

LED Life Versus LED System Life

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Abstract

The useful life of an LED is presently determined by the IESNA LM80-08 lumen maintenance standard. Even though an LED system has many components, the current industry practice rates LED system lifetime based on a single component, namely, the LED. LED system life is one of the least understood parameters, especially in application environments. As a result, any lifetime claim for a complete LED lighting system, such as a lamp or luminaire, is a guess. This paper describes an accelerated life test of an LED system to predict the lifetime at any given environment temperature and system use (ON-OFF) pattern.

Author Keywords

Light-emitting diode; LED; life; LED system, heat; accelerated testing.

1. Introduction

The commercial feasibility of white light-emitting diode (LED) technology was first demonstrated during the mid-1990s. The earliest white LED life testing paper dates back to the beginning of 2000 [1]. Low power, 5 mm type white LEDs rapidly degraded due to the epoxy encapsulant surrounding the LED die [1-3]. Manufacturers solved this issue by using silicone encapsulants that were able to tolerate higher temperatures and thus slowing down the degradation rate [4]. With improved materials for encapsulants within the LED package and better package engineering, the white LED lumen depreciation rate slowed resulting in a longer useful lifetime [4, 5]. Today there are many papers addressing the lifetime and reliability of white LEDs.

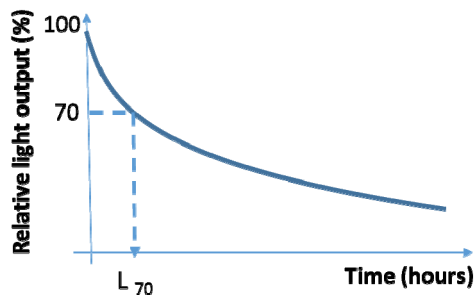


Figure 1. Lumen depreciation profile and end of useful life criterion (L_{70}) for LEDs

The Alliance for Solid-State Illumination Systems and Technologies (ASSIST), in 2005, was the first to release a recommendation for the definition of useful life of white LEDs and a test method to determine when lumen depreciation will reach 70% (L_{70}) of its initial value; see Figure 1 [6]. This became the basis for the IESNA LM80-08 lumen maintenance standard in 2008 [7]. This industry standard calls for testing LEDs at three temperatures, namely, the solder point temperature, for 6000 hours and determining the time required for the luminous flux of the LED to reach L_{70} at each temperature. Knowing the L_{70} value for each temperature, a

functional relationship between L_{70} and LED pin temperature can be derived and can be used for estimating the LED life, L_{70} , at any temperature. With rapidly improving white LED technology and frequent release of improved commercial LED products, the need for much faster life testing has become urgent. Therefore, the goal of the study presented in this paper was to investigate a short duration life-test method that can project the end of useful life of white LEDs.

There are a number of publications that present LED life testing and failure mechanisms [8, 9]. Frequently, electrical and thermal stresses are used in accelerated life testing of phosphor-converted (pc) white LEDs. The degradation of phosphor-converted (pc) white LEDs can result in light output and/or color shift and/or forward voltage increase [8]. The causes of lumen depreciation and catastrophic failure of pc white LEDs usually fall under three categories: semiconductor, interconnect-related, and package-related failures [9]. A few studies have shown voltage increase when the LEDs aged [10–12]. Meneghini et al. discussed the possible causes for optical and electrical parameter degradations at various stress temperatures [12]. In the ASSIST-funded study presented in this paper, it was shown that measurement of the forward voltage increase as a function of time as a life test metric can shorten the time significantly when compared to the commonly used light output depreciation method to predict end of life.

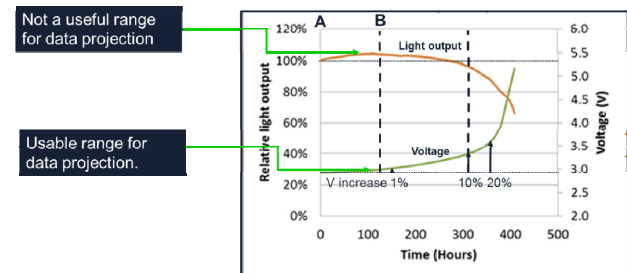


Figure 2. LED light output and forward voltage change as a function of time, when the initial LED pin temperature was at 120°C .

