Research on the Determination Method of Acceleration Coefficient in Accelerated Reliability Test of Electronic Equipment

Man Yang\textsuperscript{a}, Ming Yi\textsuperscript{b}, Gengxing Luo\textsuperscript{c}, Yuanmin Huang\textsuperscript{d}

No.3, vocational education road, Sanshui District, Foshan City, Guangdong Province
\textsuperscript{a}fzyyangm@163.com, \textsuperscript{b}fszyym@163.com, \textsuperscript{c}luogengxing@163.com, \textsuperscript{d}huangyuanming_27@163.com

Abstract: This paper analyzes the relationship between environmental stress and electronic equipment failure, studies the determination method of stress type, combination mode and stress value in reliability accelerated test of electronic equipment. Under given reliability accelerated test section, the acceleration coefficient calculation method of the reliability of electronic equipment are given, it can realize rapid assessment of highly reliable electronic equipment reliability, significantly reduce test time and test cycles, overcome traditional electronic equipment reliability test time is long, high cost, difficult to quickly evaluate the level of reliability of faults.

1. Introduction
In this paper, the acceleration stress includes temperature + random vibration comprehensive stress and fast temperature change + random vibration comprehensive stress. The high temperature + random vibration comprehensive stress is used to accelerate the temperature duration in traditional reliability test, and the fast temperature change + random vibration comprehensive stress is used to accelerate the cycle times (temperature change times) in traditional reliability test, respectively, to reduce the test time and the number of test cycles (number of temperature changes). The acceleration coefficient corresponding to the test time of traditional reliability test profile and the acceleration coefficient of test cycle times (temperature change times) are given below.

2. Calculation of failure rate based on stress analysis
The failure rate of products is different under different stress levels. Under the typical stress of main task types in the life cycle of electronic equipment, the failure rate model and failure rate data of components are used, the failure rate of components at a certain stress level is given, and the failure rate of products under a certain stress level is obtained according to the basic reliability model\textsuperscript{[1]}. Compared with the acceleration coefficient of electronic equipment under the condition of reliability acceleration test stress, the acceleration coefficient of test time under the condition of temperature and vibration comprehensive environmental stress is finally obtained.

2.1. Common failure rate model of components
The failure rate model of components is the relationship model between the failure rate of components and the factors affecting the failure rate\textsuperscript{[2][3]}. Most kinds of components have basic failure rate model and working failure rate model respectively. In general, the basic failure rate model only considers the
influence of temperature and electrical stress on the failure rate of components, while the working failure rate model reflects not only the basic factors such as heat and electricity, but also other failure rate influencing factors. In general (except for integrated circuits), it is expressed as the product of a series of correction factors (π coefficients), such as the basic failure rate (λb) reflecting the influence of electrical stress (S) and temperature stress (T), and the quality factor, environmental factor, design factor, process factor, structure factor and application factor, etc., which affect the failure rate[4][5]. That is:

\[ \lambda_p = \lambda_b \prod_{i=1}^{n} \pi_i \] (1)

However, the failure rate model of integrated circuits is different, which is the sum of the failure rate caused by temperature, electrical stress and environmental (mechanical) stress[6][7]. Therefore, there is no separate basic failure rate model for integrated circuits.

The failure rate models of common components are shown in Table 1.

