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Research on Storage Life Prediction of Fuze Based on Accelerated Life Tests

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Abstract. Fuze is an intelligent system for detection, identification and determination of targets. It is a core component of ammunition equipment and its life prediction is of great practical significance to improvement of the reliability of ammunition equipment. Based on the analysis of failure modes and failure mechanisms of fuze in natural storage environment, a storage reliability model was established for fuze. The acceleration model and the accelerated life test plan were determined. Tests were conducted in an isothermal and humidity-constant incubator to test and testing data of a fuze was processed. The results demonstrated that the storage life of this fuze was 10.05 years (prediction by Weibull distribution and maximum likelihood estimation). The proposed method improves cost effectiveness of fuze logistics and provides an important way to predict fuze life.

Keywords. Reliability, fuze, life prediction, accelerated life tests

1. Introduction

Fuze is an intelligent system for detection, identification and determination of targets. It is a core component of ammunition equipment. Fuze accelerated storage life tests aim at improving the acceleration efficiency of fuze accelerated tests, reducing the test cycle of fuze life prediction, grasping the quality change law of fuze under normal storage conditions in a short test time, and predicting storage life [1].

Through the research on accelerated storage life test of fuze technology, we obtain the reliability during fuze storage, and analyze the failure modes, failure mechanisms and failure distribution rules of equipment parts, so as to provide a basis for determining the maintenance and repair intervals of the equipment during the storage period, as well as the readiness rate of equipment and logistics support cost [2]. At the same time, it can also provide a theoretical basis for the design of a noval fuze storage reliability, maintainability and life.

When evaluating the storage life of fuze at home and abroad, the real-time 1: 1 continuous life test is mainly adopted. However, this method requires a large number of subsamples, resulting in great wastes of financial resources, material resources and time. Considering long storage period of fuze, the product is eliminated due to its backward performance before the life test is completed. Additionally, due to the rapid

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development of science and technology, the speed of product replacement is becoming faster and faster. Hence, people urgently need to obtain life information of products in a short time, especially the navigation system. Accelerated life test technology applies targeted stress according to the failure mechanism of the product, which greatly improves the cost effectiveness of the reliability test. Therefore, the research on life prediction has been widely valued in the field of reliability test engineering. Nelson, Meeker, et al. implemented systematic research on the optimization design of accelerated life test with the simple constant stress under the Weibull distribution and lognormal distribution, respectively, and obtained relatively satisfactory results. In terms of data processing of accelerated life test, Shi Shisong, Wang Lingling, Fei Heliang, et al. thoroughly studied various stress application methods of the accelerated life test, different life distributions obeyed by the product, and different conditions such as considering competing failures. Finally, many research results have been obtained [3]. The navigation institute of the Instrument Department in Shanghai Jiaotong University performed the life test analysis on the relatively simple dynamic tuning gyroscope, and the parameter performance extrapolation method was used to preliminary discuss the gyroscope life prediction method [4].

Accelerated life test technology is proposed to predict storage life of fuze, which greatly improves the cost effectiveness of fuze storage life prediction and has important practical significance.

2. Design of Accelerated Storage Life Test of Fuze

2.1. Selection of Stress and Method of Accelerated Life Test

The design of the accelerated life test scheme is to design an optimal test guidance scheme. Long-term practical experience indicates that when the components and raw materials of fuze are in a high temperature environment, thermal aging, oxidation, viscosity reduction, swelling, etc. will occur; low temperature increase the viscosity of the fuze material, leading to the occurrence of embrittlement or shrinkage [5]. During the temperature cycle, the expansion and contraction forces generated by the object are all concentrated on the weak link of the product, which accelerates the expansion of the weak link and causes the material failure of fuze, and affects the storage environmental stress of fuze that is mainly temperature stress [6]. Considering that fuze is fully sealed, temperature was chosen as the acceleration stress in this test.

Fuze is expensive, and has many test parameters, plenty of test times, long test cycles, as well as high precision and test fundings. Therefore, accelerated storage life test of fuze selected the step-stress accelerated life test method [7].

The fuze accelerated life test adopted the step-stress accelerated life test method with non-substitute timing truncation. The determination of the maximum stress level in weak parts of fuze can be based on the conclusion of the reliability enhancement test. The reliability enhancement test technology was mainly to take faults and failures as research objects. By applying a limit stress higher than the actual endurance to the prototype, the potential defects were stimulated in a short period of time, resulting in the weak links exposed as soon as possible, so that the working limit and damage limit of the test object were obtained, which provided the basis for determining the stress level parameters of accelerated life test in weak parts of fuze.

Fuze tactical technical indicator specified that the reliability afterstorage for 30 years is more than 0.5, and the reliability exceeds 0.85 and confidence is 0.8 with maintenance every 6 years during storage. Due to the reparability of fuze during storage, after comprehensive consideration of the storage period of 30 years and maintenance every 6 years, the total test time is determined according to 1/20 of the maintenance cycle specified by tactical technical indicator. The total test time is calculated as (test truncation time) 120 days.