2. A short duration LED life test

Figure 2 illustrates sample data for a commercial high-power white LED under an accelerated test condition. As seen in Figure 2, the LED voltage increases as a function of time when the LED was tested at 120°C T_{pin} . The corresponding light output decrease with time is also illustrated in the same figure. Typically, during an aging test the white LED light output initially increases (see Figure 2, time range A to B) a few percent before it starts to decrease continuously. In the case of voltage, the increase is monotonic from the beginning. In the time range A to B, the measured light output is not suitable for data extrapolation because it would not yield accurate results. However, the measured voltage increase data in the same period is more suitable for extrapolation. Analyzing the voltage data collected at different pin temperatures, we found that the time

for the LED to reach failure was very short once the voltage increase reached 20%. Based on this finding, we can select 20% voltage increase as a criterion for LED end of life. Since the goal of this study was a shorter time duration life-test method, and the time to reach 10% and 20% are correlated, we selected a 10% voltage increase as the criterion for end of life. Preliminary results showed that LED life can be predicted in less than 2000 hours. Furthermore, the measured voltage data are less noisy compared with the light output data. Since the results were preliminary at the time this paper was prepared, the detailed results will be published elsewhere in the near future once the data are completely analyzed. We would like to point out that when life testing LEDs it is important to power cycle the LED since other failure mechanisms exist and in applications LEDs are switched on and off [13].

3. LED systems life testing

LED system life is one of the least understood parameters, especially in application environments. As a result, any lifetime claim for a complete LED lighting system, such as a lamp or luminaire, is a guess. According to current industry standards, an LED system lifetime is defined based on LED lifetime (L70) in hours. The LED used in the luminaire is tested according to IESNA LM80 and the time to reach the 70% value is projected according to IESNA TM21 [14].

Defining the entire system failure as failure of only one component, which has a very long useful life, is incorrect. An LED system has many components, including, the LED or LED array, printed circuit board (PCB), heat sink, mechanical housing, electronic driver, electrical connectors, optics, and others. Failure of any one component can lead to the failure of the entire system. It is widely known that using the L70 value of the LED does not provide accurate information for the lifetime of the complete system. However, the industry still uses this life metric because there is no other industry standard at the present time for testing and quantifying LED system lifetime. In 2011, the United States Department of Energy (US DOE) in partnership with the solid-state lighting (SSL) industry published a general testing guideline for LED luminaire lifetime, reinforcing the concept that a system perspective must be taken when evaluating the lifetime of SSL luminaires [15].

During the past several years, many research groups around the world have been conducting reliability testing of complete LED luminaires. Past studies have shown that the application environment temperature is an important factor that can affect the lifetime of a luminaire. In 2007, the LRC conducted a study in which several LED luminaires were tested under different thermal environments. This study found significantly different lumen depreciation profiles and chromaticity shifts depending on the environmental conditions under which the luminaires were tested. In real-life application conditions, such as open air, non-IC and IC-rated LED downlight luminaires can have vastly different lifetime values. Based on this study, a recommendation for testing LED directional lighting luminaires under actual operating conditions was published in 2007 [16]. Presently, the only way to be sure that an LED luminaire will last at least the stated lifetime is to measure the light output according to the IESNA LM79 standard at the beginning and at the end of the stated lifetime, provided the system is still in working condition.

In reality, this is impractical because it can take years (nearly 3 years for a 25,000-hour lifetime product) to verify this. Therefore, it is clear that the industry needs an accelerated life testing metric that can better predict LED system lifetime accurately. This should be based on entire system testing, not just the evaluation of one or two components.

The electronics industry has several rapid cycle test methods for testing early failures of electronic components. Since an LED is an electronic component, some manufacturers have adopted such tests, as-is or modified. A recent publication reported the findings from a test method termed “Hammer Testing for Solid-State Lighting Luminaires,” prepared by RTI International for US DOE [16]. The “Hammer Test” uses a very high stress environment for the LED luminaires so that it creates failures in a reasonable time period. The intent is to identify potential field failure modes in luminaires [17].

