Hollow Cathode Life Test for the 80 mN Hall Thruster

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Abstract: **The Hall Thruster of 80mN requires that hollow cathodes are capable to provide currents of 4.5A for 7,500 hours and 6,000 times of ignition cycles. An overview and current status of life test for the 4.5A hollow cathodes in Shanghai Institute of Space Propulsion (SISP), China, are described. Those cathodes are equipped with barium-impregnated tungsten emitter. By May 10th 2013, hollow cathode No.1 had been operating over 10,060 hours, and the heater of hollow cathode No.2 had endured 20,000 times of thermal cycle. The performance of the two hollow cathodes had small changes on discharge voltage, keeper voltage and ignition time during the tests.**

I. Introduction

Hollow cathode is a high efficient electron source. It is regarded as an essential part of Hall thruster because it acts as both electron emitter and neutralizer. It emits electrons to ionize the propellant and neutralize the space charge in ion beam. The most important factors that determine the lifetime of Hall thruster are discharge chamber and cathodes. Although hollow cathode life is generally longer than discharge chamber, it is necessary to demonstrate the endurance of hollow cathodes for future ambition missions. Therefore, life test and cyclic test of hollow cathode are evaluation of reliability and endurance. The hollow cathode for Space Station plasma contactor accumulated life test for 28,000 hours[1] and 32,000 times of ignitions at ground[2]. The DS1 flight spare ion thruster (included discharge cathode and neutralizer cathode) operated for a total of 30,000 hours at ground[3].

In this paper, the life test of the hollow cathode for 80 mN Hall thruster in Shanghai Institute of Space Propulsion since September 2011 was introduced. By May 10th 2013, hollow cathode No.1 had been operating over 10,060 hours, and the heater of hollow cathode No.2 had endured 20,000 times of thermal cycle. By now, both tests of the hollow cathode is still continued.

II. Hollow Cathode

A section view of the hollow cathode is shown in Fig.1. It is consisted of a refractory alloy tube with an orifice plate attached to one end by electron beam welding. The cathode tube is connected to the xenon feed system by flange. The cathode insert is made of porous tungsten impregnated with a 6:1:2 molar mixture of barium oxide (BaO), calcium oxide (CaO) and aluminum oxide (Al_2O_3). The heater is fabricated by tungsten-rhenium alloy. It is fitted to the outside of the cathode tube by alumina isolator. Some layers of tantalum foils pack the heater as heat shield. The keeper was enclosed. Alumina isolators separated the keeper from the cathode and the mounting flange.

In most cases, the discharge of a hollow cathode is initiated by heating it to a temperature of about 1,000 °C, keeping a certain flowrate of propellant gas through it, then applying a potential to a keeper electrode situated

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adjacent to the tip until ignition. The discharge current to beam or space plasma, is sufficient to provide the self-heating for stable operation, the heating and ignition power supply can be powered off.

Fig.2 shows the photo of hollow cathode.

