Research on data consistency of LED based on temperature step stress acceleration test

Jingdong Lin¹, Yue Zhao²* and Chenyu Ma²

¹ Automation College, Chongqing University, Chongqing, 400044, China
² Control Science and Engineering, Chongqing University, Chongqing, 400044, China

*Corresponding author’s e-mail: 2446650442@qq.com

Abstracts. At present, whether electronic equipment can maintain the reliability of modeling under different temperature conditions is an urgent problem to be solved. This paper studies LED under stepping temperature stress. Firstly, the luminous flux of LED method is established based on the Arrhenius temperature degradation path model. Secondly, the criterion of temperature step stress is determined, and then the MATLAB is used to select the distribution model which best fits the LED flux degradation trajectory. Finally, we check the consistency of the LED data, so as to realize the establishment of the LED flux degradation trajectory model. The result show that this model has high reliability and can calculate the normal life data of LED accurately.

1. Introduction
At present, there are many phenomena such as inconsistent data and unreliable conclusions in the experiment of failure mode electronic equipment. Therefore, this paper proposes the LED data consistency study based on the temperature step stress acceleration experiment. The so-called step temperature stress means that the target object is placed in an experimental environment higher than the normal stress without changing the failure mechanism of the object, so as to achieve the purpose of accelerating the stress acceleration of the experimental object. Experimental study on the consistency of predicted target under constant stress condition after data analysis. Accelerated experiments can not only save observation time, but also stimulate the failure mode of the product quickly and efficiently. By processing and analyzing the data, the consistency can be evaluated. In practical, the target object will not only be affected by a load, but also be affected by temperature and humidity in most cases, and then leading to a variety of failure modes. There are two main forms: The first is the failure of key components in electronic equipment under long-term high and low temperature load; Secondly, fracture failure under multiple temperature loads. The two most common failure modes are the two above. In this study, the failure mode of electronic equipment in the temperature single stress environment was analyzed and the life was evaluated [1].

2. Analysis of LED flux data

2.1 The theoretical basis of the experiment
The distribution model of LED’s luminous flux degradation trajectory was selected by MATLAB. It can verify the consistency of LED data. As shown below: The first step is the completion of the initial task of detecting conformance. In the second step, the master database data and the copy data are divided into two parts, after the partitioning, the MATLAB is used to verify the data values of the normal life of
each data block, and the data values are compared with each other between the master database and the copy data block. If the data values are the same, it means that all records of the data block are consistent with each other. If the data values are different, it means that the data block has inconsistent records and the data block needs to be divided, and the first and second steps need to be repeated until inconsistent data cannot be found. The fourth step is to loop through the above operation until all records in the master library and the copy are tested.

2.2 Determining the data judgment criteria of LED
On the basis of Arrhenius model, this paper realizes accelerated degradation model according to accelerated experiment theory. In practice, electronic devices can be affected by other components, for example, electronic devices are more susceptible to high and low temperature sensitive mode. Fatigue fracture failure of electronic devices operating at different temperatures will be affected by temperature. Failure occurs because the relationship between the product and the stress environment changes during failure. The production process of the product under stepped temperature stress is shown in Figure 1.

![Production process of products under stepped temperature stress](image)

As can be seen from Figure 1, under the influence of temperature stress, the position of each component and PCB board was changed, which led to fatigue fracture failure of the experimental object.

2.3 Establishment of degradation trajectory model
Table 1 shows the relative light flux maintenance rate attenuation data of each group of samples at different time points under four different temperature stress conditions. By fitting the light flux values of each sample at four temperatures, the fitting curve is shown in Figure 2. After knowing the fitting curve, the sample light flux values at the following moments can be obtained.

