Analysis on Stress Screening of Components in Digital Background

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Abstract. This paper introduces various common defects and corresponding screening methods of electronic components. Aiming at the temperature cycle and random vibration methods with good screening effect, the calculation formula of accelerating factor and screening strength in highly accelerated stress screening (HASS) test is introduced. Based on the above discussion, the stress screening test steps of electronic components are summarized to guide the selection of reasonable stress screening items and levels for electronic components.

1. Introduction
Electronic components are an important part of electronic products; they are the most basic unit of electronic products; and the reliability of components is directly related to the reliability of the system. Therefore, the reliability of components is one of the important links to ensure the reliability of the product in the process of product development. High-reliability components are designed and produced, but even better production process and production control will inevitably produce some defective and unqualified products. The stress screening of electronic components is to test different failure modes to eliminate unqualified components or components that will cause early failure due to certain defects.

2. Failure Rate Curve and Significance of Electronic Components
Many tests and use data show that the failure rate curve of most components is featured in high at both ends and low in the middle, a bit like a bathtub, so it is also called a "bathtub" curve. Three component failure stages on this curve [1], namely, early failure, accidental failure and wear-out failure, are as shown in Figure 1:
After the components are put into use for a period, the failure rate of components can be reduced to a lower level and basically in a stable state. The failure rate can be considered as a constant basically. In the stage, the component failure is mainly caused by accidental factors and accidental failure occurs in the main working period of the product. The accidental failure period is random and the failure cause may be that the cumulative stress of the product exceeds the strength of the product at a certain time.

After the components are put into use for a long time, they enter the wear-out failure period, which is characterized by the rapid rise of failure rate. The main cause includes aging, fatigue, wear, corrosion, and other wear-out factors. The failure mechanism is caused by the physicochemical reaction of the material.

The early failure of components is often caused by material defects, or it may be caused by improper process measures and improper design in the production process. Early failure may occur quickly once the components are put into use. By strengthening quality management and adopting screening methods, make early failure of defective components happen, achieve that the whole batch of components can be at the junction of early failure and accidental failure of bathtub curve as far as possible, screen out the unqualified components, and prevent consuming the normal working time of components in advance, thus improving the reliability of components. This stage is to be discussed herein.

3. Qualitative Analysis on Stress Screening of Electronic Components
Stress screening of electronic components is an important measure to ensure the reliability of electronic components. It accelerates their internal potential defects into faults by applying reasonable environmental and electrical stresses to electronic products, and discovers and removes these faults by inspection.

3.1 Screening Category
The screening of components can be divided into two categories: routine screening and special environment screening. Products used in general environment conditions only need routine screening while products used in special environment conditions need both special environment screening and routine screening. It has been proved that products with a low failure rate are not necessarily suitable for special environment.

Special environment screening includes: radiation screening, cold and hot ultra-high vacuum screening, smog screening, mycete screening and oil mist screening.
Routine screening can be divided into:

- Checkout
  a. Microscope screening; b. Infrared screening; c. X-ray screening
- Sealing screening
  a. Liquid leaching leakage screening; b. Moisture screening; c. Radioactive tracer leakage screening; d.
Helium mass spectrometry leakage screening.

- Environmental stress screening
  a. High and low temperature cycle or thermal shock screening; b. Vibration acceleration screening; c. Impact acceleration screening;
  d. Centrifugal acceleration screening (or constant acceleration screening).
- Life screening
  a. High temperature storage screening; b. Low temperature storage screening; c. Power aging screening.

3.2 Common Defects and Screening Items

Electronic component screening tests can use various environmental stress such as thermal shock, temperature cycle, mechanical shock and centrifugal acceleration. Different screening stress leads to different screening effects [2]. Based on limited investigation and statistics of various stress effects [3], the temperature cycle and random vibration are the best, as shown in Figure 2 [4]:

![Figure 2. Comparison of stress screening.](image)

At present, it is generally believed that the temperature cycle is the most effective stress screening method for components with process defects, in which the temperature change rate is considered to be the most important parameter, namely, the higher change rate it is, the more effective it will be. In high and low temperature environment, the stress caused by thermal expansion and contraction makes the component with defects of poor connection or uneven material damaged or failed quickly. For materials with good toughness, multi-cycle screening should be adopted.

