

Operational Characteristics of 1 kW Hydrazine DC Arcjet System

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Abstract

Hydrazine dc arcjet is suitable for orbit transfer and/or stationary orbit keeping. Ground test model of 1kW arcjet system was made and tested. A thruster, a flow controller, a gas generator, and power control unit were designed and fabricated. Limited life test of 100 hours was successfully conducted to reveal no defects with hydrazine as propellant. Power consumption was 961 W to generate thrust of 0.11 N and specific impulse of 470 sec. System power conversion efficiency was estimated 25 %. The values were almost unchanged in 100 hours. The test result showed 500-sec system at 1 kW attainable by adjusting discharge impedance.

Keeping) of geosynchronous satellite.[1] PRIMEX Aerospace Co. are also under developing 2.2 kW and 0.5 kW hydrazine arcjets for orbit raising and/or NSSK.[2][3] On the other hand, we are making progress in the development of 1 kW hydrazine arcjet. 1 kW hydrazine arcjet is most suitable for NSSK of 1 ton class geosynchronous satellite.

We had obtained operational data of dc arcjet with hydrogen and nitrogen mixture gas instead of hydrazine.[4] Further, we designed and tentatively made a hydrazine flow controller and a gas generator to treat hydrazine in this study. We conducted system test by combining each component and obtained operational characteristic data of 1 kW hydrazine dc arcjet system.

1. Introduction

DC arcjet is attractive to be used for satellite maneuvering because of its high specific impulse. When using hydrazine as propellant, dc arcjet has another advantage of common ownership of propellant supply with other catalytic thrusters. No need for extra propellant tankage and valves is of benefit to satellite system engineers and customers.

In the United States, PRIMEX Aerospace Co. developed 1.8 kW hydrazine arcjet and has already marketed it for NSSK (North-South Station

2. Description on Design Concept

2.1 System Configuration

Hydrazine dc arcjet is composed of a thruster, a hydrazine flow controller, a gas generator, and power process unit, as shown in Fig. 1. Propellant hydrazine and electrical power are supplied from satellite. Other catalytic thrusters use common hydrazine for satellite attitude/orbit control. Electrical power is common to other onboard apparatus, too. Commands and monitor data are also managed by satellite system.

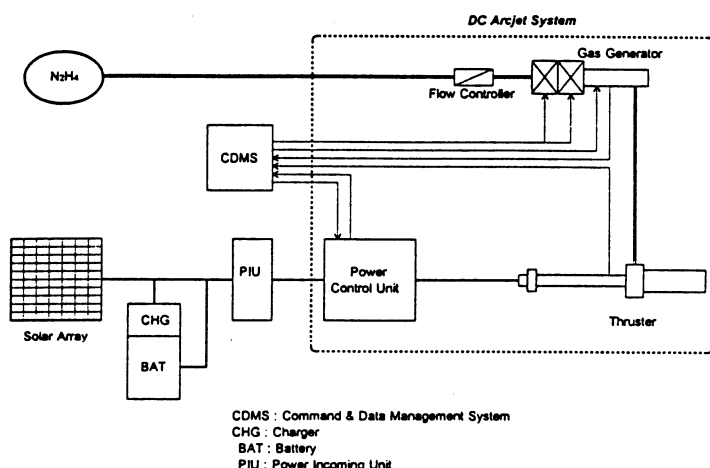


Fig.1 System configuration

2.2 Thruster

The thruster involves a cathode and a nozzle-shaped anode. It blows high velocity jet by utilizing electrical discharge, and generate reaction thrust. Electrode design follows the previous study which were examined with hydrogen and nitrogen mixture gas.[5]

Figure 2 shows the electrode configurations. The anode is made of tungsten. Throat diameter is 0.5 mm and nozzle expansion ratio is over 500. The cathode is made of 2% thoriated tungsten of which diameter is 3 mm.

