SELECTION OF PARAMETERS IN FIXED-DURATION RELIABILITY QUALIFICATION TEST SCHEME

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Abstract

This paper introduces two formulas for designing fixed-duration reliability qualification test and gives the rules about the selection of test scheme parameters. The variance of the test results when selecting different test schemes is discussed in detail. It is concluded that as the acceptance probability of equipment in different schemes varies greatly, the qualification goal is able to be achieved only through the selection of reasonable test scheme.

1 Introduction

Reliability qualification test, a test of some representative products under specified conditions by the consumer, is to demonstrate whether the product's reliability can satisfy the designing requirements. As a sampling inspection test, it can determine to some extent whether to permit finalizing the design or not.

In the sampling inspection test, we judge the quality of a batch of equipment by the result from testing one or a few products; we, therefore, tend to make two types of mistake. First is Error Ⅰ, that is, a qualified batch of products is mistakenly judged as unqualified. The other one is Error Ⅱ, that is, an unqualified batch of products is mistakenly judged as qualified. If we commit Error Ⅰ and refuse to accept a qualified batch, the equipment producer will suffer the loss; therefore, we name the probability of committing the first error as producer's risk, usually denoted as α . If we commit the second error and accept an unqualified batch, the equipment consumer will have to suffer the loss; we thus name the probability of committing Error Ⅱ as consumer's risk, usually denoted as β .

"Ideal" scheme of sampling inspection is a scheme where both producer's and the consumer's risks are equal to zero, but this scheme does never exit. It is because that to make α =0, that is, never to refuse to accept the qualified batch, will lead to the increase of β ; whereas, to make β=0, that is, never to accept the unqualified batch, will lead to the increase of α . Therefore, in practice, the producer and the consumer usually consult with each other to set down a reasonable scheme. They always evaluate one inspected parameter (such as the equipment's life-span, mean time between failures (MTBF), reliability, or probability of success) and give two values of the parameter, denoted in this paper as ω_0 and ω_1 ($\omega_0 > \omega_1$). When the sample's parameter average $\varpi \ge \omega_0$, we will accept the batch at high probability. That is: $L(\varpi) > 1-\alpha$, when $\varpi > \omega_0$; $L(\varpi) = 1-\alpha$ while $\varpi = \omega_0$ (where $L(\omega)$ represents the probability of accepting the batch). When the sample's parameter average $\varpi \le \omega_1$, we will accept the batch at low probability. That is: $L(\varpi) < \beta$, when $\varpi < \omega_1$; $L(\varpi) = \beta$ while $\varpi = \omega_1$. We could determine the sampling inspection scheme according to the above conditions[1].

2 The design formulas for the fixed-duration reliability qualification test

According to statistics, the life-span of complicated electronic equipment keeps to exponential distribution[1]; therefore, many standards e.g., GJB899-1990 in China, MIL-

STD-781D, MIL-HDBK-781 in America, etc., only give the test scheme for the equipment whose life-span keeps to exponential distribution. In this paper, we also discuss the test scheme for the equipment whose life-span keeps to exponential distribution.

2.1 The design formulas for standard fixed-duration RQT scheme[2]

GJB899 *Reliability Qualification Test and the Reliability Acceptance Test* gives the probability of accepting equipment with a true MTBF equal to θ as follows:

$$L(\theta) = P(k \le r \mid \theta) = \sum_{k=0}^{r} \frac{(T/\theta)^k}{k!} e^{-\frac{T}{\theta}} \qquad (1)$$

Where, r =number of chargeable failure permitted in a test scheme, and T =the total effective test time.

From $L(\theta_0) = 1-\alpha$ and $L(\theta_1) = \beta$, we can lead to the following equation group:

$$\begin{cases} \sum_{k=0}^{r} \frac{(T/\theta_0)^k}{k!} e^{-\frac{T}{\theta_0}} = 1-\alpha & (2) \\ \sum_{k=0}^{r} \frac{(T/\theta_1)^k}{k!} e^{-\frac{T}{\theta_1}} = \beta & (3) \end{cases}$$

Put the standard test parameters α、β、θ_0、θ_1 into Equations (2) and (3), we can get the values of T and r. For the permitted value of r is integral, the values of T and r we get are only approximations. Put the approximate values of T and r into Equations (2) and (3), we can get the actual producer's risk α^1 and the actual consumer's risk β^1 in the standard test scheme（T，r）.