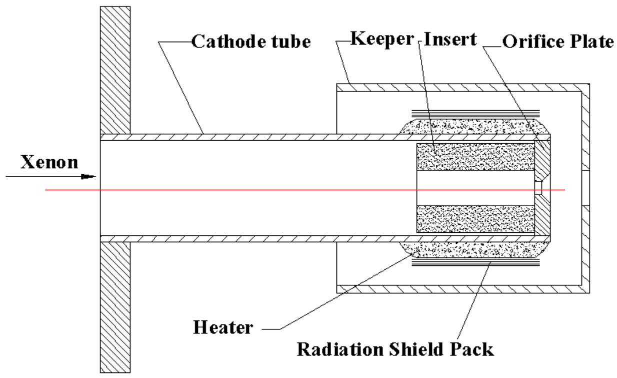

Figure 1. Sketch map of hollow cathode

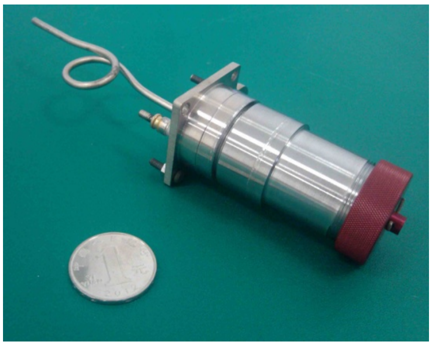

Figure2. Hollow cathode

III. Facility and Experimental System

A. Facillity

The life test was performed in vacuum facility VF-2 at SISP. VF-2 is a 1.2m long by 0.5m diameter vacuum facility (fig.3); the propellant feed unit, three power supplies. The pressure in VF-2 was measured with Pirani gauge and ionization gauge. In the first year of test, the facility was pumped by one cryopump with pumping speed of 1500L/s for air. In October 2012 another cryopump was installed with pumping speed of 2000L/s for air. Normally, two cryopumps operate in the same time. The two cryopumps are alternately stopped to regenerate, so the life test is never affected. It has a low ultimate pressure of 3×10^{-5}Pa, and a pressure of 5×10^{-3}Pa at flow rates of 2~4 sccm xenon.

Figure 3. Experimental facility

The xenon propellant feed system includes a xenon bottle, a reductor, a flowrate controller and pipes. The propellant is xenon with high purity 99.9995+%. Two 10sccm range flowrate controllers were used to control and measure the gas flow rate. All pipes and joints are high vacuum products.

The temperature of cathode is measured by thermocouples. Thermocouples are fixed at the side near the top of the keeper. They measured the equilibrium temperature of the shell in operating.

The performance of hollow cathode was tested with flat plate-anode, the distance between cathode and plate-anode was 3 centimeters. The tests include heater testing, ignition testing, and discharge testing.

B. Test Procedure

Two cathodes were testing simultaneously. Life-test was carried out for cathode No.1, operating in stable discharge state, and re-ignited once every week. The thermal cycle test was carried out for the heater of cathode No.2, with igniting and operating for 15 minutes every one or two weeks.

Fig.4 shows the electrical wiring diagram.

The life test procedure was controlled by a automatic computer software. The procedure of discharge: first, turn on three power supplies and flowrate controller and keep the parameters at set point; then the heater is lowly heated up to the emitter operation temperature (about 1050℃) and electrons are emitted. Xenon neutrals are ionized to generate ions and electrons under the impacting of electrons. The electrons move to keeper and anode by the attraction of positive voltage, and meanwhile the ions move to the insert emitter. When the anode current reached the set point (about 90% nominal value), turn off heater and ignition supplies, then the hollow cathode is working in stable discharge state by self-heating. Test chamber pressure, heater and anode currents and voltages, and xenon flow rate datas are automatically acquired which displayed and stored automatically. A Model 8860-50 Memory HiCorder (HIOKI) is used to observe high frequency data, such as the AC components of the ignition and anode voltages. Fig.5 shows the PrintScreen of the ignition progress by recorded data .Figure 6 shows the photo of hollow cathode operation in stable discharge state.

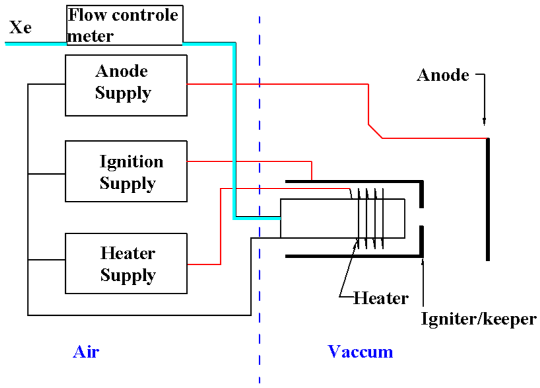

Figure 4. Electrical wiring diagram.

IV. Test results and Discussion

A. Life Test (cathode No.1)

Set the discharge current of hollow cathode to 4.5A according to the request of 80 mN Hall Thruster. Before the life test, the voltage-current characteristics at different xenon flow rate were tested. Mode testing was done to identify the cathode's spot mode and plume mode conditions.