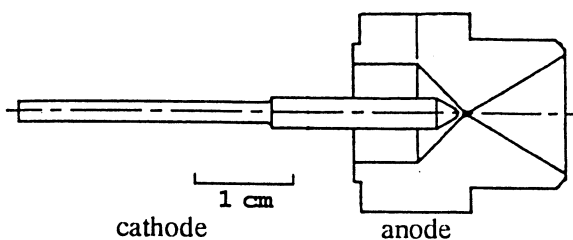


Fig.2 Electrode configuration

2.3 Hydrazine Flow Controller

Hydrazine flow rate is controlled in liquid phase by using flow resistor. Flow rate is so small that fluid resistance is required to be exceedingly high. We adopted a hydraulic restrictor traded by the LEE Co. as LEE VISCO JET. The LEE VISCO JET includes a small orifice and circular flow paths. It utilizes fluid viscosity of revolution to actualize exceedingly-high resistance.

The relationship between hydrazine flow rate and pressure drop was observed with 15 stage orifices of which diameter is 0.127 mm. Figure 3

shows the measurement result.

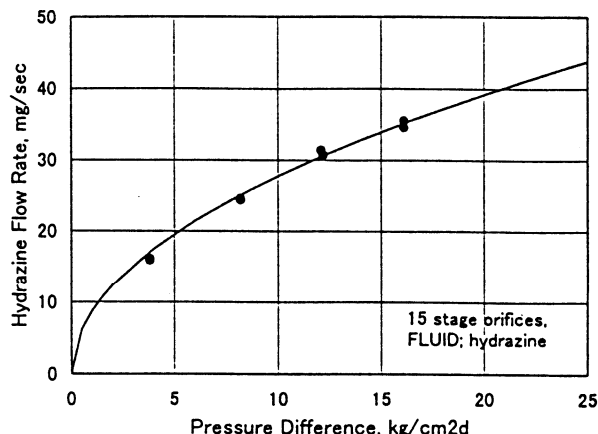


Fig.3 Hydrazine flow rate characteristic

2.4 Gas Generator

The gas generator is composed of a catalyst bed, feed tube assembly, and a propellant valve, as shown in Fig. 4. When opening the propellant valve, hydrazine flows in the feed tube, and impregnated to the catalyst bed through the injector. Hydrazine is decomposed into hydrogen, nitrogen and ammonia in the catalyst bed. As hydrazine decomposition is exothermic reaction, catalyst bed becomes hot. The feed tube assembly controls heat conduction between the catalyst bed and the propellant valve.

As to arcjet operation, the higher is ammonia dissociation rate, the higher specific impulse is obtained because of light molecular weight. Decomposed gas constituents are measured by gas chromatography and ion chromatography. High ammonia dissociation rate as 0.85 was obtained as shown in Fig. 5. The result means 61 % of hydrogen, 32 % of nitrogen and 7 % of ammonia in molecules.

