

# The acceleration effect of different stress conditions on the accelerated life test of LED driver

Jinhua Liang, Haiping Xu, Chen Gong and Yajie Mu

Key Laboratory of Power Electronics and Electric Drives, Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing 100190, China

Email: hpxu@mail.iee.ac.cn

**Abstract.** LED driver is the key component of LED lighting system, the damage of the driver will cause the failure of the whole lamp, but there is no specific test method for accelerated life test of LED driver at the system level. In order to study the acceleration effect of different stress conditions, research on the principle of LED driver, select different stress application conditions according to different electrical topology. In order to ensure that the stress does not affect the normal operation of the driver, and the failure mode or failure mechanism will not be changed, it is necessary to carry out the limit stress test before designing the test scheme. The results show that the acceleration effect is significant under the condition of constant temperature humidity or constant temperature humidity voltage compound stress, moreover, the acceleration effect is not obvious under the condition of single constant temperature or constant humidity temperature cyclic stress. The accelerated life model of LED driver is established, and the linear fitting is carried out by Weibull distribution and least square method, the variable parameters in the model are derived from the experimental data, and the accelerated life test method will be further studied.

## 1. Introduction

The driver is an important part of the lighting system, the quality of the driver directly affect the life of the whole system. The LED chips has the advantages of energy saving and long service life, the power supply must have a matching service life, improper design and process defect of the driver are easy to cause damage, which leads to the failure of the whole system, and therefore LED driver is an important factor to determine the life of lamp.

In order to test and evaluate the life of LED driver rapidly[1], some scholars have studied the accelerated aging method [2-5] of LED driver at the component level, and a large number of scholars have categorized capacitance [6-9] as the main failure component of LED driver, some other scholars study the reliability detection [10-12] of different electronic devices. Starting from the whole system level of LED driver, this paper focuses on the acceleration effect of different stress conditions on the accelerated life test of LED driver.

## 2. The principle of LED driver

LED driver mainly consists of primary side peripheral circuit, main control chip, high frequency transformer, output rectifier filter circuit, sampling circuit, bias circuit, feedback circuit and other protection circuits. The primary peripheral circuit includes input protection circuit, EMI filter, input rectifier filter and clamp protection circuit; other protection circuits include short circuit, overload, over-current, over-voltage and over temperature protection measures. In order to be used in various



complex lighting environments, some LED driver are also designed to be waterproof, which can be used in rainy day and other outdoor occasions. Some LED driver AC input voltage can be as high as 305VAC for international wide use.

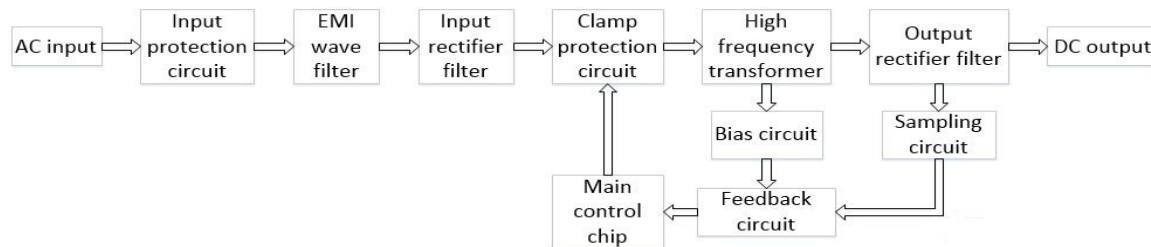


Figure 1. The main components of LED driver.

The circuit topology of LED driver are different designed according to different functions or different applicable environments, the topological structure of a circuit refers to the number of nodes, branches and loops that can reflect the essential characteristics of each circuit, even the same topology can correspond to different circuit diagrams. Therefore, in the accelerated life test of LED driver, it is necessary to select different stress application conditions according to different electrical topology to ensure that the applied environmental stress and electrical stress do not exceed the reasonable range.

