed at the highest flow rate and power (692.5 W).

3.2 Specific Impulse

Isp varied from 1382.8 s (274.8 V, 1.54 A, 16 sccm) to 2149.7 s (299.8 V, 2.5 A, 20 sccm). The highest Isp was achieved at high power and moderate flow rate, indicating efficient propellant utilization.

3.3 Anode Efficiency

Anode efficiency ranged from 21.68% (274.8 V, 1.54 A, 16 sccm) to 43.66% (249.8 V, 2.29 A, 24 sccm). Efficiency peaked at moderate voltage and high flow rate, suggesting optimal energy conversion under these conditions.

3.4 Sensor and Operational Notes

Tests on 2 July used a low-resolution laser displacement sensor, replaced on 3 July with a confocal sensor, improving measurement precision. Higher chamber pressure on 3 July (high 10^{-4} mbar) may have influenced performance. Efforts to address drift were noted, though specific solutions were not detailed.

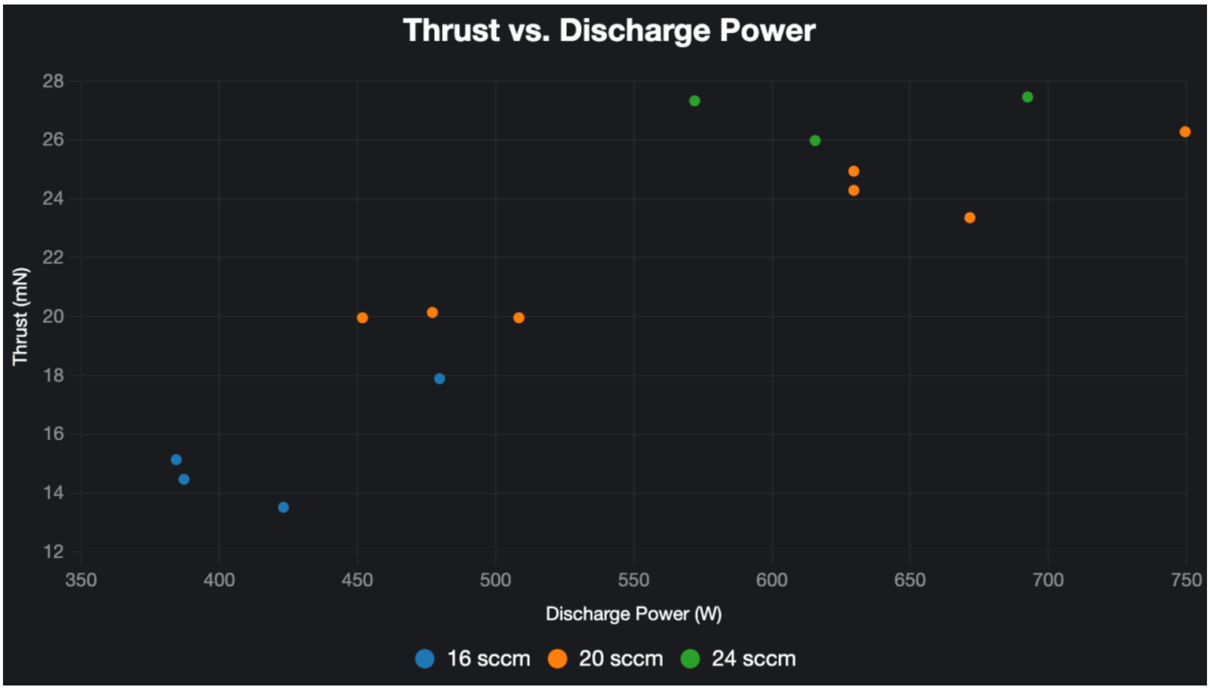

Figure 1: Thrust as a function of discharge power for different Kr flow rates.

