The reliability evaluation of LHC-5 hollow cathode heater

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Abstract: Hollow cathode assembly testing is important for ion thruster to evaluate the life of the ion thruster comprehensively. Hollow cathode life evaluation testing consists of high-cycle heater, on-off ignition and discharging life validation testing. To date four heaters have been cycled about 10000 cycles and suspended to preserve hardware. On the analysis of the Weibull, we analyze the heater reliability distribution and the expectation heater cycles reliability. The results indicated that the on-off cycles for the heater we expected was 6000, the reliability of which was better than 0.98 at 95% and 90% confidence level.

Nomenclature

LHC-5 = 5A hollow cathode
TS-5 = hollow cathode test vacuum chamber
$P(t)$ = the failure probability
t = operating time or test cysles
β = width parameter of the Weibull distribution
η = the location parameterof Weibull distribution
$T(t)$ = the reliability of Weibull distribution

I. Introduction

HOLLOW cathode is electron sources which feature high electron emission capability and long life. In order to ignite the thruster, discharge cathode and neutralizer must be first

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ignited. It represents a single-point failure since if the cathode fails to ignite and the thruster will not operate [1]. The lifetime of the cathode is directly depending on the potential failure modes, which includes heater failure, thermionic emitter failure, electrode erosion, shorts or electrical breakdown, cathode orifice plugging, and etc[2].

LHC-5 hollow cathode is discharge cathode of LIPS-200 ion thruster, which is developed by Lanzhou institute of Physics. The design on-off cycles are 6000 for station keeping of communication satellite. The hollow cathode can be separated into heater, keeper, emitter, cathode tip and cathode tube [3].The hollow cathode electron emitter material is polycrystalline LaB_6. Compared to conventional impregnated dispensers, e.g. BaO-W 411, LaB_6 is the incredible robustness, high-current density and long life. The LaB_6 cathode is insensitive to impurities and air exposures that can destroy a BaO dispenser cathode [4], which could withstand gas-feed impurity levels two orders of magnitude higher than dispenser cathodes at the same emission current density. The work function is about 2.67eV and emit temperature is 1650℃ at elctron current density of $10A/cm^2$, however BaO is only 0.06eV and 1000℃. Because of this, the challenge of life and reliability of heater development is greater for LaB_6 cathode than the BaO. So, one of the most failure risks is heater for our LHT-5 cathode by some experiment and analysis.

This paper documents the test setups and results obtain to date for heater test. Additionally, based on the experiment results, we analyze the reliability distribution and the expectation cycles reliability of the heaters.

II. Experimental Arrangement and Procedures

Four heaters were subjected to cyclic testing. The test was started in March 2010 and suspended in April 2011 as apparatus question. The following section describes the heaters that have been tested, the test setup, parameters, procedures, and testing results. The cyclic heater test results presented in this paper demonstrated that the heater of LHC-5 will yield the required cycle lifetimes. The results indicate that the on-off cycles for the heater we expected was 6000, the reliability of which was better than 0.97.

A. The heater of cathode

Figure 1 shows a schematic of the discharge hollow cathode heater used in this study. A regular heater mainly consists of a cathode tube which covers the electron emitter and an orifice plat which constricts gas and plasma flow. The insert which is made of polycrystalline LaB_6 is in the tube. The heater wire is coiled around the cathode tube where the hollow cathode insert is located and that is responsible to bring the low work function insert to thermionic emission temperature. When the cathode operations in the steady-state condition, the heater can be switched off and the temperature of the emitting material can be maintained at suitable level for thermionic emission by impinging ions from the discharge plasma. So the heater is needed to on-off cycle while the thruster is restarted.

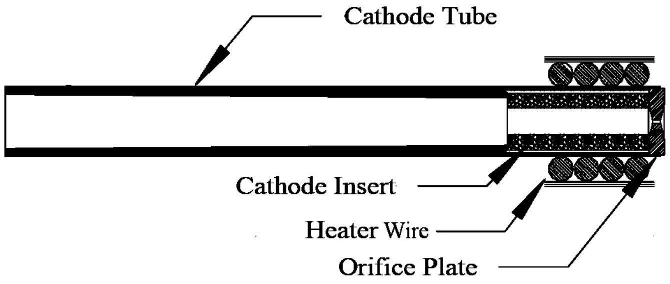
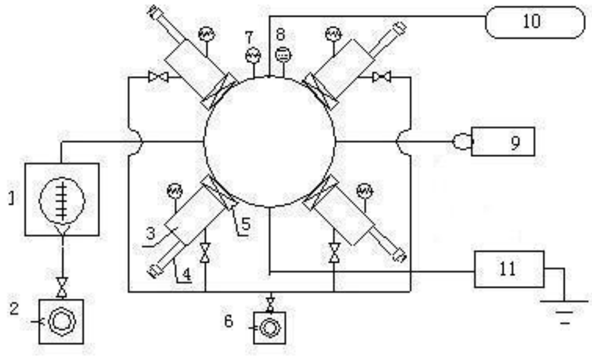


Fig. 1 The schematic of the hollow cathode heater

B. Experimental Set-up

The experiments reported in this paper were all performed in a hollow cathode performance and life test vacuum facility at TS-5[5].