### 3. Stress limit value

#### 3.1. Temperature stress limit value

The temperature limit value can be divided into high temperature and low temperature limit value, in order to test the high temperature limit value of a 12W LED driver, the experiment is as follows:

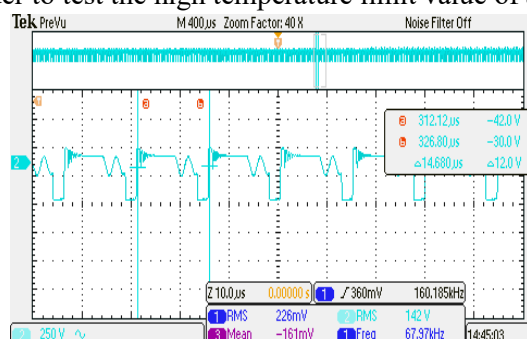


Figure 2. PWM waveform at 25°C.

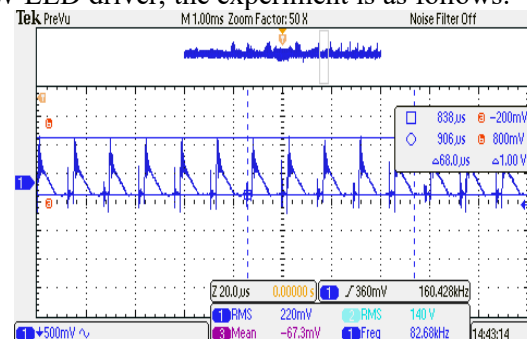


Figure 3. Chip current waveform at 25°C.

Adjust the temperature of the environment test chamber to increase by 10°C each 10 minutes, measure the electrical parameters of the LED driver during the period, and then increase 10°C under the normal operation of this temperature range. According to the above process, gradually increase the temperature, If the driver is found to work abnormally in a certain temperature range, after 10 minutes of this time, reduce the temperature of the environment chamber to the previous range, observe the operation of the power supply until it works normally, and consider this temperature as the maximum temperature stress of the LED driver. At the same time, observe the change of PWM signal and main control chip waveform in the process of temperature rising, the results show as below:

A. The average value of output voltage decreases with the increase of temperature, but the fluctuation range of voltage does not change significantly;

B. When measuring the output filter capacitor current, it is found that the ripple current changes significantly when the temperature reaches 117°C, and the LED driver can not work normally when the temperature reaches 120°C;

C. The PWM decreases in the process of 25°C-65°C, but there is no obvious change in the process

of 65°C-115°C.

Table 1. PWM and chip current in the process of temperature change.

Temperature (°C)	25	65	75	85	95	105	115
PWM (%)	16.89	13.76	13.99	14.36	14.72	14.43	13.13
Chip current(mA)	0.156	0.172	0.178	0.169	0.175	0.172	0.181

In order to test the low temperature limit of a 12W LED driver, the experiment is as follows: adjust the temperature of the environmental test chamber, when the temperature is above zero centigrade, the humidity is set to 40%; when the temperature is below zero centigrade, it is not allowed to set the humidity to prevent crystallization or icing. The setting temperature value changes between minus Sixty-five centigrade to plus Twenty-five centigrade, measuring the electrical parameters of the power supply in the process of ambient temperature change, the data show as below:

Table 2. Electrical parameters in the process of temperature change.

Temperature(°C)	25	10	0	-10	-20	-30	-40	-50	-65
Output voltage(V)	17.2	17.1	17.2	17.2	17.1	17.1	16.8	16.7	16.5
Output current(mA)	700	715	720	720	730	745	750	750	660
Output current ripple(%)	4.3	4.2	6.5	9.2	13.6	17.5	25.3	40	75

A. The cooling process of the low temperature test chamber can be approximately considered as a linear drop in temperature;

B. The output voltage is basically unchanged at 17.1V, which is due to the embedded voltage of LED load;

C. The peak value of input current decreases with the decrease of temperature;

D. When the temperature is above -50°C, the output current will increase with the decrease of temperature; when the temperature is below -50°C, the output current will decrease greatly, it is considered that the driver characteristics have a sudden change but can be recovered in the process of temperature rise;

E. The output current ripple increases and the capacity of the electrolytic capacitor decreases with the decrease of temperature, which leads to the decrease of the ability of the output capacitor to absorb ripple current, according to the failure criterion, the output current ripple of constant current driver must be less than or equal to 10%.