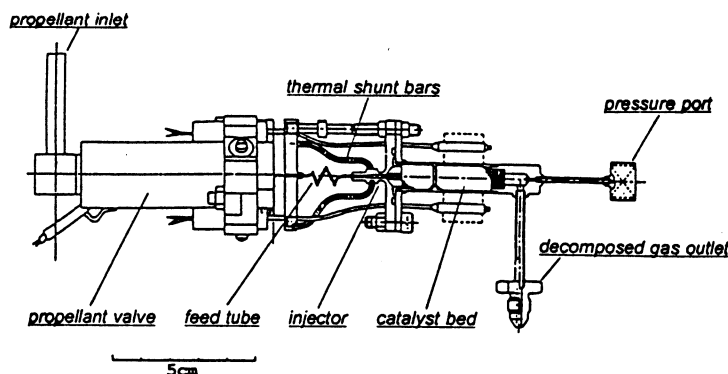


Fig.4 Gas generator

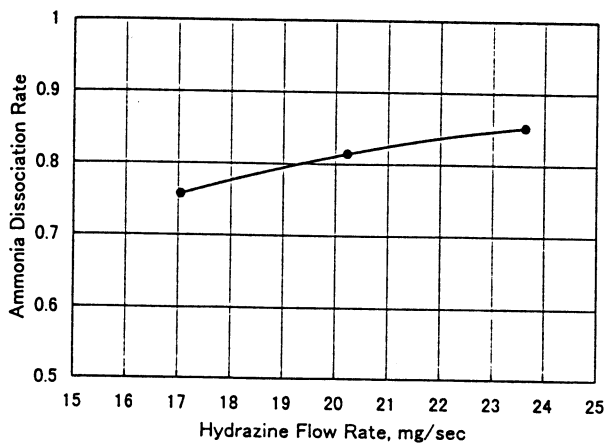


Fig.5 Ammonia dissociation rate

2.5 Power Control Unit

We used the precedently-designed and facilitated PCU[4], which is shown in Fig. 6 by photo. The PCU is a dc-dc converter which has two functions. One is to initiate arc discharge and the other is to keep discharge continuous and stable. High voltage pulses of 2 kV are ignited to initiate discharge. While steady discharge, dual feedback controls work. One is quick feedback to keep output current constant, the other is slow one to keep output power constant.

Power conversion efficiency of the PCU is 83 to 91 % as shown in Fig. 7.

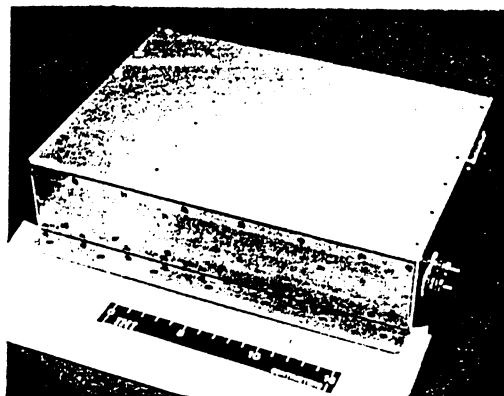


Fig.6 PCU photographic view

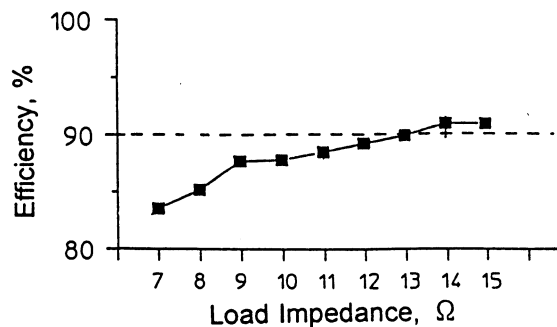


Fig.7 Power conversion efficiency of PCU

3. System Test

3.1 Test Equipment

System operation test was conducted with hydrazine as propellant. Figure 8 shows the test configuration. The flow controller, the gas generator, and the thruster were set in a vacuum chamber. While the PCU is under atmospheric condition. Hydrazine tankage pressure was regulated by nitrogen gas.

Hydrazine flow rate was measured from pressure difference between supply and thruster chamber. Thrust was estimated from thruster chamber pressure. Correlation between thrust and thruster chamber pressure was obtained with hydrogen and nitrogen mixture gas before and after the system test.