| Stress level | Sample number | Luminous flux test results/Im |
|--------------|--------------|-------------------------------|
|              |              | 0h   | 100h  | 250h  | 400h  | 550h  | 700h  | 850h  | 1000h |
| 125℃(S1)     | 1-1          | 958.2| 943.2 | 847.1 | 826.2 | 811.2 | 774.2 | 743.3 | 667.6 |
|              | 1-2          | 963.2| 926.3 | 860.5 | 827.3 | 811.8 | 780.8 | 753.2 | 708.1 |
|              | 1-3          | 968.3| 890.5 | 813.1 | 788.6 | 771.5 | 744.5 | 711.3 | 660.8 |
|              | 1-4          | 976.1| 874.3 | 819.2 | 786.7 | 771.6 | 747.2 | 713.6 | 669.6 |
|              | 1-5          | 975.2| 899.1 | 830.2 | 803.7 | 778.3 | 752.2 | 719   | 665.1 |
|              | 2-1          | 990.3| 952.6 | 841.3 | 811.8 | 788.2 | 761.7 | 721.6 | 668.6 |
|              | 2-2          | 997.4| 955.4 | 845.1 | 814.3 | 796.4 | 772.4 | 735.5 | 692.5 |
| 105℃(S2)     | 2-3          | 985.3| 762.3 | 824.8 | 792  | 767.8 | 733.8 | 699.8 | 648.8 |
|              | 2-4          | 998.3| 959.7 | 845.1 | 822.1 | 793.7 | 761.7 | 722.4 | 667.4 |
|              | 2-5          | 996.5| 932.6 | 845.4 | 823.2 | 800.6 | 773.6 | 735.2 | 685.5 |
|              | 3-1          | 978.3| 951.2 | 846.4 | 823.2 | 799.2 | 762.2 | 732.3 | 681  |
|              | 3-2          | 988.2| 922.8 | 846.8 | 824.4 | 799.4 | 768.4 | 731.4 | 677.4 |
| 85℃(S3)      | 3-3          | 984.3| 936.5 | 848.1 | 815.5 | 799.3 | 767.3 | 740.1 | 699.5 |
|              | 3-4          | 984.5| 958.8 | 824.9 | 794.2 | 771.2 | 738.2 | 705.2 | 652.2 |
|              | 3-5          | 988.2| 948.3 | 846.9 | 826.3 | 776.3 | 742.2 | 709.5 | 661.5 |
| 65℃(S4)      | 4-1          | 964.1| 985.2 | 848.2 | 827.4 | 770.4 | 735.6 | 701.7 | 654.4 |
|              | 4-2          | 958.5| 975.2 | 824.1 | 788.7 | 764.5 | 729.9 | 694.5 | 647.9 |
With the help of MATLAB, the paper has fitted three models of average light passage maintenance rate. Figure 3 shows the fitting of four groups of linear, exponential and Weibull models under different temperature stresses.

The least square method was used to analyze the data, and the square sum of residual errors fitted by the degradation trajectory model was obtained, as shown in table 2. The residual data in the table show that the exponential model can well fit the performance degradation of LED. Therefore, we choose the exponential distribution model to fit the light flux degradation trajectory of LED [5]. That is, the change of relative luminous flux with working time is expressed by exponential function as:

\[ P_t = P_0 \exp(-\theta t + \mu) \] (1)

The initial luminous flux is \( P_0 \), the luminous flux of a certain working time after heating is \( P_t \), the degradation coefficient is \( \theta \), for constant is \( \mu \), the working time is \( t \).

| Table 2. Residual sum of squares |
|--------------------------------|--|--|--|--|
| Exponential model              | S1 | S2 | S3 | S4 |
|                               | 0.0028 | 0.0006 | 0.0011 | 0.0009 |
| Weibull model                  | 0.0068 | 0.0009 | 0.0007 | 0.0009 |
| linear model                   | 0.0164 | 0.0007 | 0.0012 | 0.0004 |
3. Processing method of step accelerated test data

3.1 Test data statistics and basic assumptions
The following three basic assumptions should be satisfied when we deal with relevant data:

1) The failure mechanism of the product remains unchanged at different stress levels.
2) It can correspond to a certain functional relationship when the service life of the product corresponds to different stress levels. That is, accelerated degradation model.
3) The characteristic life always obeys the same distribution under different stress levels.

3.2 Determining the distribution type of product life failure
Under the condition of different temperature stress, it is considered as failure when the light flux of LED attenuates to 70% of the initial light flux. The pseudo-failure life of the experimental sample is obtained from the performance degradation trajectory, and Table 3 is the pseudo failure lifetime of the samples.

Table 3. The pseudo failure lifetime of the samples

| Temperature | 1     | 2     | 3     | 4     | 5     |
|-------------|-------|-------|-------|-------|-------|
| S1          | 598.3 | 2391.65 | 2650.35 | 4123.49 | 4552.3 |
| S2          | 492.67 | 2405.54 | 960.8 | 3206.7 | 3867.32 |
| S3          | 452.74 | 1050.35 | 976.5 | 3867.48 | 3207.16 |
| S4          | 542.78 | 1342.6 | 1653.82 | 3317.06 | 2877.49 |

The results of lognormal and Weibull distribution fitting show that the reliability curve of Weibull distribution is closer than that of Weibull distribution. By comparison, the reliability life obtained from the life obeying Weibull distribution is longer. Figure 4 shows the reliability curves of the two distributions.

3.3 Theoretical basis of reliability assessment
Taking different temperature as the variable of the accelerated test, the reliability of the product is evaluated by analyzing and processing the data. The results show that the effect of temperature on the product conforms to Arrhenius model [6].

\[
\frac{dM}{dt} = Ae^{-\frac{E}{k_BT}}
\]

Where: \( M \) is the degradation quantity of the experimental objective; \( t \) is time, the left-hand side is the rate, \( A \) is a general constant, \( E \) is activation energy; \( k_B \) is Boltzmann constant, \( T \) is the thermodynamic temperature.

Before the experiment on the samples, the normal life data values of the samples under the condition
of mutual independence were calculated on the basis of the Arrhenius model [7].

