Development of Accelerated Life Test

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***Abstract*—This paper summarizes the development of accelerated life test types, model, statistical method and its progress. To the mechatronic component whose failure mechanism is related to various operational stresses, the best way is to exploit variable stress Accelerated Life Test (ALT), obtain the likelihood function with failure accumulative method, and then calculate the normal life on the basis of the parameter evaluation. Directing to the parameter evaluation difficulties of multiple parameters, the optimization method is widely used based on genetic algorithm.**

***Keywords*—accelerated life test; accelerated stresses; accelerated model; statistical method**

I. INTRODUCTION

With the rapid development of technology and the emergence of advanced mechanical and electronic products, the products which is related to national security and economic lifelines become more and more complex and its reliability and life become higher and higher. In order to win the competition of market, it is urgent to shorten new product development cycle and decrease development costs. For complicated products especially in aviation, aerospace, power, transportation, energy and other key national economy areas, the life of product plays a very important role, how to assess the life and reliability of these complex products rapidly and accurately becomes the key to ensure the rapid market occupation or the advanced capability of the weapons.

Usually the life of mechanical and electronic products can be acquired by life test under normal conditions. But for the highly reliable products which generally have long-life, the traditional method often implies that the test will cost very long time. In some occasion, the products have been discarded for out-date before the life test finishes. So ALT is applied in life evaluation especially in critical safe fields. In 1967, USA Rome Air Development center (RADC) firstly gave the general definition of ALT [1] and provide the corresponding application manual for ALT. The earliest ALT is based on constant stresses and its statistic method depended on graphics assessment algorithm, which is not suitable to the actual condition obviously. Then the study of ALT based on actual operational stresses was urgent to research. At the same time, the accelerated model under different stresses was investigated with failure physics and chemical reflection theory in order to achieve the life degradation rule of product. Accompanying the complexity of stresses and operational spectrum, it is difficult to get the parameter evaluation when the evaluated parameters are more than 3. So the global optimization statistic method became the hot topic in ALT.

II. ACCELERATED LIFE TEST TYPES

According the different spectrum of test stress imposed on products, ALT can be divided into four types: constant stress ALT, step stress ALT, progressive stress ALT and variable stress ALT.

A. Constant stress ALT

In the constant stress ALT, all samples are divided into several groups, and each group of samples is tested under a constant accelerated stress. The test is carried out until the prescribed time (also known as censoring time) or prescribed failure amount (also known as censoring amount).

B. Step stress ALT

In the step stress ALT, all samples are tested on a certain accelerated stress level that varies in steps.. The failure samples are thrown off the test after certain time, and the test stress put on the remnant samples is improved to the next high level. This process will be carried out until all the samples fail or the prescribed time is arrived.

C. Progressive stress ALT

The procedure of the progressive stress ALT is basically same as the step stress accelerated life test, the only difference between these two tests is the stress put on the samples. In the progressive stress ALT, the stress is a increasing function varied with the time.

D. Variable stress ALT

In the variable ALT, the actual stress-time load spectrum can be directly adopted, and the valid data obtained by other tests can be used to assess parameters. So it can not only reduce the samples, but also increase the estimated accuracy, and this test method is the development direction of accelerated life test.

III. ACCELERATED LIFE TEST MODEL

A. The analysis of failure mechanism

The target of the ALT is to measure the life of the product in the shortest time by putting the intensified stress on products. So the precondition of ALT is that the failure mechanism of the

products should not be changed, otherwise it is unreasonable to predict the life reliability character determined by a certain failure mechanism using the data related with another failure mechanism. It is necessary to analysis the failure mechanism and the model of the product before the accelerated life test is carried out.

The failure mechanism of the product is the inherent failure character related with the physical, chemic and mechanical processes. The failures mechanism is varied with the types and working environment of the product, but it behaves in the form of fray, fag, part, rot, oxidation, aging and concussion.

Besides the external failure factors such as working stress, environment stress and the working time, the failure mechanism is the inherent failure reason of the product. The different stresses lead the different failures, and it corresponds with different models. The failure has close relationship with the model. The idiographic failures of the product are different, but it is known that the model can be divided into several types by statistic and analysis based on statistical analysis. If the failure model is known, the reliability and life can be predicted. There are two types of general failure model as follows.