Mechanical stress (e.g. vibration, shock, centrifugation, etc.) is used to screen the components with potential cracks or defects in structures, welding, packaging, etc.

In the screening process of temperature cycle and vibration, in case of no comprehensive test box of temperature cycle and vibration, carry out temperature cycle first and then conduct random vibration.

The main screening items and defects of electronic components are as follows (Table 1) [5]:

| Table 1. Common defects and screening items. |
| Test items                        | Microscopy | Non-destructive bonding forces | leakage detecting | Constant acceleration | Mechanical shock | Frequency conversion vibration | Vibration fatigue | Temperature cycle | Humidity test | RADI | PIND | High-temperature storage | High-temperature aging |
|----------------------------------|------------|-------------------------------|------------------|-----------------------|------------------|-----------------------------|------------------|------------------|--------------|------|------|---------------------------|-----------------------|
| Reverse layer channel conduction| √          | √                             |      | √                     |      | √                           |      | √               |              |      |      |                           |                       |
| Bonding loosening and breaking   | √          | √                             |      | √                     |      | √                           |      | √               |              |      |      |                           |                       |
| Improper bonding position       | √          | √                             |      | √                     |      | √                           |      | √               |              |      |      |                           |                       |
| Poor connection of chip and tube holder | √      |                               |      | √                     |      | √                           |      | √               |              |      |      |                           |                       |
| Oxide defects                    | √          |                               |      |                       |      |                             |      |                 |              |      |      |                           |                       |
| Defect of metal layer            | √          |                               |      |                       |      |                             |      |                 |              |      |      |                           |                       |
| Crack of chip                    | √          | √                             |      | √                     |      | √                           |      | √               |              |      |      |                           |                       |
| Internal movable surplus         | √          |                               |      |                       |      |                             |      |                 |              |      |      |                           |                       |
| Shell defects                    | √          | √                             |      | √                     |      | √                           |      | √               |              |      |      |                           |                       |
| Wiring defects                   | √          |                               |      | √                     |      | √                           |      | √               |              |      |      |                           |                       |
4. Quantitative Calculation of Stress Screening and Accelerated Stress Screening for Electronic Components

4.1. Calculation of Screening Strength
Screening strength (recorded as SS) refers to the probability that a potential defect sensitive to screening stress exists in the product in the form of a fault. Two types of typical screening stress (temperature cycle and random vibration) are discussed here. Their screening strength formula is as follows.

4.1.1. Screening Strength of Temperature Cycle

\[
SS_T = 1 - e^{-0.0017(R+0.6)^{0.6} \ln (v+1)^{2}N}
\]  

(1)

Where, R indicates the range of temperature cycle (°C), v indicates the temperature change rate (°C/ min), and N indicates the number of temperature cycles.

4.1.2. Screening Strength of Random Vibration

\[
SS_V = 1 - e^{-0.0046(G_{\text{rms}})^{1.712}t_v}
\]  

(2)

Where, \(G_{\text{rms}}\) indicates the root-mean-square of acceleration and \(t\) indicates the time of vibration. According to the 2026 definition [6] of MIL-SID-883D,

\[
G_{\text{rms}} = \left[ \int_{t_1}^{t_2} \frac{G^2}{f} df \right]^{1/2}
\]  

(3)

Where, \(t_1\) and \(t_2\) are the start time and end time of vibration, \(G\) indicates the vibration acceleration, and \(f\) indicates the vibration frequency.

