OPTIMIZATION OF PLANS FOR ACCELERATED ENDURANCE TESTS FOR RELIABILITY

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Abstract

A method and program package have been developed to evaluate the average and gamma-percentage lifetime based on results of tests of stationary plasma Hall thrusters (SPHTs).

The accuracy of obtained results is estimated by the statistic modelling method. An example is given of optimization of the plan for accelerated tests for reliability.

Introduction

SPHTs are thrusters of high lifetime values that can be of 6000 to 8000 hours and over. That is why it is advisable to define the reliability requirements in the form of the average T_{cp} and gamma-percentage lifetimes. It is diffucult to evaluate these parameters by full-endurance tests as it required a lot of time and funds.

Some investigations of accelerated endurance tests (e. g., [1, 2]) were a basis for developing a program package to solue the following problems:

1. Estimation of reliability indices based on accelerated endurance test results.
2. Estimation of the accurace of the obtained indices.
3. Optimization of plans for accelerated endurance tests for reliability.

The erosion value of the outer wall of the accelerating channel is considered as the parameter determinating the lifetime. An approximating erosion dependence of time is used to predict the lifetime.

Calculation Procedure and Analysis of Results

To estimate the reliability based on results of accelerated endurance tests of several thrusters, the lifetime of each thruster is predicted [1]. The reliability is estimated on the basis of the obtained lifetime values. In doing so, the weight of each test is considered. It depends on the prediction error.

The accuracy of the reliability estimated is determined by the statistic modelling method. For this purpose, a distribution low is preset for the real lifetime. The parameters of the law are calculated depending on the type of the low, reliability requirements and lifetime hypothetic dispersion. Fig. 1 gives three density functions of the real lifetime for the below example. The lognormal law is adopted here as the real distribution law based on earlier investigations. The average lifetime T_{cp} is admitted as a reliability index. Its value as well as the values of the mean square lifetime dispersion δ_T are assigned with regard to available SPHT test results.

Test results are then modelled. For each thruster, the operation time and times of erosion measurements are arrigned. The erosion values are determined as follows. The lifetime is randomly extracted from the true lifetime distribution and coefficients are calculated for the true erosion dependence of time. The erosion values in tests differ from the true erosion value by E_i that has a normal distribution N (O, δ), where δ is the mean

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square dispersion of points relative to the regression. The values E_i are obtained as a result of random extraction from this law. When assigning δ, available results of endurance tests are taken into account. Here, $\delta = 0.1$ mm is adopted.

The test results modelled are used to estimate the reliability indices as shown above. Repeated modelling results in comparison of the reliability values obtained in estimation and their true values.

In this example, the accuracy of the average lifetime estimation is characterized by the mean square error of determination of the average lifetime as a percentage of the true lifetime.

In each modelling, the lifetime distribution density can be evaluated. Fig. 2 gives lifetime distribution densities for three test conditions averaged over 1000 modellings. For these three test conditions, the 4000 hour operation time is distributed evenly between two, three and four thrusters respectively. Fig. 2 also presents the true lifetime distribution density. Evidently, the shape kind of the distribution density curve depends on the number of thrusters for which the preset total operation time is distributed.

Practically, it is normally required to estimate the SPHT reliability with restrictions in the total operation time of several thrusters. It is important to the developer to know what number of thruster should be tested with these conditions and how to distribute the total operation time between the thrusters. The calculation procedure described above enables one to answer these questions.

Fig. 3, 4 and 5 present variations of the mean square error of determination of the average lifetime with the total operation time that were obtained by the statistic modelling method. In Fig. 3, the mean square dispersion of the true lifetime $\delta_T = 200$ hours, in Fig. 4, 800 hours, and in Fig. 5, 1200 hours. In the graphs, points obtained in modelling and appoximating curves are shown. The calculations were performed for the four following operating time distributions:

1. Evenly over two thrusters.
2. Evenly over three thrusters.
3. The leader thruster with 6000 hour operation time and the remaining operation time is for one thruster.
4. The leader thruster with 6000 operation time and the remaining operation time is evenly distributed between two thrusters.

An analysis of the graphs results in the following:

1. The error of determination of the average lifetime increases with the mean square dispersion of the true lifetime, the curves remaining of the same appearance.

2. Comparison version 1 and 2 result in the conclusion that it is better to perform reliability tests with two thrusters until some total operation time is achieved. As the available total operation time increases, the number of thrusters should be increased. The total operation time, at which more thruster should be tested, increase as the true lifetime dispersion decreases.