B. Model based on reaction theory

The failure of product is caused by oxidation, separating out, electrolysis, pervasion, evaporation, fray and fag. Generally the failure will occur when the bad reaction reaches certain degree. So this type of model is based on the theory of reaction.

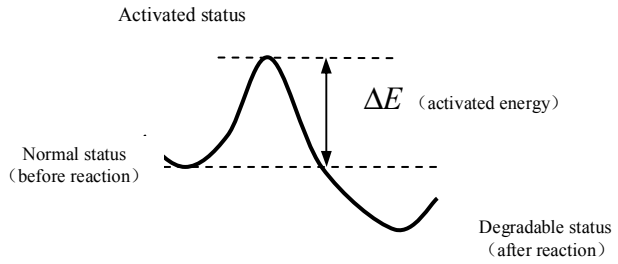

Figure 1. the process of the product failing

There is an energy barrier between degenerative state and the normal state. The power used to pass through the barrier is provided by the environment stress. When it passes though the power barrier, the failure will happen with certain probability, as shown in figure 1. The failure model based on the theory of reaction can be classified into Arrhenius model, verse Power Law model and Eyring model as follows.

Arrhenius model:

$$\eta = A_1 e^{\frac{B}{T}} \tag{1}$$

Where η is life; A_1 is constant; B is temperature coefficient; T is temperature.

Inverse Power Law model:

$$\eta = A_2 S^{-\alpha} \tag{2}$$

Where A_2 is constant; α is the power coefficient; S is stress except temperature.

Eyring model:

$$\eta = A_3 T S^{-\alpha} e^{\frac{B}{T}} \tag{3}$$

Where A_3 is constant.

C. Variable stress ALT model

In the actual operating conditions, the stress imposed on the products is rarely typical constant stress, step stress or progressive stress, and actually the load spectrum put on the products is often varying stress. To enable accelerated life test closer to the real situation, the variable stress accelerated life test model was developed. Assumed that the accelerated stress of product is the comprehensive stress such as pressure, velocity and temperature $\vec{S}(P,V,T)$, the physical failure model can be acquired by virtue of general Eyring model:

$$\eta = A P^{-\alpha} V^{-\beta} e^{\frac{B}{T}} \tag{4}$$

Where，

η—characteristic life time;

P—pressure;

V—velocity;

T—temperature;

A, B, α β---parameters to be estimated.

According to reliability theory, if the partial product failure can cause the overall system failure, then the life of the product obeys Weibull distribution. Since the majority of mechatronic products accords the above regulation and the mechatronic products' failure distribution under constant stress obeys Weibull distribution, varying stress hybrid Weibull model can be obtained by cumulative damage theory.

The model is based on the assumptions as follows:

1) Under a constant stress $\vec{S}(P,V,T)$, the life follows the Weibull distribution:

$$F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^m} \quad (m > 0, t \geq 0, \eta > 0) \tag{5}$$

Where，

F(t)—failure distribution function;

m—shape parameter;

η—Characteristic life time.

2) The shape parameter m in the Weibull distribution is independent to the stress.

3) The characteristic life time η in the Weibull distribution relates to comprehensive stresses:

$$\eta = A P^{-\alpha} V^{-\beta} e^{\frac{B}{T}} \tag{6}$$

Products cumulative percentage of failure is only relate to the current stress and the cumulative damage, and it is irrelated to the process of damage cumulative.

Assumed that varying load of stress spectrum is $\vec{S}_1, \vec{S}_2, ...\vec{S}_i, ...$, the relevant cumulative time is $0 \to t_1 \to t_2 ... \to t_i \to ...$. The test is carried out from t=0 to t=t_1 under stress $\vec{S}_1(P_1, V_1, T_1)$, and then test continue executing to t= t_2 under stress $\vec{S}_2(P_2, V_2, T_2)$ … . Here $\vec{S}_1, \vec{S}_2, ...\vec{S}_i, ...$ and $0 \to t_1 \to t_2 ... \to t_i \to ...$ are determined by the spectrum of comprehensive stresses life test.