It is considered that the low temperature limit of the 12W LED driver is -10°C, and the temperature range of temperature cycle acceleration test should be set in the range of -10- +115°C.

The author found that the temperature limit range of the non isolated LED driver is the widest, followed by that of the isolated LED driver without PFC, the isolated LED driver with PFC is often equipped with a variety of protection circuits, and the temperature limit range is the narrowest.

### 3.2. Humidity stress limit value

Humidity is a physical measure of the dryness of the atmosphere, which refers to the percentage of water vapor contained in a certain volume of air at a certain temperature.

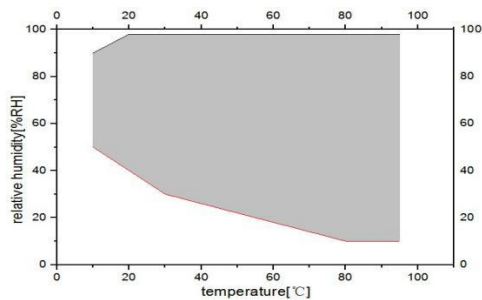


Figure 4. Distribution of temperature and humidity above 100°C.

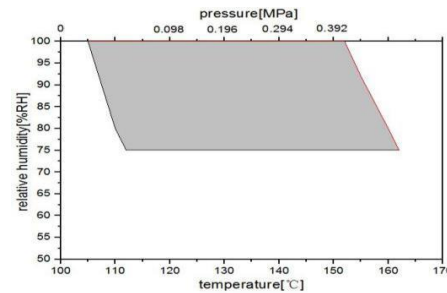


Figure 5. Distribution of temperature and humidity at less than 100°C

Relative humidity is generally used as the acceleration factor, and humidity cannot be applied as a single stress, so it must be combined with temperature. The physical phase transition will occur when the humidity is below zero centigrade, this paper will not discuss the situation when the humidity is below zero centigrade. Limited by physical conditions, the temperature and humidity above zero centigrade are not randomly combined, it has its own inherent physical laws. The commonly used temperature and humidity combined environmental test chamber is mainly divided into two categories, which can be divided by 100°C, so the actual situation should be fully considered in the design of accelerated life test experiment scheme.

The steady-state operation can only be achieved within the shadow area in the figure, specific parameters of different environmental chamber may be slightly different. All in all, during the accelerated life test of LED driver, only when the combination of temperature and humidity is controllable at the same time, this test data is valid.

### 3.3. Voltage stress limit value

There are two ways to apply the electric stress, one is that the AC input side voltage can be boosted by the AC voltage regulator, the other is that the DC output side voltage can be adjusted by the LED load.

Generally, the AC input voltage range of LED driver is 90-264VAC, some special designs can increase the AC input voltage to 305vac. According to the inverse power law model, the greater the ratio of voltage stress UH at high acceleration rate to voltage stress UL at low acceleration rate, the more obvious the acceleration effect is.

Therefore, in the design of accelerated life test scheme, it is necessary to ensure that the temperature, humidity, electrical stress and other test conditions do not affect the normal operation of the LED driver itself, and all electrical parameters are all within a reasonable range, because unreasonable stress application may lead to the change of failure mode or failure mechanism, resulting in the wrong conclusion.

## 4. Single stress experiment

### 4.1. Constant temperature accelerated life test

The single temperature test chamber generally refers to the oven, which only controls the temperature conditions in the environmental chamber, not controls the humidity conditions.

The experiments show that the test life is longer than that the same driver at the same temperature and normal humidity, when the temperature increases, the relative humidity in the air decreases, which may be the reason for the decrease of acceleration multiple, therefore, it can be inferred that the humidity acceleration multiple is less than 1 in the single temperature accelerated life test.