The derivation of the reliability function of the experimental sample data is shown as follows:

It is assumed that $R_i$ different failure modes of components occur in the accelerated temperature cycle experiment. In the experiment under the first thermal stress $S_i$, there were $n$ target products that failed due to the occurrence of failure mode $i$. And the failure time is $t$, $\beta = 1,2,3,\ldots,n$ [8]. The reliability function of the sample under accelerated degradation can be expressed as the probability of final failure when multiple failure modes of the target product are independent of each other, namely equation (3), as shown below.

$$f(t) = \prod_{i=1}^{n} N_i(t) = M_i(t) \prod_{i=1}^{n} N_i$$  

(3)

In equation (3), $f(t)$ denotes the reliability of failure mode $i$ at time $t$, $N_i$ is the PDF of the failure mode; $M_i$ is the failure rate function of failure mode $R$ at time $t$ [9]. The reliability function of the target product under constant stress is derived from equation (3), namely equation (4), as shown below.

$$L_i = \sum_{\beta=1}^{\beta} \{ \ln [M_i(t)^\beta] \}$$  

(4)

Equation (4) represents the reliability function for any failure mode in all experimental samples under the $i$th step-by-step temperature pressure $R_i$. Finally, the function of the sample data under the step stress acceleration of all temperatures in the temperature cyclic acceleration experiment can be obtained as equation (5), as shown below.

$$L = \sum_{i=1}^{i} L_i$$  

(5)

Equation (5) is a conversion method for the temperature step pressure acceleration experiment. This conversion method is established based on the Arrhenius model. The life of each target product failure mode is not related to the specific accumulation method, but only related to the accumulated current stress level.

4. Reliability assessment

In order to illustrate the validity of the proposed model, and to ensure the stability and reliability of the model, it is compared with the traditional exponential accelerated degradation model [10], as shown in Figure 5; The experimental data were compared by fitting, as shown in Figure 6, it indicate that the acceleration model conforms to the hypothesis. Through the experiment, it can be known that the life value of the experimental object will constantly change with the time in the temperature environment. The designed model can calculate the normal life data value in different temperature environments accurately, and the evaluation result is close to the reliability level of the target product in the working environment, which proves that the model has high reliability.

![Figure 5. Reliability curve of LED tube at normal stress level](image)

![Figure 6. Comparison of characteristic life](image)

5. Conclusion

The effect of electronic equipment will be changed by any failure mode. In order to solve the problem of inconsistent experimental data of failed electronic equipment, the data consistency of LED research
based on temperature step stress acceleration experiment was proposed. In the paper, the data judging standard and the consistency of data results were studied, and the light flux attenuation model was established. In addition, the failure mode of electronic equipment under different temperature conditions was studied, so as to evaluate the reliability of electronic equipment. The experimental results show that the design is reliable and can be widely used.

References
[1] Tan Y, Zhou K, Luo T Y, et al. (2017) Application of Data Processing Method for Step-up Stress Accelerated Life Test in Product Life Testing. Equipment Environmental Engineering, 14(1):1672-9242.
[2] Li S, Chen Z, Pan E S. (2017) Step-Stress Accelerated Degradation Test Plan for Generalized Inverse Gaussian Process. Journal of Shanghai Jiaotong University, 51(2):186-192.
[3] Wang P, Liu H L, Deng H, et al. (2017) Research on Life Assessment Method of DC/DC Power Supply for Spacecraft Based on Multi-Performance Accelerated Degradation. Spacecraft Environment Engineering, 39(3):2171-2174.
[4] Xu H, Liu G X, Yu R B. (2016) LED reliability assessment of performance degradation distribution. China testing, 42(9):1674-5124.
[5] Xiao C D, Liu C J, Liu W D, et al. (2014) Reliability evaluation of LED lamps based on acceleration degradation. Journal of luminescence, 35(9):1000-7032.
[6] Gao L N, Zhao L. (2014) Life prediction of electronic devices based on step accelerated degradation test under temperature stress. Electronic components and materials, 33(6):1001-2028. Wang
[7] Wang H, Zhou Y G, Liu S W, et al. (2017) Study on life assessment method of spacecraft DC/DC power supply based on accelerated degradation of multivariate performance. Spacecraft environmental engineering, 34(4):4139-4145.
[8] Qiu L P. (2017) Application of EM algorithm in statistical analysis of accelerated life test based on interval data. Journal of Sichuan Institute of Technology (Self-discipline Edition), 23 (4): 281-286.
[9] Liu X P, Zhang L J, Shen K K, et al. (2017) Step Stress Accelerated Degradation Test Modeling and Remaining Useful Life Estimation in Consideration of Measuring Error. Acta Armamentarii, 38(8):1586-1592.
[10] Fallou B, Buruiere C, Morel J F. (1979) First approach on multiple stress accelerated life testing of electrical insulation, Conference on electrical insulation and Dielectric Phenomena, Pocono USA: MNRC, 621-628.