Therefore, the failure probability is:

$$F_i(t) = 1 - \exp\left[-\left(\frac{t - t_{i-1} + \tau_{i-1}}{\eta_i} \right)^m \right] \tag{7}$$
$$(t_{i-1} \le t < t_i)$$

Here:

$$\tau_{i-1} = (t_i - t_{i-1} + \tau_{i-2}) \left(\frac{P_{i-1}}{P_i} \right)^{\alpha} \left(\frac{V_{i-1}}{V_i} \right)^{\beta} e^{B\left(\frac{1}{T_i} - \frac{1}{T_{i-1}} \right)} \tag{8}$$
$$\eta_i = A P_i^{-\alpha} V_i^{-\beta} e^{\frac{B}{T_i}}$$

$t - t_{i-1} + \tau_{i-1}$ denotes the time when the damage under stress $\vec{S}_1, \vec{S}_2, ...\vec{S}_{i-1}$ cumulates to $\vec{S}_i$ level. Here τ is called as reliability displacement transfer factor. By this statistical method, the comprehensive stress life test model based on the varying load spectrum can be established.

IV. ACCELERATED LIFE TEST STATISTICAL METHOD

The statistical assessment of ALT consists of following methods:

A. Graphically analytic estimation

Graphically analytic estimation can be applied to the accelerated life test statistics analysis under constant stress. For these data acquired under different stress level, graphically analytic estimation uses curves to analyze these data and obtains the required results.

B. Maximum likelihood method

Firstly the maximum likelihood function of accelerated life test is built up, and then the parameters of the maximum likelihood function are estimated, finally the life target under normal stress is obtained.

C. Optimal estimation method

The Simulated Annealing Algorithm was introduced by Kirkpatrick to solve the combination optimization problems in 1982. The Simulated Annealing Algorithm is a stochastical optimization technique that is used to solve continuous, order discrete and multi-modal optimization problems. It accepts not only better but also worse neighboring solution with a certain probability. This make the algorithm can converge the global optimum. Theoretically when the time of calculate and reiteration is long enough, packing problems can get its optimum.

Genetic algorithms were formally introduced in the United States in the 1970s by John Holland at University of Michigan. A genetic algorithm is a search technique used in computing to find true or approximate solutions to optimization and search problems. Genetic algorithms are categorized as global search heuristics.

The maximum likelihood function of varying stress accelerated life is a nonlinear multi-dimension complex object function, whose parameter estimation is easy to get into local optimization with grads descending algorithm while has low searching efficiency with global optimal algorithm. To solve the bottleneck between direct and intellective optimization of multi — dimension complex object function, the genetic accelerated algorithm was presented based on real code genetic algorithm and Powell method. Through using perfect switch with adaptive function, the genetic accelerated algorithm takes the advantages both genetic algorithm and Powell method at furthest that ensure global optimization and keep rapid searching velocity to multi-dimension complex object function.

V. THE PROGRESS OF ALT

ALT is a field of research focus on reliability engineering; it has important research and application of high reliability products for the life assessment. Through the key technical and statistical analysis of the accelerated life test, we can see that statistical methods of accelerated life test still exist in the further development of space, and it is primarily embodied in the following aspects:

1) The statistical analysis accuracy of accelerated life test. ALT is a branch of statistics which is very important for the accelerated life test. This is common problems of the statistical test for studying. Statistical accuracy of evaluated parameters will be a theme of accelerated life test analysis method.

2) Efficiency of ALT method. For statistics of simulation test, the aim of accelerated life test is to make the testing process more efficient and cost-effective. Thus it gets the purpose of life assessment at the lowest price. Therefore the question of efficiency constitutes a theme of precision alternative. Overall, statistical analysis of accelerated life test and optimization of the design should be a compromise of the efficiency and precision.

3) Engineering applications of ALT. ALT depends on the actual operational spectrum, which makes the ALT model complexity and parameter evaluation difficulties. So the real practical application of ALT is still very limited, the method of

accelerated life test need to further practical, and enhance the greater efforts to promote the application of the project.

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