## 5. Two dimensional composite stress experiment

### 5.1. Accelerated life test of constant temperature and humidity

According to Arrhenius model, the acceleration factor is as follows:

$$AF_T = \frac{L_{TL}}{L_{TH}} = \frac{Ae^{E/kT_L}}{Ae^{E/kT_H}} = e^{\frac{E}{k}(\frac{1}{T_L} - \frac{1}{T_H})} \quad (1)$$

It is considered that the distribution of LED driver life is Weibull distribution, the least square method is used to estimate the characteristic life  $\eta$  and shape parameter  $\beta$ :

$$a = \frac{\sum y_i}{N} - b \cdot \frac{\sum x_i}{N} = \bar{y} - b\bar{x} \quad (2)$$

$$b = \frac{\sum x_i \cdot y_i - \frac{\sum x_i \cdot \sum y_i}{N}}{\sum x_i^2 - \frac{(\sum x_i)^2}{N}} \quad (3)$$

$$a = -16.4417, b = 4.0551, \beta = 4.0551, \eta = 57.6606$$

Table 3. Calculation table of least square method

N	Test life(h)	$\ln(t_i)/x_i$	$F(t_i)$	$y_i$	$[\ln(t_i)]^2$	$y_i^2$	$\ln(t_i) \cdot y_i$
1	33	3.49	0.10	-2.15	12.22	4.65	-7.54
2	47	3.85	0.26	-1.18	14.82	1.39	-4.54
3	49	3.89	0.42	-0.60	15.14	0.36	-2.34
4	55	4.00	0.57	-0.14	16.05	0.02	-0.58
5	59	4.07	0.73	0.28	16.62	0.08	1.16
6	71	4.26	0.89	0.79	18.17	0.63	3.39
$\Sigma$		23.56	2.97	-3.00	93.02	7.15	-10.45

Through a number of experimental data, it can be concluded that the value of activation energy  $E$  in Arrhenius model can be divided into two temperature segments, with 85°C as the dividing point.

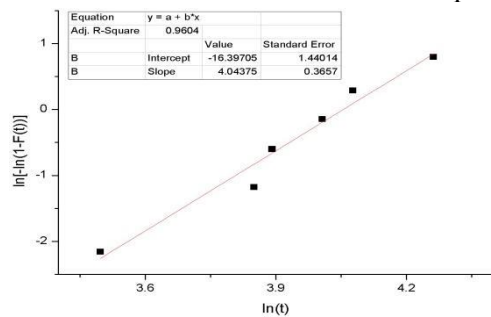


Figure 6. Linear fit at 120°C/75%RH.

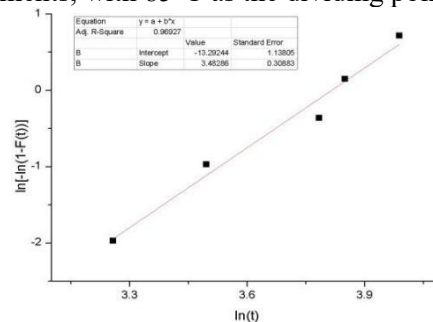


Figure 7. Linear fit at 120°C/95%RH.

According to the peck model, the acceleration factor is as follows:

$$AF = \left( \frac{RH_u}{RH_s} \right)^{-n} e^{\frac{E_a}{k} \left( \frac{1}{T_u} - \frac{1}{T_s} \right)} \quad (4)$$

Through the comparison of experimental data, the conclusion is that when the relative humidity is greater than 85%, the humidity has no obvious acceleration effect, and the effective humidity acceleration range is 55% - 85%.