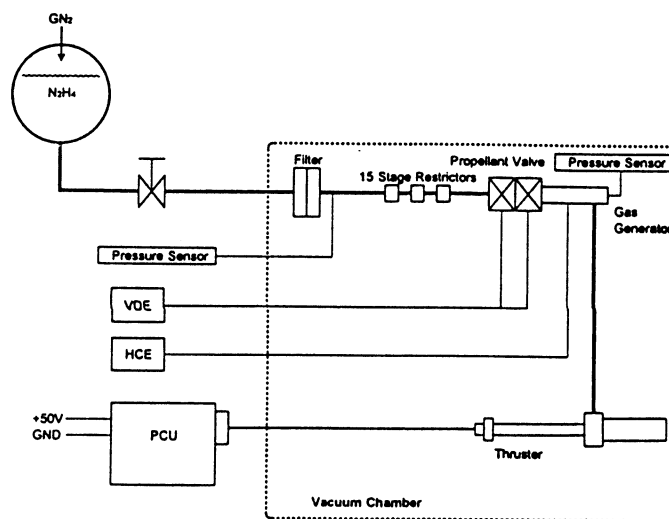


Fig.8 System test configuration

3.2 Test Results and Discussion

Starting Characteristics

The catalyst bed is beforehand heated to relax initial thermal shock imposed on catalyzer and to enhance initial reaction. After then, the propellant valve is opened and hydrazine runs into the gas generator.

Before arc discharge is ignited, much hydrazine flows because of low thruster chamber pressure. When the PCU turns on and arc discharge starts, thruster chamber pressure rises rapidly. Hydrazine flow rate decreases in company with pressure increase, and is settled at aim. Figure 9 shows the above-mentioned starting characteristic.

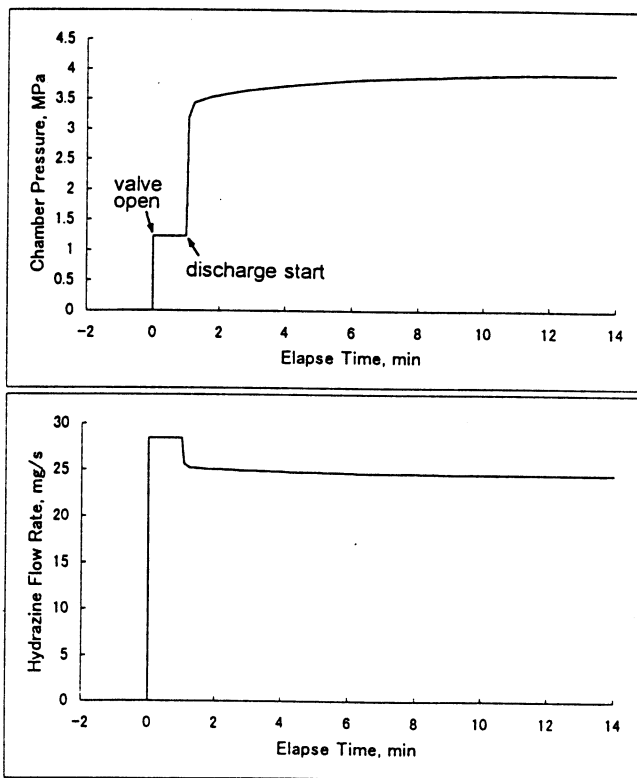


Fig.9 Starting characteristic

System Energy Flow

Figure 10 is energy flow chart obtained at steady state in this system test. It was evaluated from temperature correlation measured at multiple points of the experimental apparatus.

Total input power was 962 W, and system efficiency was 25 %. Discharge resistance was 7.5 Ω , where PCU worked at a disadvantage in efficiency shown in Fig. 8. Adjustment of discharge impedance to the advantage PCU design point will improve system efficiency by 2.5 points.

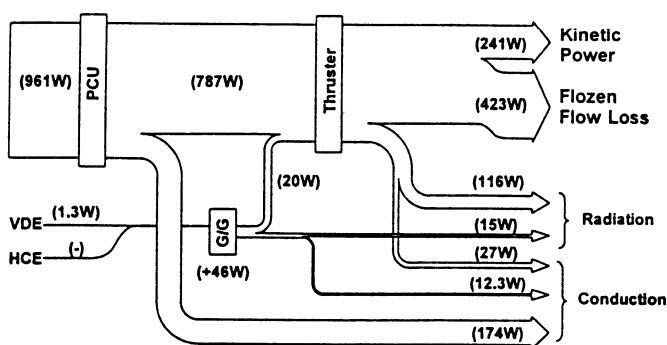


Fig.10 System energy flow

Limited Life Test

Limited life test of 100 hours was conducted. Hydrazine supply pressure was fixed at 1.18 MPa. The test went on voluntarily, and terminated at integrating 100 hours. The system experienced 13 starts. Historical data are plotted in Fig. 11. The operational characteristic was stationary in this life test. Average specific impulse was 470 sec at discharge power of 787 W and hydrazine flow rate of 24.5 mg/sec, which corresponds to that obtained with hydrogen and nitrogen mixture gas. [5]