In the early stage of test, the operation mode was spot mode at the flow rate of 3 sccm(at discharge current value 4.5A), the fluctuations of anode current and anode voltage were smallest. Since the temperature of insert can not be directly measured due to the limitation of facility and technique conditions, the temperature of operating cathode was indirectly measured by a type K thermocouple, which was fixed at the side near the top of keeper.

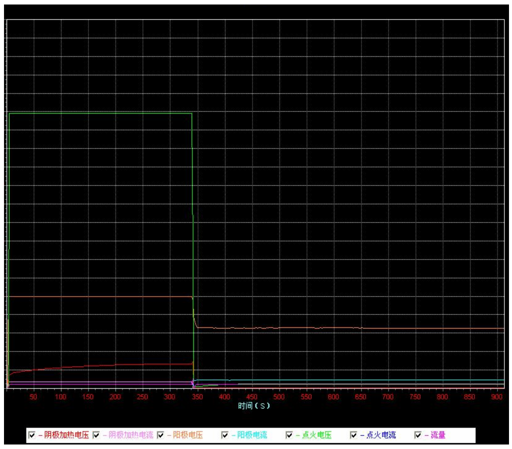
Figure 5. Picture of the ignition progress.

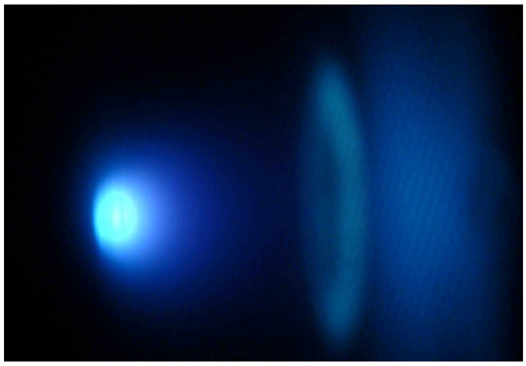
Figure 6. Stable discharge of cathode

Figure 7~11 show the performance of cathode No.1 in the 10,060 hours life test.

The variation of ignition time in the life test is shown in figure 7. In usual the cathode No.1 continuously operated for a week then re-ignited after cooling time. Major reasons for the re-ignition were the limit of database capacity, xenon-bottle replacing, regeneration of cryopumps, and maintenance of facility. Causes of the unexpected interruption were failures of cryogenic pumps. Ignition of cathode No.1completed 134 times in the 10,060 hours life test. The ignition times were 300~350s if cooling times were within 30 minutes, but the ignition times were about 400s if cooling times were over 4 hours. The increase of ignition times involves two reasons, the cathode completely cooled; it adsorbed gas impurities when the pressure of chamber increased because cryopumps were regenerating.

The variation of anode voltage in the life test is shown in figure 8. As can be seen, the anode voltage is above 17 V, which is slightly higher in the first 1000 hours of life test. Then the anode voltage slowly drops below 16V. After 5600 hours life test the anode voltage increases to about 16.5V till the end of 10,060 hours life test, since a new cryopump was equipped, two cryopumps maintained the pressure of chamber 25% lower compared with one cryopump.

The variation of peak to peak values of anode current&voltage in the life test are shown in figure 9. The fluctuations of anode current&voltage are in a certain range, the peak to peak value of anode current is between 0.3~0.6A, and the peak to peak value of anode voltage is between 5～6.6V.

The variation of temperature of keeper/ignitor in the life test is shown in figure10. Temperature is the equilibrium temperature after cathode operates in stable discharge. The temperature was between 380~400 °C, which is slightly higher in the first 1000 hours of life test. Then the temperature slowly decreases to about 345°C. The temperature of keeper cannot directly represent the internal temperature of cathode, but it shows the stability of cathode in the 10,060 hours life test.

The performance of ignition and discharge of hollow cathode No.1 was normal and stable during life test. Hollow cathode No.1 was normal and stable during life test.