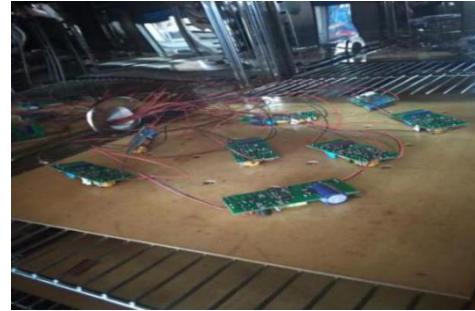
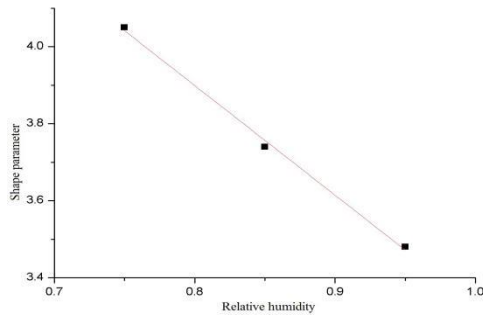


Figure 8. Shape parameter and relative humidity. Figure 9. Samples in environmental chamber.

Table 4. Different shape parameters correspond to different distribution curves.

Shape parameter	$\beta < 1$	$\beta = 1$	$1 < \beta < 3.6$	$\beta = 3.6$	$\beta > 3.6$
Curve distribution	Inverted J	Exponential	Left deviation	Normal distribution	Right deviation

There is a linear relationship between the humidity and the shape parameter of Weibull distribution, the shape parameter decreases with the increase of the humidity stress, and the area with the largest probability density moves to the left, that is to say, a large number of samples fail at an earlier time, which satisfies the theory of increasing the stress and reducing the test time.

## 6. Three dimensional composite stress experiment

### 6.1. Accelerated life test of constant temperature and humidity

According to the inverse power model, the acceleration factor is as follows:

$$AF_V = \left( \frac{U_H}{U_L} \right)^c \quad (5)$$

Table 5. Sample electrical parameter at 120°C/85%/38V

Power number	A	B	C	D
Output current(mA)	116.48	113.39	105.18	109.58
Output voltage(V )	37.37	38.36	38.85	38.32
Ripple wave(%)	36	30.4	40.2	34.9
Output power(W)	4.35	4.34	4.09	4.19
Efficiency(%)	87	86.8	81.8	83.8

The output voltage of DC side can be increased by adjusting LED load, according to the statistical analysis of the test life of four groups of samples, the characteristic life of 5W LED driver is 34h, while the test life of LED driver is 39h under the condition of 120°C/ 85% normal voltage stress. Since the rated voltage of the LED driver is 30-36V, when the rated value is 36V, the inverse power model is as follows:

$$AF_V = \left( \frac{38}{36} \right)^{3.1} = 1.18 \approx \frac{39}{34} = 1.15 \quad (6)$$

The calculation and derivation results of the inverse power law model formula are consistent with the test results, and  $c$  is taken as 3.1.

The AC input side voltage can be boosted by the AC voltage regulator, the acceleration multiple calculated through the actual test of the LED driver is 1.28 times. The voltage regulator will increase the AC voltage to 260vac, according to the formula of the inverse power model, it can be deduced that  $c$  is taken as 1.5.

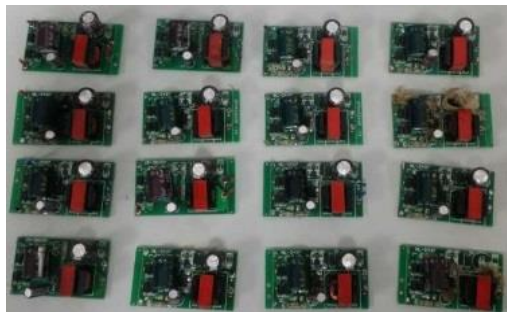


Figure 10. The sample of LED driver with electric stress applied on AC input side.

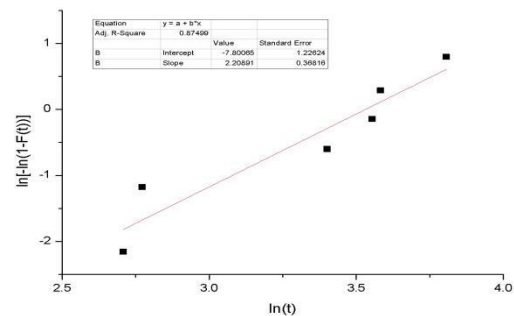


Figure 11. Linear fit at 120°C/85%RH/1.25U

## 7. Comprehensive stress experiment

### 7. 1. Accelerated life test of constant humidity temperature cycle

Table 6. Experimental conditions of constant humidity temperature cycle accelerated life test

humidity	Minimum temperature	Maximum temperature	Heating rate/cooling rate
85%	25°C	85°C	2°C/min
Retention time	cycle	Sample size	Accumulated time
30min	2h	8	527h

Constant humidity temperature cycle means that under the condition of constant humidity, the temperature rises or falls within the range of minimum temperature and maximum temperature.