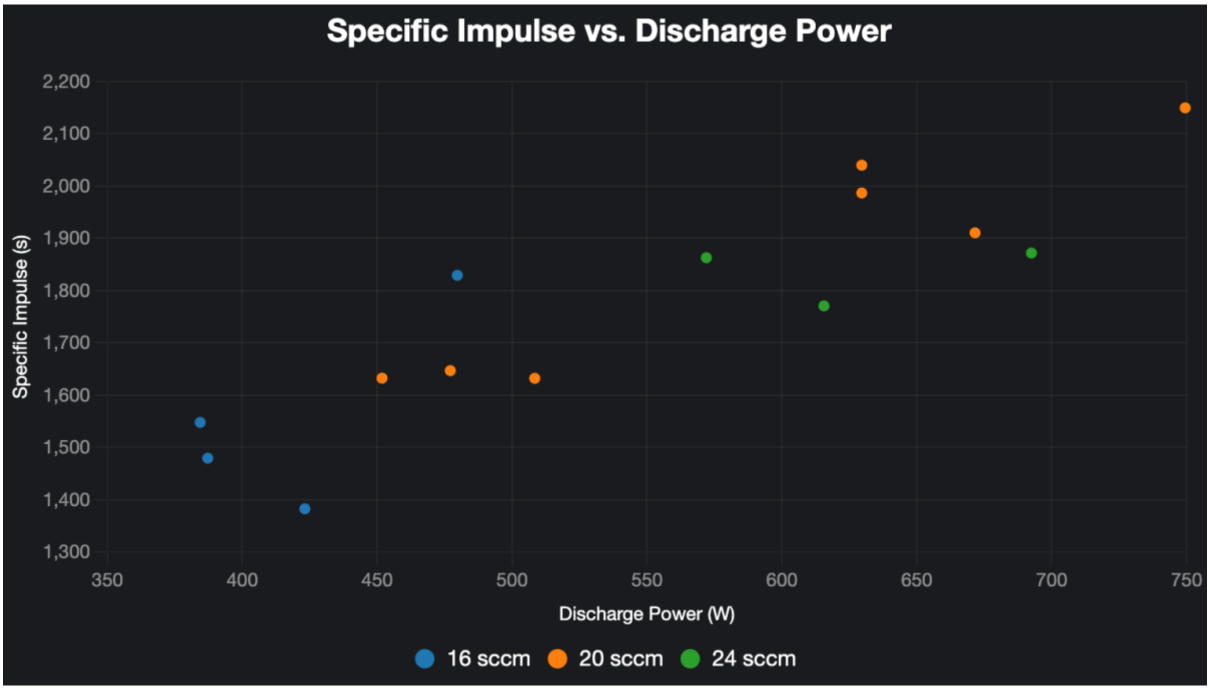

Figure 2: Specific impulse as a function of discharge power for different Kr flow rates.