3. Comparison of the variants with and without the leader thruster results in the conclusion that test results should be used under the conditions considered of the leader thruster for more than 10000 hour operation time. In doing so, the more is the mean square dispersion of the true lifetime, the more effective is increase in the accuracy of estimation of the average lifetime.

Conclusion

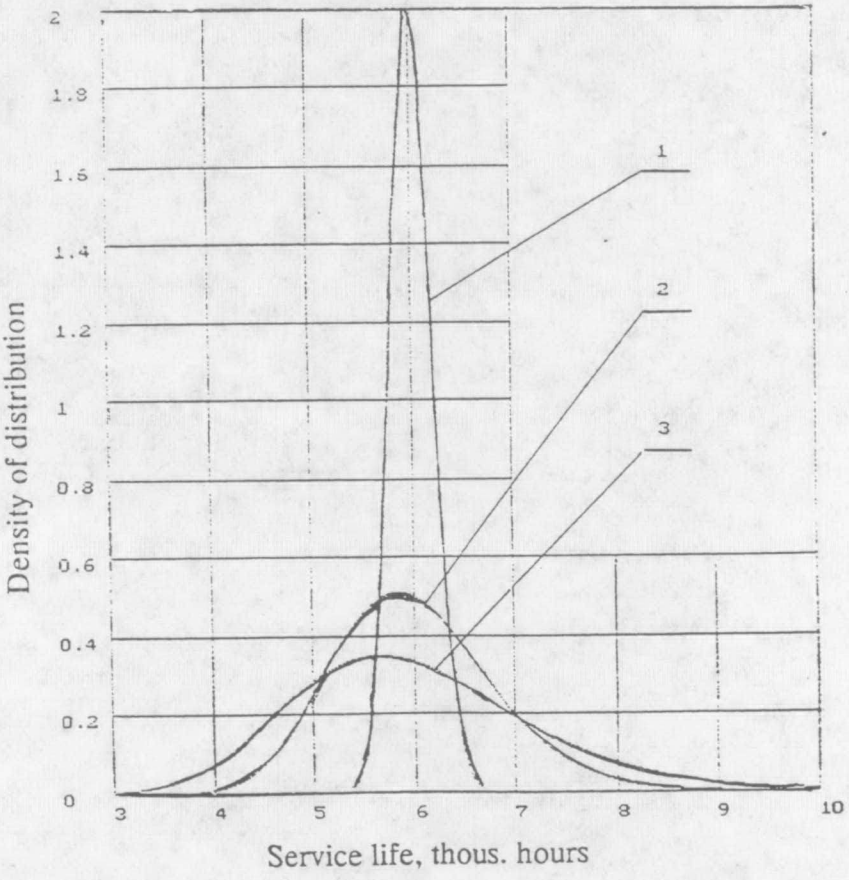
An algorithm and program for data processing of SPHT endurance test have been developed that enable solving the following problems:

1. Estimate the average and gamma-percentage lifetime values.
2. Determine the error of the reliability estimation.
3. Optimize a plan for accelerated tests for reliability.

References

1. V. I. Baranov, A. I. Vasin, A. A. Kalyaev, V. A. Petrosov. Prediction of Electric Thruster Lifetime, 23 rd IEPS. IEPS-93-099. Seatle, USA, 1993.

2. V. I. Baranov, A. I. Vasin, A. A. Kalyaev, V. A. Petrosov. Electric Rocket Engine Accelerated Test Concept, 23 rd IEPS. IEPS-93-100. Seatle, USA, 1993.



1 - T_{cp} = 6000 h, σ_r = 200 h

2 - T_{cp} = 6000 h, σ_r = 800 h

3 - T_{cp} = 6000 h, σ_r = 1200 h

Fig. 1. Density of True Service Life Distribution

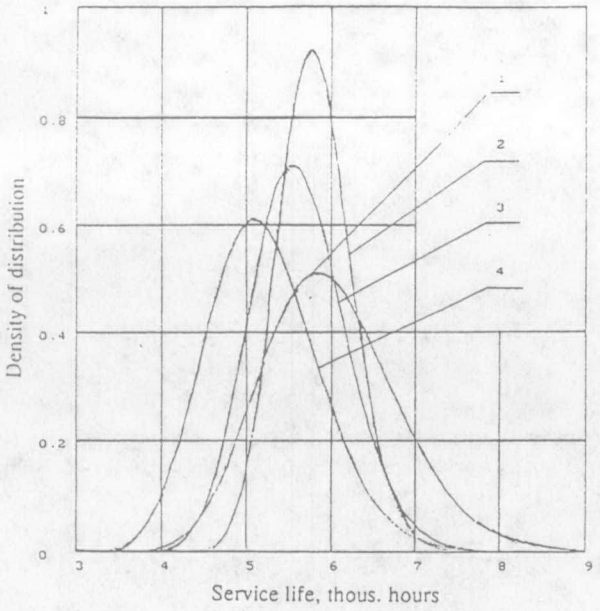


Fig . 2. Densities of Service Life Distribution

1 - true service life, T_{cp} = 6000 h, σ_t = 800 h;

2 - life prediction, t = 4000 h, 2 thrusters;

3 - life prediction, t = 4000 h, 3 thrusters;

4 - life prediction, t = 4000 h, 4 thrusters.