We noticed that the time spent in progress of transition to the spot mode slowly increased with lifetime increasing. After ignition, cathode quickly

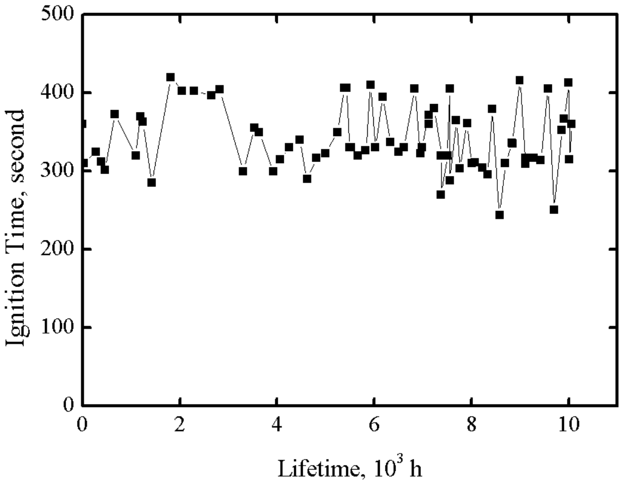

Figure 7. Variation of Ignition time in life test

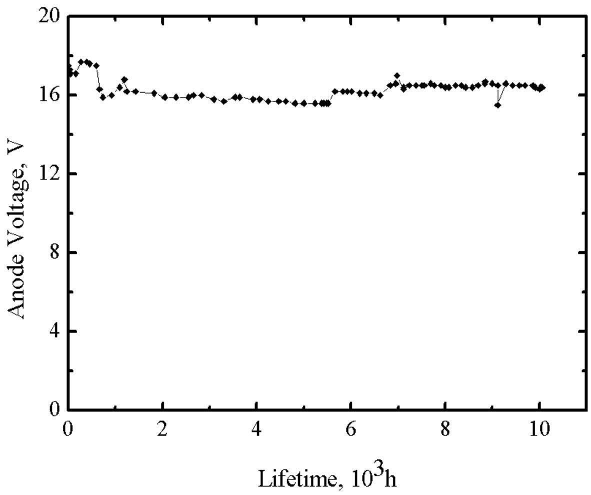

Figure 8. Variation of Anode voltage in life test

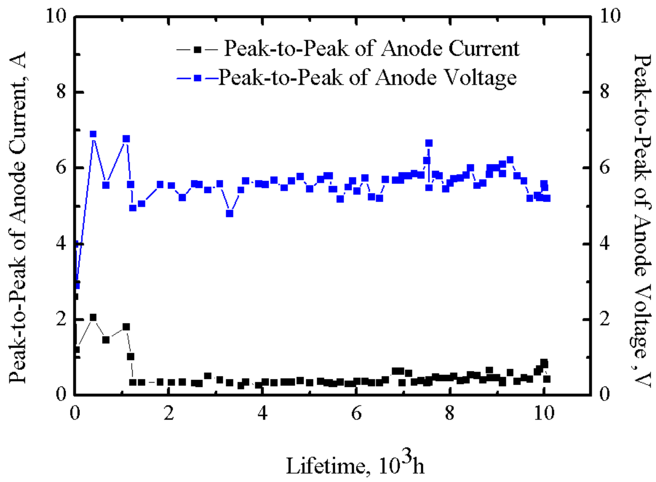

Figure 9. Variation of peak-peak of anode current&voltage in life test

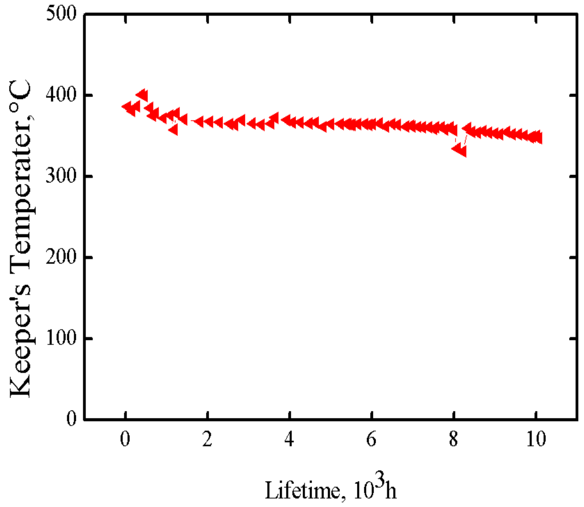

Figure 10. Variation of temperature of keeper in life test

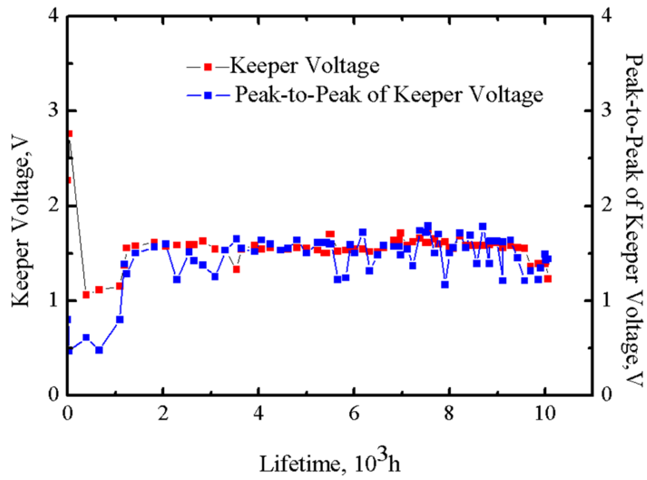

Figure11. Variation of keeper voltage and its peak-peak in life test

transited (with 30s) from plum mode with high anode voltage(22～26V) and high frequency oscillation to spot mode with low anode voltage(about16V) and stable discharge in the early test. When life time accumulated to 7,300 hours, it needed to spend 2 minutes for transition to spot mode. When the life time was over 9,000 hours, the discharge of cathode maintained in plum mode, if the flow rate was not changed. According to experience, the major reasons for the transition of mode is that the diameter of the orifice plate increase with lifetime increasing. The flow rate should increase by 5~10% after 7,300 hours life time, and accordingly the time of transiting to spot mode is cut to 40~60s.