A schematic of the test facility is shown in figure 2. It consists of five basic components: vacuum chamber, vacuum pump system, flow system, control system and power supply. The main vacuum chamber is conducted within a 800mm inner diameter, 800mm long stainless steel. Four cathodes or heaters could be tested in the chamber at the same time. Base pressure were on the order of 2.0×10^{-4}Pa as measured by an ion gauge. A low background pressure was necessary to preclude excessive oxidation of heater and cathode components which could result in inaccurate performance data and/or failure [6].



1. 2X-15 Mechanical Pump 2. F250/1500 Molecular Pump 3. Subaltern chamber
4. Magnetic Driver 5.Valve 6. 2XZ-4 Mechanical Pump 7. Vacuum Gauge 8. Ionization Gauge
9. Xenon Bottle and Gas Flow Controller 10. Control System 11. Power Supply

Fig. 2 Schematic of the Hollow Cathode Test Vacuum Facility

C. Test Procedures

Four theaters that were subjected to cyclic testing were mounted onto keeper with LaB_6 insert installed to simulate the cathode thermal mass. The cathode was secured to ceramic isolators that were mounted on a platform of vacuum chamber, as shown in figure 3.

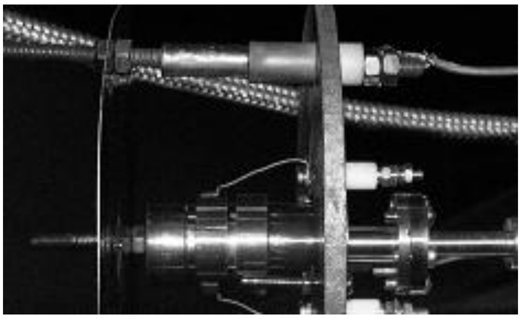


Fig. 3 The hollow cathode heater test platform

A computer data acquisition and control system are utilized for the testing. Control parameters include heater current and heated time. The heater voltage could be measured after the heater operated continuously for 3 minutes, because the cathode tip temperature could be stabilization 3min later of the power on, heater current, heater cool resistance, the pressure are automatically acquired by computer. Each cycle consisted of 6 minutes at input power on to simulate ignition and 30 minutes at power off for cooling. The heater power continues time is decided by hollow cathode expectative ignition time.

Ⅲ. Experiment Result and Discussion

The testing results for all heaters are shown in table 1.It is no failures date from the test. Non failure test data typically provides very conservative bounding information about location and variability of failure destruction, but we could obtain some reference information by analyzing.

Table 1 LHC-5 hollow cathode heater cyclic test results summary

Heater Number	Heater Current	Cycles	Status	Notes
LHC-5-814	7.5A	8135	intentional Interruption	Destructive evaluation experiment
LHC-5-800	7.5A	9483	intentional Interruption	Being undergone discharging life test
LHC-5-804	7.5A	12669	Suspended from test as equipment	Being undergone discharging life test
LHC-5-813	7.5A	12843	Suspended from test as equipment	Destructive evaluation experiment

The erosion failure modes of thruster, include hollow cathode assembly and grids system, and hollow cathode heater follow a Weibull distribution,

$$P(t) = \frac{\beta}{\eta}(\frac{t}{\eta})^{(\beta-1)} \exp\left[-(\frac{t}{\eta})^{\beta}\right] \tag{1}$$

Where $P(t)$ is the failure probability, t is operating time, β is the width of the distribution, and

η is the location parameter [7, 8].For N non-failure tests (i.e. test which are terminated before the hollow cathode or heater actually fails) of equal duration t, the best estimate of η with a confidence C is[9],

$$\eta = T\left[-\frac{\ln(1-C)}{N}\right]^{(-1/\beta)} \tag{2}$$

The reliability of Weibull distribution is

$$R(t) = e^{-(\frac{t}{\eta})^{m}} \tag{3}$$

A simple method，which changes the conventional Weibull equation into logarithmic format, could be estimate the parameters of Weibull distribution[10]. A Weibull analysis of four no-failure heaters is performed using the logarithmic change method. The values for β and η are determined to be 5.2264 and 11798, respectively. The determined relative probability of Weibull distribution is plotted with the parameter in figure 4. The Weibull distribution is used to calculated the heaters reliability with 90% and 95% confidence, showed in figure5.