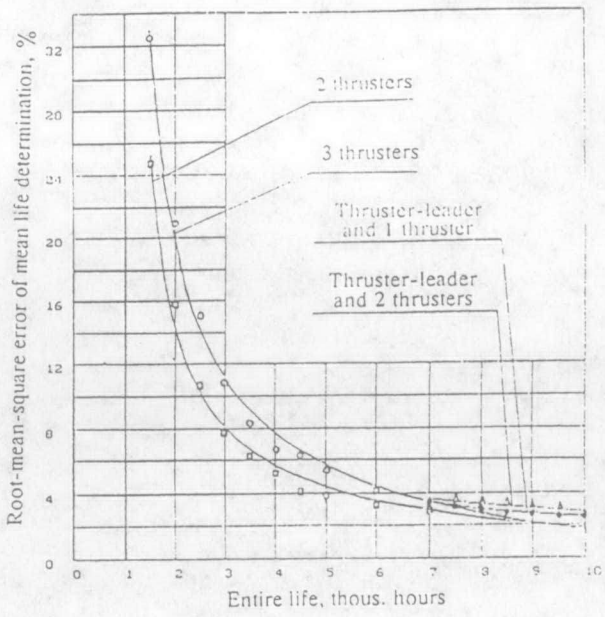


Fig. 3. Root-Mean-Square Error of Mean Life Determination Versus Entire Life (σ_t = 200 h)

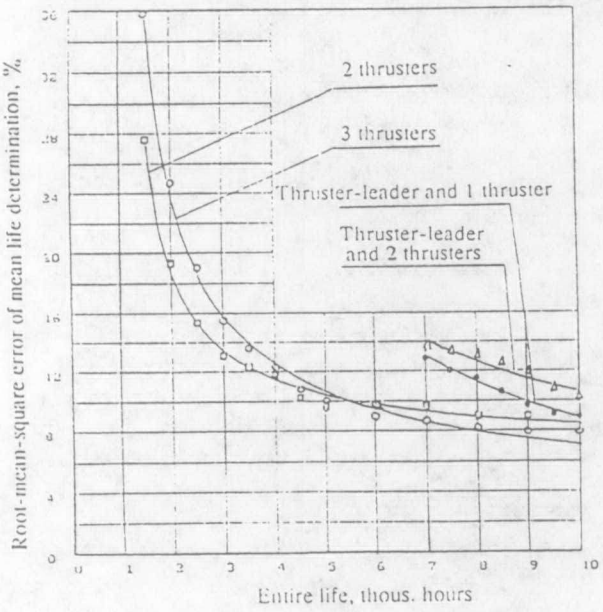


Fig. 4. Root-Mean-Square Error of Mean Life Determination Versus Entire Life (σ_t = 800 h)

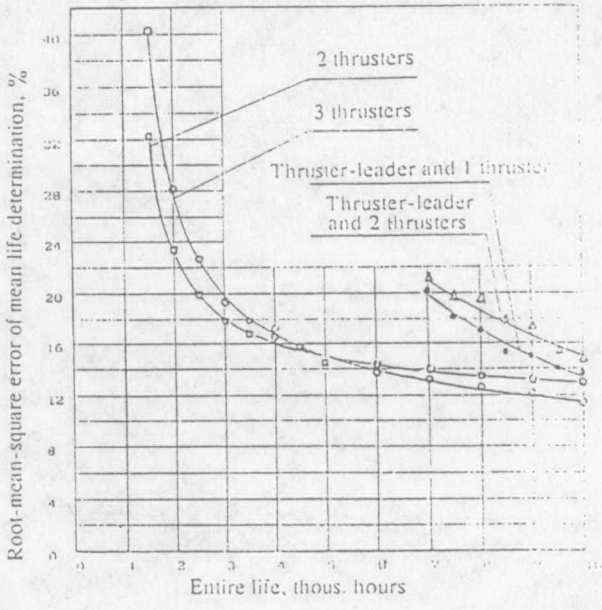


Fig. 5. Root-Mean-Square Error of Mean Life Determination Versus Entire Life (σ_t = 1200 h)