Most of the above mentioned test protocols are meant to be pass/fail tests. For example, LED systems are cycled (power or temperature) for a certain number of cycles (typically 1000 cycles) to a certain upper and lower limit. If the luminaires did not show failure then these luminaires are considered reliable and expected to last the stated lifetime. Even though these test methods help in terms of reducing the uncertainties associated with LED system life, they cannot be used to predict luminaire lifetime at a given ambient condition and use pattern, which is what end users want to know.

Typical use patterns for LED systems in applications are:

- Office lighting: 6am to 6pm (12 hrs on, 12 hrs off)
- Home lighting: 6am to 10am, 6pm to 10pm (4 hrs on, 4 hrs off)

With funding from ASSIST, we have been conducting research projects during the past few years to predict the lifetime of LED integral lamps at any given environment temperature and system use (on-off) pattern [18].

LED system failures can be parametric (lumen depreciation) or catastrophic (complete failure). Generally, continuous testing of LED systems yields lumen depreciation results. However, to catch catastrophic failures the life testing must include on-off cycling. One of the main reasons why lamps fail when temperature is cycled is because the thermal expansion coefficients of the components in the system are different and they strain the interfaces between the components, leading to breakage.

It is common in the industry to either rapidly cycle the temperature of the products or test them at elevated temperatures with cycling to induce failure. We have found that rapid cycle testing of LED products failed to accurately predict system lifetime, based on catastrophic failure. Figure 3 illustrates temperature variation data for several LED lamps. In this case, the lamps were cycled at the rate of 2 minutes on and 2 minutes off. As seen in Figure 3, the delta temperature between the maximum and minimum during cycling was less than 8 degrees. Since the components do not see a large temperature variation, they do not experience large strain values to fail.

As explained earlier, LED systems in application are cycled at much longer on-off cycles. To study the failure patterns and to

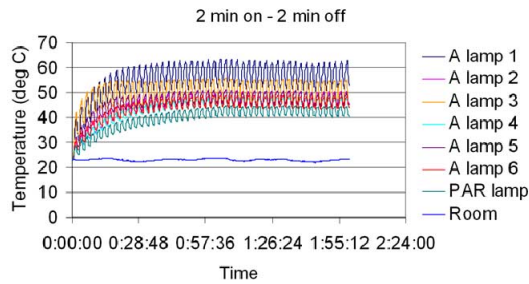


Figure 3. Temperature variation experience by LED lamps when cycled rapidly, 2 minutes on and 2 minutes off.

understand the failure modes of commercial A-lamps, a life test was conducted with power cycling. In this study, commercial LED A-lamps were used. The sample size was five lamps at each condition. The power cycling profile of the LED lamp life testing is shown in Figure 4. In this study, the two experiment variables were delta T and dwell time.

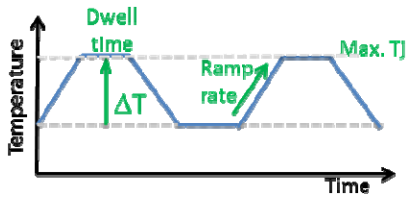


Figure 4. LED system power cycling pattern

The study included two types of integral lamps, namely, 40W equivalent 6W G25 LED lamps and 60W equivalent 10W LED A-lamps.

For the selected 6W LED product, cycling without dwell time did not show any lumen degradation or failure. Furthermore, at 70°C delta T for all dwell times, cycling with dwell time did not show any lumen degradation or failure. But at 90°C delta T for all dwell times there weren't any catastrophic failures but they showed lumen depreciation. Figure 5 shows sample lumen output data as a function of time.

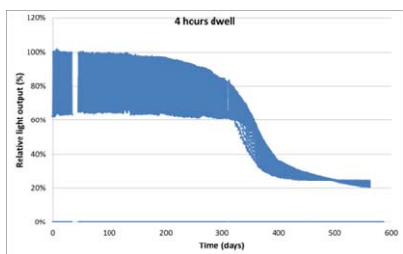


Figure 5. Lumen depreciation profile for the LED lamps cycled at 90°C delta T with a 4-hour dwell time.

Analyzing these aged samples showed multiple failure modes that resulted in lower light output, including electrical parameter changes due to aged components within the driver and greater light absorption caused by age-related color changes within the package. About 40% light loss was due to electrical parameter change and 13% light loss was due to optical changes.