B. The thermal cycle test of heater(Cathode No.2)

First the performance of ignition including heating power, ignition time and the temperature variation for cathode No.2 is repeatedly tested. The result of testing of cathode No.2 is used to determine parameters of thermal cycling test: heating for 8 minutes, and then cooling for 22 minutes. The heater supply is a current stabilized supply. During the progress of test the heater voltage and the temperature of keeper were measured. The cathode No.2 was ignited every several weeks.

The heater of cathode No.2 accumulates 20,100 thermal cycles, performance of test is shown in Fig.12~14.

Fig. 12 shows the variation of heating power in the cycle test of heater. It can be seen that, heating power is about 55W, the maximum value is no more than 60W. In the cycle test the heating power slowly increases. The major reason is that the material of heating wire slowly evaporates which cause the wire diameter decreased, resulting in the resistance increasing, and as the final result, the heating power increases.

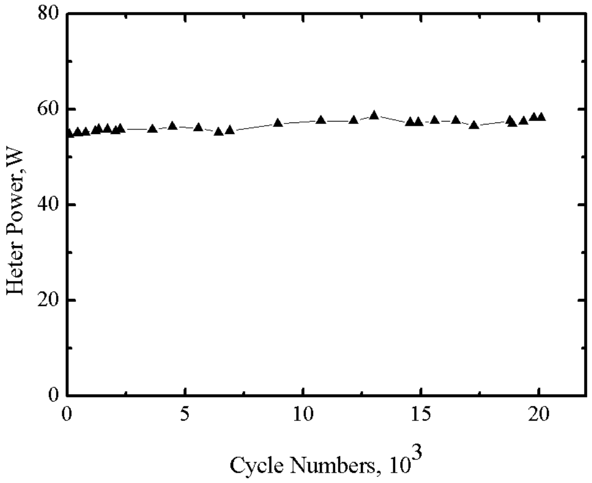

Fig. 12 Variation of heating power in the cycle test of heater of cathode No.2

Fig. 13 shows the variation of ignition time of cathode No.2 in the cycle test. The variation of ignition time is between 300-480s as the cooling time is different.