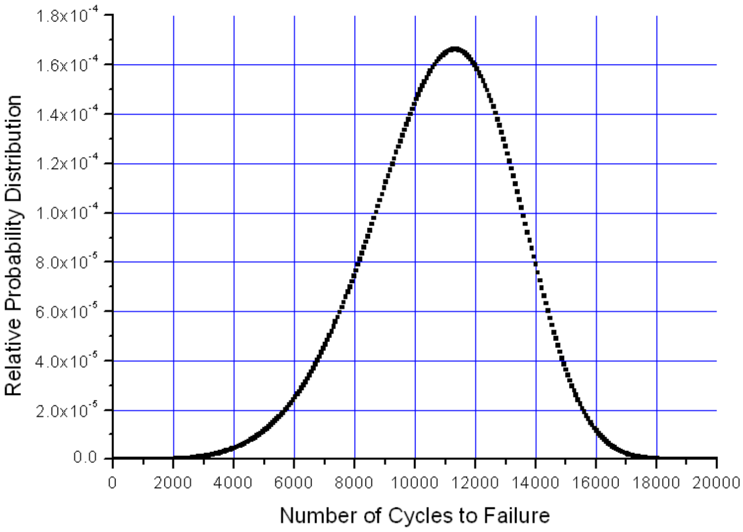


Fig. 4 The reliability distribution of LHC-5 hollow cathode heater

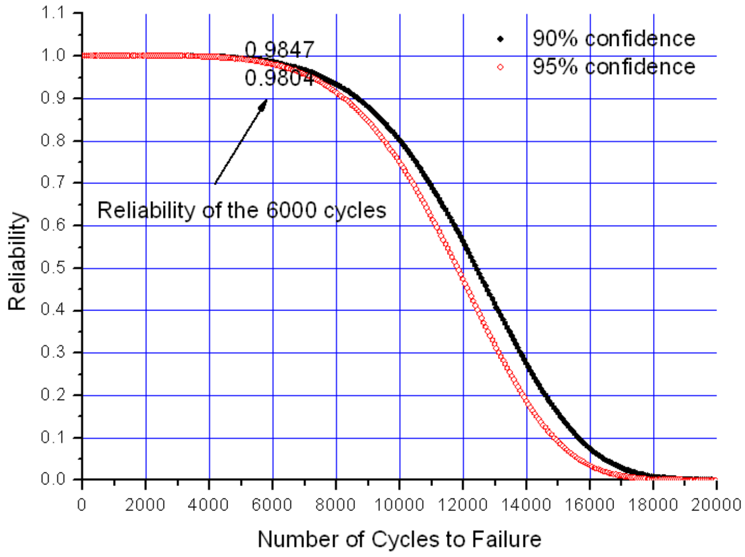


Fig.5 The reliability distribution of LHTC-5 hollow cathode heater

at 90% and 95% confidence

Figure 5 shows that the expectative on-off cycle, which is about 6000 cycles, reliability of LHC-5 hollow cathode heater cycles are 0.9847 and 0.9804, while its confidence is at the 90% and 95%, respectively. It indicates that the heater cycles reliability could be sufficient for the station keeping of communication satellite.

Ⅳ. Conclusion

Hollow cathode is a critical part of the LIPS-200 ion thruster. If the cathode fails to ignite, the thruster would not operate, which represents a single-point failure. In addition to the hollow cathode heater cycles test has been completed, several component or the thruster life tests are underway or planed, e.g. hollow cathode ignition on-off, hollow cathode discharge, high-voltage propellant isolator and the electrical propulsion system. To date four heaters have been cycled about 10000 and suspended to preserve hardware or intentional interruption. On the analysis of the Weibull, we analyze the heater reliability distribution and the expectation heater cycles reliability. The results indicate that the on-off cycles for the heater we expected are 6000, the reliability of which was better than 0.98 at 95% and 90% confidence level. It shows that the heater cycles reliability could be sufficient for the station keeping of communication satellite.

When the data from tests consists of some number of trials with no failure, which is always the case for ion thruster or its component, the data is weak information source for reliability demonstration or failure risk information. And no failure test data typically provides very conservative bounding information about location and variability of failure distribution, the analysis result could provide an importance reference at present. Therefore, we propose that the life test must to be failure of the thruster or its component for the future, and increase the number of experiment sample.

Acknowledgments

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