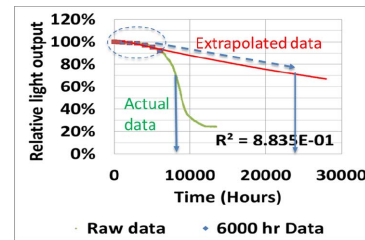


Figure 6. Relative light output data for a 6W G25 LED lamp.

A lesson learned from this study was that extrapolating lumen depreciation data gathered up to 6,000 hours and extrapolating to determine L70 value may lead to erroneous results as shown in Figure 6. The projected life is 25,000 hours but continuing the test beyond 6,000 hours showed the actual life is only 8,000 hours. Therefore, in the case of LED systems, testing for 6,000 hours and extrapolating lumen depreciation data to determine L70 is not suitable due to multiple failure modes in a system.

Next, for the selected 10W LED A-lamp power cycling life test, the objective was to understand the effect of different delta temperatures and dwell times on failure time. There were four delta T cases including 90°C, 80°C, 70°C, 60°C. The delta T temperature upper limit was selected based on the maximum and minimum temperature the LED system experienced when installed in a three-lamp surface mount light fixture. The dwell times selected to test were 1, 2, 3, 4, and 7 hours. In this study, the lamps failed catastrophically and showed faster failure with increasing delta T. Analyzing failed samples showed that the failure was due to solder joint failure. The solder attaching the LED to the electronic board failed and resulted in open circuit failure in most cases.

The results did not show strong evidence for dwell time affecting time-to-failure except in the case of 90°C, where time-to-failure decreased when dwell time increased from 1 to 3 hours and then time-to-failure increased when dwell time increased from 3 to 7 hours.

Data analysis showed that the time to failure correlated well with the time averaged temperature experienced by the lamps, as shown in Figure 7.

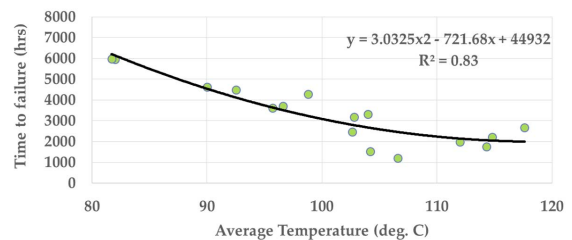


Figure 7. Time to failure versus time averaged temperature for the 10W LED A-lamp.

An additional LED system life study using LED MR16 products further showed evidence for cycled power resulting in product failure while continuous-on showed no failure, Figure 8 makes the case for cycled power in LED system life testing.

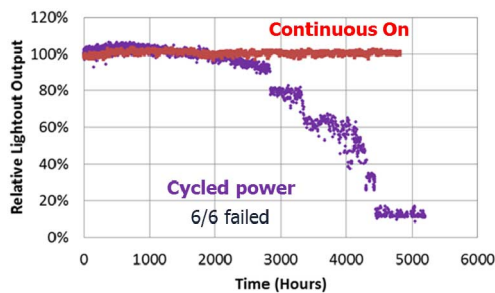


Figure 8. LED system life, continuous-on and cycled power.

4. Discussion

LED system failures can be parametric (lumen depreciation) or catastrophic (complete failure). Generally, continuous testing of LED systems yields lumen depreciation results. However, for catastrophic failures to show the life testing must include on-off power cycling. Very fast cycling may not show failure due to insufficient stress on the components. When life testing LED systems, lumen depreciation can be due to several factors including electrical and optical. Therefore, a simple function extrapolation to determine L70 values for systems may lead to erroneous results.

Failure acceleration using delta T and dwell time is a promising method to predict LED system life under different operating conditions. To the best of our knowledge, this is the first accelerated life testing study that has shown promise in predicting LED system lifetime at different operating conditions.

However, more products need to be tested to validate this test procedure. With funding from the Bonneville Power Administration (BPA), the New York State Energy Research and Development Authority (NYSERDA), and the Alliance for Solid-State Illumination Systems and Technologies (ASSIST), a new LED system life test with multiple LED system types is under way to further validate the test procedure. The final results will be available towards the end of 2016. The intent of this project is to develop a short duration life test for LED systems.

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