The test time of the prototype under each stress level T1 is determined according to the principles of long accelerated storage life time under low stress and short accelerated storage life time under high stress. The truncation time of this test scheme under each stress level T1 is: t1 = 45d; t2 = 30d; t3 = 24d; t4 = 21d.

2.2. Determination of the Number of Sample

The step-stress accelerated life test requires only one set of samples. Therefore, the total number of samples is greatly reduced. When scheduling the step-stress accelerated life test, the number of samples cannot be too small, otherwise it will cause difficulties in data analysis.

According to the principle of accelerated life test and the selected the step test method, and considering the accuracy of data processing, the number of samples selected 40 in this test.

3. Analysis of Fault Mode and Failure

A summary of fault modes is shown in **Table 1**.

Table 1. A summary of fault modes

Number	Fault prototype number	fault modes	Reasons of faults
1	N04, N21	The working voltage and current output that provide combat fuze are both 0.	Transistor 3CG21C (01V6) 3CG130C (01V7) is open.
2	N04, N24	The working voltage and current output that provide fixed depth fuze are both 0.	Transistor 3CG21C (01V8) 3CG130C (01V9) is open.
3	N20, N34	The working current that provides microcomputer fuze is less than 45 mA.	Magnification drift of crystal triode 3CG130C (01V5)

As observed, the main factors causing faults of the accelerated life test prototypeare the open circuit failure of the transistors 3CG21C and 3CG130C, and the hFE parameter drift of the 3CG130C. The temperature stress accelerates performance degradation of physical and chemical reactions for transistors, such as ion migration, impurity diffusion, intermetallic compound synthesis, molecular changes, creep, crystalline changes, and rearrangement of microstructures in insulating materials, as well as the material aging, which results in parameter changes or failures.

4. Working Life Prediction

4.1. Calculation of Fault Occurrence Time of Fuze Prototype

The fault occurrence time of each fuze prototype is calculated as **Eq. (1)**:

$$t_{ikj} = t_{jk-1} + \frac{t_{ik} - t_{ik-1}}{r_{ik} + 1} j \tag{1}$$

where i is the sequence number of different stress levels; k is the serial number of prototype test at the same stress level; r_{ik} is the cumulative number of faults in the k-th test interval (t_{ik-1}, t_{ik}) at the i-th stress level; j is the sequence number of the fault prototype in the k-th test interval (t_{ik-1}, t_{ik}) at the i-th stress level.

The prototype fault time statistics are shown in **Table 2**.

Table 2. Prototype fault time statistics.

Stress level Ti	**T1 = 363 K**			**T2 = 368 K**	
Test number i, k	T1, 1	T1, 2	T1, 3	T2, 1	T2, 3
Test moment t_{ik}	10.06	10.16	10.22	10.29	11.12
The number of faults r_{ik}	3	1	1	1	2

4.2. Storage Life Prediction

The evaluation data of storage life of fuze was obtained entirely through the step-stress accelerated life test, and the following assumptions are made before the test processing:

- Assumption 1: Under the condition of temperature stress, the life tof the fuze prototype obeys the dual-parameter Weibull distribution, and the Weibull distribution cumulative failure function is expressed as **Eq. (2)**:

$$F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^{m}} \tag{2}$$

  where m is the shape parameter and η is the characteristic life.
- Assumption 2: Under different stress levels, the fuze failure mechanism is the same, that is, m in the life distribution remains unchanged under each stress.
- Assumption 3: η and T_i of the fuze are expressed as **Eq. (3)** according to Arrnenius model:

$$\eta = e^{a + \frac{b}{T_i}} \tag{3}$$

  where a is the intercept of the acceleration equation and b is the slope of the acceleration equation.

4.3. Storage Life Prediction

Since the fuze prototype adopted timing truncation tests, the storage life of all failure prototypes under accelerated stress was converted to the failure time at normal temperature. According to the numerical solution, the likelihood estimate can be obtained: a = -12.50; b = 6380; m = 3.35. Table Type Styles.

4.4. Estimation of Characteristic Life

From the acceleration equation **Eq. (4)**, the estimated characteristic life (η_0) under the normal storage temperature stress T_0 can be obtained:

$$\eta_0 = e^{a+\frac{b}{T_0}} \tag{4}$$

4.5. Working Life Predication

Define R(t) as storage reliability of fuze, then its reliability life can be calculated by **Eq. (5)**:

$$t(R) = \eta(-\ln R)^{\frac{1}{m}} \tag{5}$$

If reliability = 0.8, a storage life of fuze is 10.05 years.

5. Conclusions

Based on the analysis of the failure mode and failure mechanism of fuze in a natural storage environment, its storage reliability model is established. The storage acceleration model and accelerated life test scheme are determined, and relevant tests are conducted. Finally, based on the failure data obtained from the test and related theories, the storage life of fuze t = 10.05 is successfully predicted when the reliability is 0.8, which provides a method with important practical significance for product life prediction.

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