| Component type | Basic failure rate model | Working failure rate model | Remarks |
|----------------|--------------------------|---------------------------|---------|
| Semiconductor integrated circuit | \( \lambda_b = Ae^{\frac{N_T}{N_e}} \) \( \frac{T^{273} + T S}{T_m} \) | \( \lambda_p = \pi_Q \{ C_1 \pi_T \pi_V + (C_2 + C_3) \pi_T \pi_S \} \pi_L \) | C1, C2: circuit complexity failure rate C3: package complexity failure rate G, J, h: P: acceleration constant N_T: temperature constant N_e: stress constant T_m: hot spot temperature N_s: shape parameters |
| Semiconductor diode/triode resistor | \( \lambda_b = Ae^{\frac{N_T}{N_e}} \) \( \frac{T^{273} + T S}{T_m} \) | \( \lambda_p = \lambda_b \pi_Q \pi_E \pi_T \pi_C \pi_TH \pi_TB \) | C1, C2: circuit complexity failure rate C3: package complexity failure rate G, J, h: P: acceleration constant N_T: temperature constant N_e: stress constant T_m: hot spot temperature N_s: shape parameters |
| Potentiometer | \( \lambda_b = Ae^{\frac{N_T}{N_e}} \) \( \frac{T^{273} + T S}{T_m} \) | \( \lambda_p = \lambda_b \pi_Q \pi_E \pi_T \pi_C \pi_TH \pi_TB \) | C1, C2: circuit complexity failure rate C3: package complexity failure rate G, J, h: P: acceleration constant N_T: temperature constant N_e: stress constant T_m: hot spot temperature N_s: shape parameters |
| Inductive element | \( \lambda_b = Ae^{\frac{N_T}{N_e}} \) \( \frac{T^{273} + T S}{T_m} \) | \( \lambda_p = \lambda_b \pi_Q \pi_E \pi_T \pi_C \pi_TH \pi_TB \) | C1, C2: circuit complexity failure rate C3: package complexity failure rate G, J, h: P: acceleration constant N_T: temperature constant N_e: stress constant T_m: hot spot temperature N_s: shape parameters |
| Relay | \( \lambda_b = Ae^{\frac{N_T}{N_e}} \) \( \frac{T^{273} + T S}{T_m} \) | \( \lambda_p = \lambda_b \pi_Q \pi_E \pi_T \pi_C \pi_TH \pi_TB \) | C1, C2: circuit complexity failure rate C3: package complexity failure rate G, J, h: P: acceleration constant N_T: temperature constant N_e: stress constant T_m: hot spot temperature N_s: shape parameters |

Taking a product as an example, according to the above failure rate model and GJB/Z 299C, the failure efficiency can be calculated under different ambient temperature conditions[8], as shown in Table 2.

| Model specification | S | nE | nQ | nR | λb (×10⁻⁷/h) 70°C | λb (×10⁻⁷/h) 80°C | λP (×10⁻⁷/h) 70°C | λP (×10⁻⁷/h) 80°C | λP (×10⁻⁷/h) 80°C | NλP (×10⁻⁷/h) 80°C |
|---------------------|---|----|----|----|-------------------|-------------------|-----------------|-----------------|-----------------|-------------------|
| RMK1206-1/4W-100Ω-GB | 3 | 0.1 | 11.5 | 0.3 | 1 | 0.007 | 0.007 | 0.02415 | 0.07245 | 0.07245 |
| RMK3225-1/4W-100KΩ-J | 1 | 0.1 | 11.5 | 0.3 | 1 | 0.007 | 0.007 | 0.02415 | 0.02415 | 0.02415 |
2.2. Statistics of product failure rate under traditional reliability test profile

According to the typical task profile and the measured stress of the product, the reliability test profile of
the product can be obtained. The calculation of the failure rate of the product considers two factors:
temperature and vibration[9].

1) Statistics of product failure rate under traditional reliability test profile

According to the traditional reliability test profile of the testing machine, the list of components and
parts, reliability block diagram and other information provided by the manufacturer, and according to
the basic reliability model, the failure rate of the testing machine under different comprehensive stress
levels \( \lambda_{pi} \) (i representing different comprehensive stress levels) is calculated respectively by using stress
analysis method. According to the proportion \( k_i \) of each comprehensive stress level in the reliability test
profile \( k_i \), the product failure rate under each stress level is weighted to obtain the product failure rate
\( \lambda_{p1} \) under the reliability test profile. The formula is as follows:

\[
\lambda_{p1} = \sum_{i=1}^{n} \lambda_{pi} k_i
\]  

2) Correction of product failure rate under traditional reliability test profile

For products containing large-scale integrated circuits, high-power devices, power modules and other
components with high heat output, the surface temperature of components with high heat output and the
temperature of components around the components are not necessarily the ambient temperature of the
reliability test profile, and the ambient temperature \( T \) should not be directly used for the calculation of
the failure rate model of components. In order to get more accurate product failure rate, it is
recommended to measure the real surface temperature or local ambient temperature of components
under the specified ambient temperature conditions, and then substitute it into the component failure
rate model for calculation, so as to get the modified product failure rate \( \lambda_{p1} \).

3) Statistics and correction of product failure rate under accelerated test conditions

The temperature stress coefficient \( \pi_T \) and the basic failure rate \( \lambda_b \) of components are selected
according to the temperature \( T_{acceleration} \) of acceleration stress, the environmental coefficient \( \pi_E \) is
selected according to the value of \( V_{acceleration} \) of vibration, and the failure rate of products \( \lambda_{p2} \) under
the comprehensive stress level is calculated by stress analysis method. In the same way, for products with
high power or large heating element, in order to get more accurate product failure rate under accelerated test conditions, according to the same method above, the corrected product failure rate $\lambda_{p2}$ is obtained.