Taking the standard Test Scheme 17 in GJB899 for example, we can get that the values of the scheme parameter are $\alpha=\beta=20\%$ and discrimination ratio $d = \theta_0/\theta_1$=3. If we put these values into Equations (2) and (3), we can obtain the approximate values of T and r are $4.3\theta_1$ and 2, respectively. Again if we put $4.3\theta_1$ and 2 into Equations (2) and (3), we can derive the corresponding values are α^1 =17.46% and β^1=19.74%. This result is completely consistent with the value listed in Table A3 in GJB899. According to Equations (2) and (3), we can also design fixed-duration standard test scheme with discrimination ratio not equal to 1.5, 2, or 3.

2.2 The design formula for the Limiting Quality RQT scheme[1]

After a thorough negotiation about the values of parameters α、β、θ_0、θ_1 by both sides of the producer and the consumer, we can then obtain the values of T and r in the standard test schemes. Therefore, it is not easy to control directly in the standard test scheme the important parameter value T. If the total effective test time T is needed to be controlled directly as time and cost permitted in the RQT are limited, we can choose the scheme of Limiting Quality (LQ) recommended in GJB899 (see Chart A21--A23). The design of the scheme is similar to that of the LTPD (Lot Permit Product Defectives) scheme of the products of successful-or-unsuccessful type. From the given values of β and θ_1, and other restricting conditions such as the number of failure permitted or the total effective test time, we can design the LQ test scheme（T，r）by using Equation (3).

Let's take the LQ Test Scheme 10-1 in Chart A21 in GJB899 for example. Supposing β =10% and the additional restriction r =0, we can get the value of T =2.3026 θ_1. Substituting the values of T and r into Equation (2), we can derive the results as follows:

α= 30%，while d =6.4557;

α= 20%，while d =10.3188;

α= 10%，while d =21.8545.

Observed MTBF($\hat{\theta}$) in Chart A21~A23 is calculated on the basis of the assumption that the (r +1)th chargeable failure will occur only after T, thus $\hat{\theta}=T/(r+1)$.

The consumer often concerns only the values of β and θ_1, because these values affect directly his benefit. For example, the LTPD scheme adopted by the American army to control the electronic components' reliability is of this type. Of course, to draw a reasonable LQ scheme, the consumer should consult with the equipment producer because RQT is not just the matter the consumer should consider about.

3 Different test results obtained from different test scheme parameter values

3.1 The principle of selecting the values of test scheme parameters

3.1.1 How to determine the values of α and β

The total effective test time T is determined by α、β、θ_0、θ_1 . On the condition when the upper test MTBF (θ_0) and the lower test MTBF (θ_1) are constants, the greater the values of α and β are, the less the value of T is; the less the values of α and β are, the greater the value of T is. Therefore, when we determine the values of α and β, we should take into account the factors that both the consumer and the producer could bear such as test time, cost, etc. The values of α and β recommended in GJB899 are from 10% to 30%, and we often select the values of α and β from this interval. If the values of α and β are not evenly equal to 10%, 20%, or 30%, we can design other test schemes by using Equations (2) and (3).

The values of α and β should be equal in general, because the consumer and the producer are au pair. However, when test time, cost or equipment is limited and when the consumer or the producer is willingly to bear higher risk, the values of α and β could be unequal.

3.1.2 How to determine the values of θ_0 and θ_1

Different from equipment performance indexes, the reliability of equipment is increasing continuously during its life-span. Therefore, when testing the performance of new equipment, the consumer often gives a reliability index two values: the goal value and the threshold value. The goal value is a using reliability expected by the consumer, which can not only satisfy the using requirement but also optimize the equipment's effect-cost ratio. This value could be achieved in the service duration of the equipment. The threshold value is a using reliability that the equipment must be achieved, and it is the basis for determining the minimum acceptance value. Generally speaking, the using reliability is not cited directly in the contract because it is not convenient to be controlled by the producer. Therefore, the goal value and the threshold value are generally transformed into specified value and the minimum acceptance value respectively and are then put into the contract. The specified value is a contractual index expected to be achieved, which is the goal to be obtained by the producer through utilizing sorts of reliability designing methods; the minimum acceptance value, as a contractual index that the equipment must achieve, is an index to testing or validating the equipment reliability. [3]

Some believe that θ_1 should be greater than the minimum acceptance value (e.g., 25% greater), which, we think, is unnecessary. It is emphasized in GJB450 *General Reliability Program for Material Development and Production* that the lower test MTBF(θ_1) should equal the minimum acceptance value. According to He Guowei's, the upper test MTBF(θ_0) is not determined by the specified value, but should refer to the specified value, that is to say, θ_0 should equal the specified value approximately. This regulation can be accepted by both the consumer and the producer[5].

