STATIONARY PLASMA HALL THRUSTER ACCEPTANCE
ACCELERATED TESTS

A. A. KALYAEV*

Abstract

A method and program package have been developed for acceptance checkout of lifetime of stationary plasma Hall thrusters (SPHT) based on accelerated test results. The lifetime is decided to comply with preset requirements if the predicted lifetime exceeds a norm. The latter is established so that the producer’s or consumer’s risk would not exceed required values.

Introduction

One of the most important parameters of the SPHT is lifetime. That is why it is necessary in delivery to check this parameter for compliance with preset requirements. However, it is extremely difficult to check the lifetime by testing the SPHT for its full lifetime, as it can be of 6000 to 8000 hours and more. This paper deals with a method for checkout the lifetime based on accelerated tests. Accelerated tests are tests during which the SPHT operating time for part of its lifetime. In such tests, measured is the degradation parameter that determines the lifetime and the latter is predicted as described in [1]. The erosion rate of the accelerating channel is adopted as the degradation parameter.

The acceptance test procedure is supposed to be as follows. Each thruster undergoes short tests in which its operation and compliance of a number of its parameters with preset requirements are checked. One of the thrusters of the batch is taken to perform wear tests. After it has operated for 1000 to 2000 hours, its conditions are checked, parameters are measured and lifetime is predicted. If the thruster’s state, parameters and predicted lifetime comply with preset requirements, then the remaining thrusters are delivered. The indicated thruster, so-called leader thruster, is tested further for endurance. Such an approach enables not only lifetime demonstration and prediction but also revealing "bottle necks" of the design and manufacturing process and refinement of accelerated test results as well [2].

Accelerated Test Inspection Plan Preparation

The predicted lifetime that is determined in accelerated tests is a random value. Its variation depends on the operation time, number of wear-measuring spots, error of wear measurement, etc. So one can be mistaken when checking the lifetime based on its predicted value. The checkout procedure is that the lifetime requirements are considered satisfied if the lifetime, predicted on the basis of accelerated tests, exceeds some norm. This paper deals with the following ways to calculate this value:

1. The norm $T_1$ is set so that the producer’s risk $\alpha$ would be provided. The producer’s risk is the maximum probability of making the wrong decision on non-compliance of the lifetime with preset requirements.

* Keldysh Research Institute of Thermal Processes (NIITP), Moscow, Russia.
2. The norm $T_2$ is set so that the consumer's risk $\beta$ would be provided. The consumer's risk is the maximum probability of making the wrong decision on compliance of the lifetime with preset requirements.

The checkout plan is test conditions (operation time $t$, time intervals between wear measurements $\Delta t$), norms ($\alpha$ and $T_1$ or $\beta$ and $T_2$) and required lifetime $T$.

A clear idea of the checkout plan is given by an operative characteristic. This is a relation between the probability of making the decision on compliance with preset requirements and the real lifetime.

The checkout norms and operative characteristics were calculated by the statistic simulation method employing a program package developed for that. Let us consider a particular calculation. Let the required lifetime be $T \geq 8000$ hours. We adopt $\alpha = \beta = 0.05$. $T_1$ and $T_2$ are calculated as follows.

1. The coefficients are determined of the wear dependence of the operation time, at which the lifetime equals to the required lifetime $T$. For this purpose test results of similar thrusters and the leader thruster are used.

2. For preset test conditions and means square dispersion of points relative to the regression line, erosion rates are repeatedly simulated at adequate time instants and lifetime values are predicted.

3. The lifetime distribution law and $T_1$ and $T_2$ are determined:

$$F(T) = \alpha,$$

$$1 - F(T) = \beta,$$

where $F(\cdot)$ is the distribution function.

Fig. 1 shows densities of distribution for three test conditions ($\Delta t$ is time intervals between wear measurements). The areas of the shaded regions under the curves at the left are equal to $\alpha$ and those at the right are equal to $\beta$. The vertical lines of the region boundaries intersect the abscissa axis at the points $T_1$ in the left part of the graphs and at the points $T_2$ in the right one. As seen, $T_1$ and $T_2$ approximate to $T$ as the operation time $t$ increases and $\Delta t$ decreases. This accounts for contraction of the curves of the densities of distribution for the predicted lifetime because of decrease in the prediction error.

The operative characteristics are calculated as follows:

1. For preset test conditions and a hypothetic lifetime value $T$, erosion rates are repeatedly simulated and the distribution law of the predicted lifetime is determined.

2. The probability $p(T)$ is determined of the predicted lifetime exceeding the norm $T_1$ or $T_2$.

3. As the procedure as per items 1 and 2 is implemented for various $T$, points of the operative characteristic are obtained.
In Fig. 2, the shaded areas are operative characteristic values at three real lifetime values $T$. In this particular case, $T_2 = 9205$ hours. As $T$ decreases, the densities of distribution get narrower because of decrease in the acceleration coefficient $K = T/t$.

Fig. 3 presents the operative characteristics for the three above-mentioned test conditions. The curves are covered with points obtained in simulation. The curves 1, 2 and 3 are the operative characteristics of the plans providing the supplier's risk to be of $\alpha = 0.05$. The curves 4, 5, 6 corresponds to the plans with the consumer's risk of $\beta = 0.05$. For plans with the producer's guaranteed risk, the decision with more than 0.5 probability can be made on compliance of the lifetime with its required value of 8000 hours at the real lifetime exceeding 7100 hours. For plans with the customer's guaranteed risk, the decision with more than 0.5 probability can be made on non-compliance of the lifetime with its required value at the real lifetime below 9300 hours. As the operation time increases and time intervals between wear measurements decrease, the operative characteristics approximate to the ideal characteristic. For the latter, the decision with 1.0 probability is made on non-conformance of the lifetime with its required if the real lifetime is less than the required one, and on conformance if the real lifetime is greater than the required one.

Stability of the lifetime can also be checked in accelerated tests. The lifetime can be considered stable if its value is supported at the level obtained in tests of the leader thruster. Operative characteristics of the check plan are presented in Fig. 4. In this case, the ideal characteristic corresponds to making the decision on non-conformance in all cases but when real lifetime is 8000 hours.

Conclusion

1. A concept for SPHT acceptance lifetime tests has been developed.

2. A program package has been developed that enables one to calculate check plans and the operative characteristics of SPHT acceptance lifetime test plans.

References


Fig. 1. Densities of Life Prediction Distribution
1 - $t = 2600 \text{ h.}, \Delta t = 200 \text{ h.}, T_1 = 7373 \text{ h.}, T_2 = 8733 \text{ h.}$
2 - $t = 2000 \text{ h.}, \Delta t = 100 \text{ h.}, T_1 = 7262 \text{ h.}, T_2 = 8673 \text{ h.}$
3 - $t = 2000 \text{ h.}, \Delta t = 200 \text{ h.}, T_1 = 7027 \text{ h.}, T_2 = 9205 \text{ h.}$

Fig. 2. Densities of Life Prediction Distribution
($t = 2000 \text{ h.}, \Delta t = 200 \text{ h.}$)

Fig. 3. Routine Characteristics of Life Control Plans

Fig. 4. Routine Characteristics of Life Stability Control Plans