2.3. Determination of acceleration coefficient

2.3.1. Acceleration coefficient of test time

Based on the stress analysis method provided by GJB299C, according to the selection of components and reliability model of the tested equipment, the failure rate of the equipment under different environmental stress levels is analyzed, and the test time coefficient under different vibration stress in GJB1032-1990 and MIL-STD-2164 is used to comprehensively give the acceleration coefficient of the test time in the reliability acceleration test of the tested equipment.

1) Acceleration coefficients of different environmental stress levels $\tau_i$ determination

The acceleration coefficient is the ratio of the test time when the product reaches a certain failure probability at the normal stress level to the test time when the product reaches the same failure probability at the accelerated stress level. For electronic products subject to exponential distribution, the failure efficiency is a constant, and its failure probability function is:

$$F(t) = 1 - e^{-\lambda t}$$  \hspace{1cm} (3)

Suppose that the failure distribution function of a component under the normal stress level $s_0$ is $F_0(t)$, the failure efficiency is $\lambda_0$, $t_{p0}$ is the time when the failure probability reaches $p$, that is $F_0(t_{p0}) = p$, and the failure distribution function of the component under the accelerated stress level $s_i$ is $F_j(t)$, the failure efficiency is $\lambda_j$, $t_{pj}$ is the time when the failure probability reaches $p$, that is $F_j(t_{pj}) = p$. According to the definition of acceleration coefficient, then:

$$F_0(t_{p0}) = F_j(t_{pj})$$  \hspace{1cm} (4)

Namely

$$1 - e^{-\lambda_0 t_{p0}} = 1 - e^{-\lambda_j t_{pj}}$$  \hspace{1cm} (5)

$$\tau_i = \frac{t_{p0}}{t_{pj}} = \frac{\lambda_j}{\lambda_0}$$  \hspace{1cm} (6)

Then according to the series model of basic reliability, the failure rate of each unit is equal to the sum of the failure rates of all components included, and the failure rate of the product is equal to the sum of the failure rates of each unit:

$$\lambda_s = \sum_{i=1}^{n} \lambda_i$$  \hspace{1cm} (7)

Therefore, the formula (5) can be deduced as follows:

$$1 - e^{-\sum_{i=1}^{n} \lambda_i t_{pj}} = 1 - e^{-\sum_{i=1}^{n} \lambda_j t_{pj}}$$  \hspace{1cm} (8)

$$\tau_i = \frac{t_{p0}}{t_{pj}} = \frac{\sum_{i=1}^{n} \lambda_i}{\sum_{i=1}^{n} \lambda_j} = \frac{\lambda_s}{\lambda_s}$$  \hspace{1cm} (9)

$\lambda_i$ - the failure rate of component number $i$ unit under normal stress level;

$\lambda_i'$ - the failure rate of component number $i$ at the accelerated stress level;

$\lambda_s$ - the failure rate of products under normal stress level;
\[ \lambda_s \] -- the failure rate of the product at the accelerated stress level;  
\[ n \] -- the number of units that make up the product.

According to the above derivation, the ratio of the failure rate \( \lambda_{p2} \) or \( \lambda_{p2} \) (correction value) under the accelerated test condition to the failure rate \( \lambda_{p1} \) or \( \lambda_{p1} \) (correction value) under the traditional reliability test profile is to determine the acceleration coefficient \( \tau_1 \) through stress analysis method under different environmental stress levels.

2) Acceleration coefficient of different vibration stress levels \( \tau_2 \) determination

According to the equivalent time formula of different vibration stress given by GJB1032-1990 and MIL-STD-2164, the calculation method of acceleration coefficient of different vibration stress levels is as follows:

\[
\tau_2 = \left( \frac{v_2}{v_1} \right)^3
\]  \hspace{1cm} (10)

Where:  
\[ v_2 \] -- the vibration power spectral density in accelerated test section;  
\[ v_1 \] -- the vibration power spectral density (weighted value) under the traditional test section;

3) Acceleration coefficient of test time \( \tau \) determination

The acceleration coefficient is:

\[
\tau = \tau_1 + \tau_2
\]  \hspace{1cm} (11)

The reliability accelerated test time is:

\[
T_{acceleration} = T_{tradition} / \tau
\]  \hspace{1cm} (12)

2.3.2. Number of cycles (number of temperature changes) acceleration coefficient

The temperature change satisfies the creep theory for the deformation of electronic equipment, especially for various interconnection structures. The creep rate of structures generated by different temperature change rates is different. According to a group of temperature change test data of an electronic equipment, when the upper and lower range of high and low temperature and the number of excitation faults are constant, the temperature change rate and the number of temperature changes show an inverse relationship. See Table 3 for details.