The test results show that the output current decreases with the increase of temperature, but other electrical characteristics of LED driver have no obvious attenuation or sudden failure. Compared with the decay characteristics of the same driver at 85°C/85% for the same test time, it can be concluded that the high humidity temperature cycle has no obvious accelerated aging effect on the 5W non isolated power supply. Further analysis of the reasons for the decrease of the output current is as follows:

**A.** The ESR of the output filter capacitor decreases with the increase of the temperature, The embedded voltage of the LED load causes the branch current of the filter capacitor to increase and the output current to decrease;

**B.** The temperature rise of other devices causes the output current to decrease.

## Acknowledgments

The authors acknowledge the financial support on this research from National Key Research and Development Program of China (2017YFB0403300/2017YFB0403305).

## References

- [1] Yunfei Liu, Haiping Xu, Zengquan Yuan and Jinhua Liang Developing an accelerated life test method for LED driver and failure analysis. 43rd Annual Conference of the IEEE Industrial Electronics Society 2017
- [2] Hui Zhang Reliability and lifetime prediction of LED drivers. 2017 14th China International Forum on Solid State Lighting: International Forum on Wide Bandgap Semiconductors China
- [3] Lei Han, Nadarajah and Narendran An accelerated Test Method for Predicting the Useful Life of an LED Driver. IEEE TRANSACTIONS ON POWER ELECTRONICS, vol 26 pp 8 2011
- [4] Hao Niu, Xuerong Ye, Shujuan Wang and Guofu Zhai Reliability Assessment of LED Driver Considering Parameter Variations in Strength and Stress Model. 2018 Annual Reliability and



## Maintainability Symposium

- [5] Song Lan and Cher Ming Tan Degradation Model of a Linear-Mode LED Driver and its Application in Lifetime Prediction. IEEE Transactions on Device and Materials Reliability
- [6] Sam G. Parler, Jr. and P.E Deriving Life Multipliers for Electrolytic Capacitors. IEEE Power Electronics Society Newsletter vol 16 no 1 Feb 2004
- [7] Bo Sun, Xuejun Fan, Lei Li, Huaiyu Ye, Willem van Driel and Guoqi Zhang A Reliability Prediction for Integrated LED Lamp With Electrolytic Capacitor-Free Driver. IEEE Transactions on Components, Packaging and Manufacturing Technology
- [8] Karim Abdennadher and Pascal Venet A Real time predictive maintenance system of Aluminium Electrolytic Capacitors used in Uninterrupted Power Supplies. Emerging Technologies Department Critical Power and Cooling Services Schneider Electric INOVALEE Montbonnot St Martin 38334 Saint Ismier, France 2012
- [9] José R Celaya, Sankalita Saha and Kai Goebel Accelerated Aging in Electrolytic Capacitors for Prognostics. Reliability and Maintainability Symposium (RAMS), 2012 Proceedings Annual
- [10] Max Wagner, Hristo Ganev, Alexander Herzog, Quang Vinh Trinh and Tran Quoc Khanh Analysis of accelerated LED degradation by statistical methods. 2016 13th China International Forum on Solid State Lighting
- [11] Chen Gong, Haiping Xu, Jinhua Liang, Yunfei Liu and Zengquan Yuan Optical design of a LED searchlight system. International Conference on Optical Instruments & Technology: Optical Systems & Modern Optoelectronic Instruments 2018
- [12] Qi Chen, Quan Chen and Xiaobing Luo Fast estimation of LED's accelerated lifetime by online test method. 2014 IEEE 64th Electronic Components and Technology Conference