The preceding results with hydrogen and nitrogen mixture gas told that 500 sec of specific impulse was performed at 900 W of discharge power. If discharge impedance is adjusted, 900W of PCU output will be obtained at 1 kW input. It implies that 500 sec is attainable in our 1 kW system by optimizing discharge impedance to the PCU efficiency characteristic.

Anode erosion was 0.3 mg in 100 hours, while cathode erosion was 1.6mg. Cathode tip recession was 0.15 mm, as shown in Fig. 12. Catalyzer was reduced by 2% after 140 hours running.

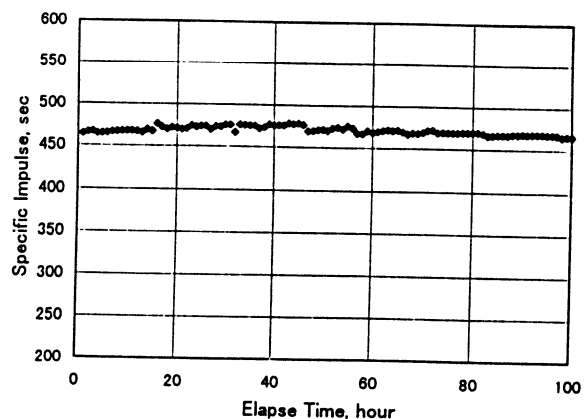
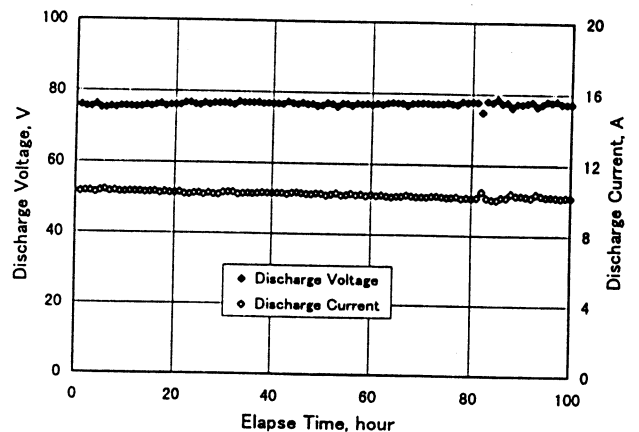


Fig.11 Limited life test results

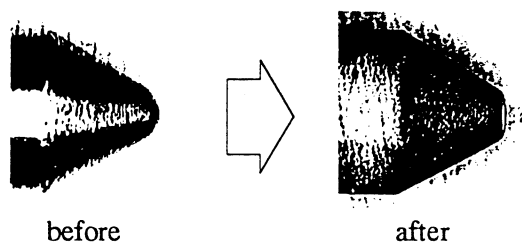


Fig.12 Cathode tip recession

4. Conclusion

1 kW hydrazine dc arcjet system was designed, tentatively fabricated, and tested. The system is composed of a thruster, a hydrazine flow controller, a gas generator and PCU. Each component performs appropriate characteristic and performance for system operation.

The limited life test of 100 hours was executed with hydrazine as propellant to reveal no faults. Operational characteristics were stable thrust performance were not changed. System efficiency will be improved by optimizing discharge impedance to attain 500 sec of specific impulse at 1 kW system operation. So small electrode erosion and catalyzer reduction imply still longer life.

This successful result proves that the development of 1 kW hydrazine arcjet system is favorable.

References

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