Table 3 the relationship between the rate of temperature change and the times of temperature change of an electronic equipment (below 100°C)

| Serial number | Temperature change rate | Required times |
|---------------|-------------------------|----------------|
| 1             | 10                      | 17.0           |
| 2             | 15                      | 12.0           |
| 3             | 20                      | 9.0            |
| 4             | 25                      | 7.0            |
| 5             | 30                      | 6.0            |
| 6             | 40                      | 4.0            |

According to the fitting analysis of the data in the above table, the temperature change rate and the number of cycles (temperature change number) meet the inverse power model:

\[
N = \frac{A}{X^m}
\]  \hspace{1cm} (13)

\[ X \] -- temperature change rate;  
\[ N \] -- number of cycles;  
\[ M \] -- temperature change rate and cycle number dependence index, which can be taken as 1.17 in the range of 5°C ~ 100°C according to engineering experience statistics;
A **-- frequency factor.**

By using this model, the proportional relation of cycle times under traditional reliability test and accelerated test environment can be derived.

Under the traditional reliability test environment:

\[ N_u = A / X_u^m \]  

(14)

Under accelerated test environment:

\[ N_A = A / X_A^m \]  

(15)

The acceleration coefficient of the number of cycles is obtained

\[ \frac{N_u}{N_A} = \left( \frac{X_A}{X_u} \right)^m \]  

(16)

If the vibration stress is applied simultaneously in the process of temperature change, the acceleration coefficient of temperature cycle is:

\[ \tau_3 = \left( \frac{X_A}{X_u} \right)^m + \tau_2 \]  

(17)

Number of reliability accelerated test cycles:

\[ N_A = N_u / \left( \left( \frac{X_A}{X_u} \right)^m + \tau_2 \right) \]  

(18)

### 3. Conclusion

According to the relationship between the environmental stress and the failure of electronic equipment, the types of sensitive environmental stress are determined, and the typical reliability accelerated test stress combination mode of high temperature + random vibration, rapid temperature change + random vibration is established. Using the stress-based analysis method, under the typical stress of the main task type in the whole life cycle of the electronic equipment, the failure rate level of the electronic equipment is comprehensively analyzed, and the failure rate of the electronic equipment in the whole life cycle is obtained. Compared with the acceleration coefficient of the electronic equipment in the reliability acceleration test stress condition, the acceleration coefficient of test time under the condition of temperature and vibration combined with environmental stress is finally obtained. The relationship between the rate of temperature change and the number of cycles is studied. The inverse power model of the rate of temperature change and the number of cycles (the number of temperature changes) is put forward, and the calculation method of the acceleration coefficient of the number of test cycles is determined.

### Reference

[1] Yin Pengcheng. Analysis and Processing of Reliability Accelerated Life Test Data [D]. University of Electronic Science and Technology of China, 2011.

[2] Liu Xiuping. Accelerated Storage Reliability Model and Statistical Analysis of Electronic Products [D]. Guizhou University, 2007

[3] Yao Jun, Han Na. Accelerated Storage Life Test and Reliability Evaluation [J]. Equipment Environmental Engineering, 2019, 16 (03): 71-75.

[4] Analysis of GB/T 34986-2017 Product Accelerated Test Method [J]. Environmental Technology, 2017.

[5] Lev M.Klyatis. Accelerated Reliability and Durability Testing Technology. Wiley, 2012: 65-90.

[6] Xiujie Zhao, Kangzhe He, Way Kuo, Min Xie. Planning accelerated reliability tests for mission-oriented systems subject to degradation and shocks[J]. Taylor & Francis, 2020, 52(1).

[7] Muhammad Noor, Fang Zhigeng, Shah Syed Yaseen, Haider Daniyal. Reliability and Remaining Life Assessment of an Electronic Fuze Using Accelerated Life Testing.[J].
[8] Analysis of GJB / Z 299c-2006 Reliability Prediction Manual for Electronic Equipment [J].
Reliability Technology, 2006.

[9] Peng Li, Chuanri Li, Wei Dang. Accelerated Reliability Demonstration Testing Design Based on
Reliability Allocation of Environmental Stresses [J]. Quality and Reliability Engineering
International, 2017, 33(7).