Fig. 14 shows the variation of temperature of keeper in the cycle test of heater. The temperature is between 300-350°C. It shows that the performance of heater is stable and reliable.

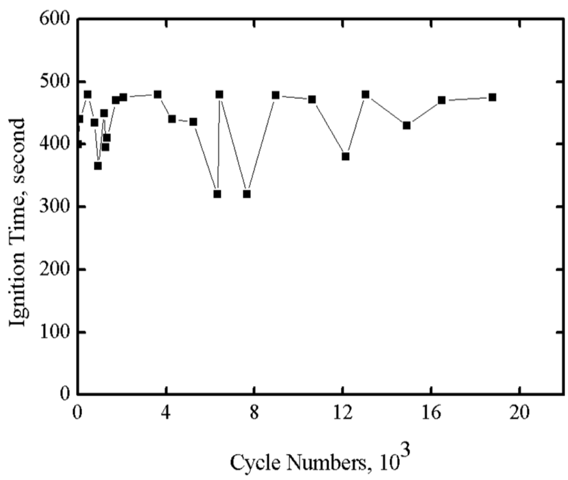

Fig.13 Variation of ignition time of cathode No.2 in the cycle test

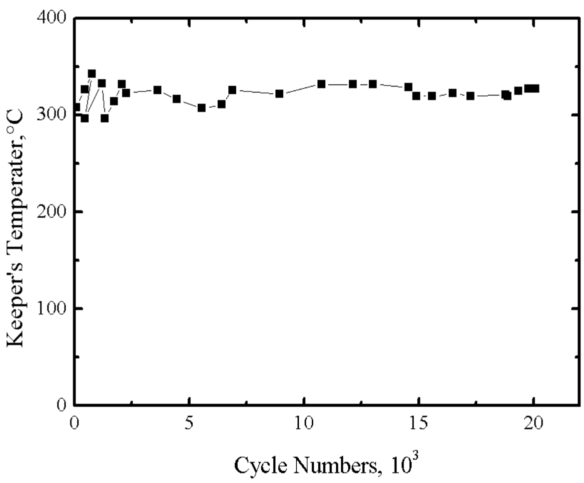

Fig. 14 Variation of temperature of keeper in the cycle test of heater of cathode No.2

V. Following test

The life test of the cathode No.1 was started in September 2011, and the cumulative operation time reached 10,060 hours by May 2013. Now the cathode No.1 test start ignition cycle test. The progress of ignition test: preheat to discharge for 2 minutes, then cool for 20 minutes, and that cycle repeats. By the end-August 2013, the cathode No.1 accumulated 5,500 ignitions. The ignition time is 5-6 minutes. The time of transiting to spot mode is about 60s after ignition. The performances of ignition and discharge of cathode are stable.

The thermal cycle test of heater of cathode No.2 is continuing now. After 20,000 cycles of heater, the heating power increased 10-15% in order to meet the demand of higher power for ignition in the end of life. By the end-August 2013, the heater of cathode No.2 accumulated 25,000 times of thermal cycle.

VI. Conclusions

Two hollow cathodes for 80mN Hall thruster have been tested in SISP. The cathode No.1 completed 10,060 hours life test, and the cathode No.2 completed 20,100 times of thermal cycle test of heater by May 2013. Now the cathode No.1 starts ignition cycle test. The performance is stable except the operating mode. The flow rates have to be increased in order to transit to spot mode in short time. The thermal cycle test of heater of cathode No.2 will be continued until the heater no longer functions.

References

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