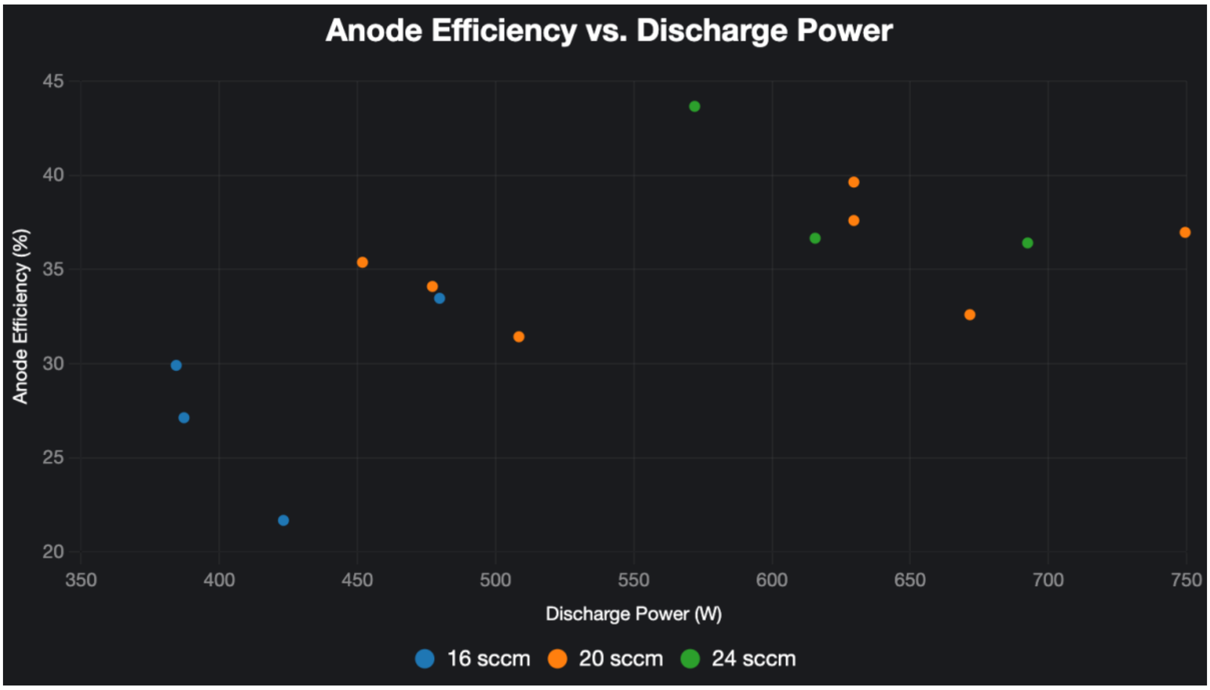

Figure 3: Anode efficiency as a function of discharge power for different Kr flow rates.

4. Discussion

The 500W HET demonstrated robust performance across a wide operating envelope. Thrust increased with higher flow rates and power, as expected, due to greater propellant mass and energy input. The maximum thrust of 27.46 mN at 692.5 W and 24 sccm is competitive for a 500W-class thruster using Kr, though lower than Xe-based HETs due to Kr's higher ionization energy. Isp peaked at 2149.7 s, indicating efficient propellant utilization, particularly at high power (749.5 W) and 20 sccm. This suggests an optimal balance between mass flow and energy input at these conditions.

Anode efficiency reached 43.66% at 572 W and 24 sccm, a strong result for Kr-based propulsion. Efficiency generally improved with higher flow rates, likely due to increased plasma density enhancing ionization efficiency. However, efficiency dropped at higher voltages (e.g., 21.68% at 423.2 W, 16 sccm), possibly due to plasma stability issues at lower flow rates.

The upgrade to a confocal sensor on 3 July improved measurement accuracy, as evidenced by consistent displacement readings. Higher chamber pressure on 3 July may have increased background gas interactions, potentially affecting performance, though no clear trend was observed. Drift issues, noted in the data, require further investigation, possibly related to thermal effects or magnetic field stability.

Compared to literature, the thruster's performance aligns with expectations for Kr-based HETs. For example, studies report Isp of 1500–2000 s and efficiencies of 30–40% for similar power levels, though Xe-based thrusters often exceed 50% efficiency. The cost advantage of Kr makes these results promising for cost-sensitive missions.

Limitations include the exclusion of cathode data, which prevents total efficiency calculations. Future work should integrate cathode performance and conduct tests at nominal pressures (low 10^{-4} mbar) to isolate pressure effects. Additionally, addressing drift will require improved thermal management and a reassessment of the drop-down feedthrough's flexibility and configuration.

5. Conclusion

The 500W HET test campaign demonstrated strong performance with Krypton propellant, achieving thrust up to 27.46 mN, Isp up to 2149.7 s, and anode efficiency up to 43.66%. The thruster operated reliably across 384–749.5 W, with higher flow rates enhancing performance. Sensor upgrades improved measurement precision, and ongoing efforts to mitigate drift promise further improvements. These results position the thruster as a viable option for cost-effective electric propulsion, with applications in satellite and deep-space missions. Future work will focus on total efficiency calculations, drift mitigation, and optimization for operational environments.

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