3.2 The acceptance probability of equipment tested by using different test schemes

If the consumer requires that the MTBF index of equipment whose life-span abides by exponential distribution be as follows: the specified value=200 hours; the minimum acceptance value=100 hours. The consumer also demands that the consumer's risk in the RQT implemented in the finalizing phase be 20%. After predicting and evaluating the reliability of the product, let us suppose that the actual MTBF of the equipment is about 150 hours. According to GJB450 that the lower test MTBF should be endowed with 100 hours and that the consumer requires that β=20%, we can then design many test schemes satisfying the contract by using Equations (2) and (3) through selecting different θ_0 s and α s. In this paper, we only take the Standard Test Schemes 10, 11, 13, 14, 15, 16 and the LQ Schemes 20-1, 20-6, 20-11, 20-20 in GJB899 for examples to show different acceptance probability of equipment in different test schemes.

3.2.1 *The acceptance probability of equipment in different standard test schemes*

We can get the acceptance probability of equipment in different standard test schemes by using Equation (1) (see Table 1).

Table 1 The acceptance probability of equipment in different standard test schemes

Scheme number	α	β	α^1	β^1	d	T (hour)	r	P
10	10%	20%	10.9%	21.4%	1.5	2990	25	89.1%
11	20%	20%	19.7%	19.6%	1.5	2150	17	80.3%
13	10%	20%	9.8%	20.9%	2.0	1240	9	68.3%
14	20%	20%	19.9%	21.0%	2.0	780	5	58.1%
16	10%	20%	10.9%	21.3%	3.0	540	3	51.6%
17	20%	20%	17.5%	19.7%	3.0	430	2	45.5%

α ——nominal value of producer's risk;
β ——nominal value of consumer's risk;
α^1 ——actual value of producer's risk;
β^1 ——actual value of consumer's risk;
d ——discrimination ratio;
T ——total effective test time, (unit: hour);
r ——number of permitted failures;
P ——The acceptance of the equipment whose MTBF is 150 hours.

Abiding by the rules described in Section 3.1, the values of α and β should be equal, and the upper test MTBF (θ_0) should be selected by referring to the specified value (200 hours). Then, Scheme 14 is the most appropriate, in which the acceptance probability is about 58.1%.

As shown in Table 1, we can conclude that the acceptance probability of the same equipment varies greatly in different test schemes, that is, decreases from 89.1% in Scheme 10 to 45.5% in Scheme 17. The difference is obviously caused by different values of α s and θ_0 s. In Scheme 10, the maximum acceptance probability of the equipment whose MTBF is 150h is 1- α^1 =1-10.9%=89.1%, because the nominal producer's risk (10%) is less than the consumer's risk (20%), and the discrimination ratio is less than the ratio of the specified value and the minimum acceptance value. In Scheme 11, the discrimination ratio is also less than the ratio of the specified value and the minimum acceptance value though α = β , then the acceptance probability is 1- α^1 =1-19.7% = 80.3% , still greater than 58.1%. In Scheme 13, the discrimination ratio is 2, which equals the ratio of the specified value and the minimum acceptance value, but here $\alpha < \beta$, then the acceptance probability (68.3%) is still greater than 58.1%. In Scheme 16, the discrimination ratio is 3, greater than the ratio of the specified value and the minimum acceptance value, but $\alpha < \beta$, then the acceptance probability (58.1%) is derived to be less than 58.1%. In Scheme 17, the discrimination ratio is 3, greater than the ratio of the specified value and the minimum acceptance value, and α = β , thus the acceptance probability (45.5%) is the least.

3.2.2 *The acceptance probability of equipment in LQ schemes*

Using Equation (1), we can derive the acceptance probability of equipment in different LQ schemes (see Table 2).

As shown in Table 2, the acceptance probability of equipment in different LQ schemes also varies greatly, and the longer the test time is, the greater the acceptance probability is. Therefore, we suggest the producer select the LQ scheme of longer test time under the condition when the factors of time and cost are not the main concern of the consumer.

Table 2 The acceptance probability of equipment in LQ schemes

Scheme number	β	T (hour)	r	P
20-1	20%	161	0	34.2%
20-6	20%	791	5	56.9%
20-11	20%	1365	10	69.4%
20-20	20%	2363	19	82.8%

4. Conclusion

It can be concluded from the analysis above that the results vary greatly when we select different schemes. Therefore, in the design of a qualification test scheme, firstly, the test scheme parameters should be made to satisfy the contract; and then the producer can select purposefully a test scheme from GJB899 according to the acceptance probability that they have known well about the equipment before the reliability qualification test. Only in this way is the equipment able to pass the test to the greatest extent.

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