4.2. Acceleration Factor
The screening stress varies a lot. On the premise of achieving the same objective and not changing the failure mechanism of product, increase of stress will shorten the screening time, thus saving time and economic cost. Now, foreign countries have developed quantitative screening and HASS test technology.

The acceleration factor is the time ratio required for the acceleration test to reach the equal cumulative failure probability under certain conditions and the reference stress. Namely, \(AF = t_a/t_r\) (\(AF > 1\)), where the \(t_a\) and \(t_r\) represent the time [7] required for the reference stress and the accelerated stress to reach the same screening strength respectively. The following are several acceleration factors for screening stress.

4.2.1. Acceleration Factor of Temperature Stress

Arrhenius equation describes the effect rule of temperature stress on component failure, and it is widely used in reliability screening. Its acceleration factor is

\[
AF = e^{\Delta E/(K(T_0-T_1))}
\]

Where, \(\Delta E\) indicates activation energy, \(K\) indicates Boltzmann constant, and \(T_0\) and \(T_1\) are absolute temperature in use and screening tests respectively.

Basing on different raw materials, activation energy has different values, generally:

- Oxidation membrane destruction: 0.3 Ev
- Ionicity (Na ion drift in SiO₂): 1.0~1.4 Ev
- Ionicity (slow trap at Si-SiO₂ interface): 1.0 Ev
- Break due to electrical migration: 0.6 Ev
- Aluminum corrosion: 0.6-0.9 Ev
- Growth of intermetallic compounds: 0.5-0.7 Ev

4.2.2. Acceleration Factor of Voltage Stress

Eyring model describes the power law relationship between electrical stress and component failure.
Its acceleration factor is

\[ A_F = \left( \frac{V_1}{V_0} \right)^c \]  

(4)

Where, \(V_0\) and \(V_1\) indicate the voltage in use and screening tests respectively. \(c\) is a constant, usually between 1-2.

4.2.3. Acceleration Factor of Temperature Cycle

According to the Coffin-Manson model, the acceleration factor of temperature cycle is

\[ A_F = \left( \frac{\Delta T_1}{\Delta T_0} \right)^m \]  

(5)

Where, \(\Delta T_0\) and \(\Delta T_1\) indicate the D-value between maximum and minimum temperatures in use and screening tests respectively. \(m\) is a constant, usually between 4-8.

4.2.4. Acceleration Factor of Humidity

Hallberg and Peck calculate the humidity acceleration factor

\[ A_F = \left( \frac{RH_1}{RH_0} \right)^n \]  

(6)

Where, \(RH_1\) and \(RH_0\) indicate the relative humidity in use and screening tests respectively. \(n\) is a constant, usually between 2-3.

4.2.5. Acceleration Factor of Comprehensive Stress

During component stress screening tests, more than one type of stress may be applied. Temperature, humidity, and electrical stress may be used to accelerate the test at the same time, such as Temperature& Humidity with Bias testing (THB), which is mainly to evaluate the moisture resistance of the components. Its acceleration factor is

\[ A_F = A_F(T) \times A_F(RH) \times A_F(V) \]  

(7)

Where, \(A_F(T)\), \(A_F(RH)\) and \(A_F(V)\) indicate acceleration factor of temperature, humidity, and electrical stress respectively.

5. Stress Screening Steps of Electronic Components

Based on the above discussion, the steps of screening electronic components are as follows:

1) Determine the failure mechanism of electronic components and their corresponding activation energy;
2) According to the failure mechanism and activation energy, select the appropriate screening items and screening strength;
3) In order to save time and economic cost without changing the failure mechanism, select the acceleration factors corresponding to the stress screening test items.

6. Conclusion

This paper discusses the stress screening items of electronic components and their corresponding failure reasons. It also discusses the calculation formula of acceleration factors of HASS test and screening strength. The stress screening of electronic components cannot improve the inherent reliability of the product, but the effective screening can find the defects caused by design and manufacture and feed them back to the quality control of design and production for taking corrective measures, so as to truly improve the reliability of the product.

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