HOW IS THE OPERATIONAL FAILURE OF LED FIXTURES IDENTIFIED?

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INTRODUCTION

Selecting the most effective light source or lighting system for a given application requires the comparison of a number of figures of merit for the options under evaluation. One of the most important characteristics to consider is the useful lifetime of the lighting system. For aviation lighting, knowing the expected useful life of airfield luminaires allows designers, airport owners, administrators, and operators to make informed decisions that impact initial and operational costs, maintenance programs, and overall service reliability. LED-based solutions have become more prevalent in airport systems because of their potential to aid pilots' visibility and the impressive improvements that this technology has seen in the last few years, including energy efficiency and their potential for long life [1,2]. While the rated life of commercially available LED systems, usually between several to tens of thousands of hours, is much longer in comparison to the incandescent lamp-based products they are replacing, there is no clear definition of an airfield's luminaire life. Additionally, because of the recent history of LEDs in the market, there is no sufficient field information to fully validate the long-life claims of such products. Funded by the Federal Aviation Administration (FAA) and the Alliance for Solid-State Illumination Systems and Technologies (ASSIST), researchers at the Lighting Research Center (LRC) conducted a laboratory study to understand the long-term performance of LED systems as a starting point to develop a functional definition of useful lifetime for airfield luminaires. To complement this body of research, LRC researchers are working presently on the development of an accelerated test method to project catastrophic failure of LED systems.

BACKGROUND

LED-based lighting systems offer multiple potential benefits to airport operations, from improved pilot visibility to energy efficiency and reduced maintenance costs. However, designers, airport owners and operators need to know the useful lifetime of airfield luminaires in order to make informed decisions when evaluating alternative options and to establish maintenance programs. To date, there is no agreed-upon definition of what constitutes the useful lifetime of airfield luminaires. In principle, one such definition could be based on the operating time until a given fixture type falls out of specifications. Because airfield luminaries are used to provide visual guidance under many different visual and field conditions, the light fixture would be considered useful only if it can provide at all times all of the required photometric characteristics for which it was designed. These characteristics include the intensity distribution and the color of the light. In combination, these photometric characteristics could be used as the starting point to define the useful lifetime of airfield luminaires.

Understanding the long-term performance of airfield LED luminaires under realistic conditions is the first step of an effort to establish a functional definition of useful LED luminaire life. Unlike incandescent lamps, which mostly fail catastrophically (i.e., a filament breaks), LED systems when operated under nominal conditions tend to suffer more from parametric changes rather than catastrophic failures, but both failures can occur depending on how a system is integrated and the specific conditions under which the system is being used. It is important to emphasize that LEDs are but one of the many components in the lighting system, and the long-term reliability of the system depends on all of these parts providing the desired functionality, including the optical, thermal, and electrical, which can also suffer both parametric or

catastrophic failures. For the LED package, light output depreciation and color shift are the two most common parametric changes that occur as a function of time and operating conditions (i.e., the electrical current and the temperature of the junction, and on-off cycling patterns). These two parameters have a direct impact on the functionality of the fixtures in their intended applications. For most applications, it is reasonable to expect that at some point the light output depreciation (or color shift) from the system will have reached a threshold for which the minimum target criteria are no longer met, thus rendering the lighting system out of specification and no longer useful. In response to the typical parametric changes in LEDs, the lighting industry has adopted a useful lifetime definition for LEDs on the basis of light output and color shift [3]. For general illumination, the industry reference is a 70 percent light output maintenance (denoted as L70), which is the point at which the light output has depreciated by 30 percent from when it was a new system. Thus, LED manufacturers rate the life of the products as the time in hours until the light output has reached the L70 criterion for a given temperature of operation. The Illuminating Engineering Society of North America formalized the tests required to measure the relative light output of LED products as a function of time for three operating temperatures in what is now known colloquially as the LM-80 test [3,4]. These temperatures are meant to represent a wide range of conditions that would be found in typical applications. By applying mathematical models, it is expected that the lumen maintenance at other temperatures within the range tested could be derived [5]. It is worth mentioning that this approach was developed for LED packages alone with the intention that the resulting information would be used by LED fixture manufacturers in developing their products and then in turn measure their complete systems under conditions representative of intended application by following a similar procedure [3]. However, the lighting industry has often used the results from LM-80 tests (that is for the LED packages only) to indicate the useful lifetime of luminaires, even when it is not reasonable to expect the same results because of system integration differences, the environmental conditions of the application, and on-off cycling patterns.

TOWARD A DEFINITION OF USEFUL LIFETIME OF AIRFIELD LUMINAIRES

As mentioned in the previous section, the photometric characteristics of airfield luminaires could be used as the starting point to define their useful lifetime. Airfield luminaires are designed to provide specific visual information to pilots in terms of intensity at different viewing angles and the color of the light. Thus, the useful lifetime of airfield luminaires could be defined as the time in hours of operation until the amount of light or its color have fallen out of specification, when operated under conditions representative of realistic conditions.

Long-term photometric performance of LED based airfield luminaires

To learn more about these issues, LRC researchers began in 2011 a long-term study to measure the light output depreciation and color shift of a limited number of in-ground luminaires as a function of operating temperature. The samples under test included three red/white directional runway centerline fixtures (type L-850A) and three white touchdown zone fixtures (type L-850B). The samples were under continuous operation for over 10,000 hours during the period from October of 2011 to January of 2013 [6,7]. The test was designed to monitor the relative changes in light output and color of the light as a function of time and operating temperature. Three LED pin temperatures (nominally 55°C, 80°C, and 100°C) were selected to

represent a wide range of application environments and to loosely match the conditions of LM-80 tests for LEDs [3,4].

The results of the test showed that three of the samples failed catastrophically because of problems with the electronic circuits and not the LEDs. The failures occurred at 560 hours (100°C condition) and 3360 hours (80°C condition) for two of the L-850B samples, and at 7630 hours (100°C condition) for one of the L-850A samples. In all likelihood, the failure was due to the electrolytic capacitors at the output of the circuit [8,9]. Of the three samples that were under test for the duration of the study, one (L-850B, 55°C) showed minimal (~6%) light output depreciation while the white side of the other two (L-850A at 59°C and 80°C) reached 30% light output depreciation at approximately 9000 hours of operation. The red side of the L-850A sample operating at 80°C also showed a 30% reduction in light output at approximately 9000 hours, and it was estimated from the measurements that the red side of the L-850A operating at 59°C would reach the 30% depreciation mark within 14,000 hours of operation. All of the tested samples showed color shift from the white light side and in all cases the color shift was in the "yellow" direction. This type of color shift is typically associated with LED primary optic or encapsulant degradation due to high temperature. While the samples at the 80°C and 100°C test conditions showed much more color shift, even the samples at the lowest temperature (~59°C) also showed noticeable color shift. More importantly, in all cases the color shift was sufficiently large to bring each of the test samples to a chromaticity outside of the present FAA white color boundary specifications [10].

Development of an accelerated test method for estimating LED system life

It is important to note that the light output depreciation and color shift of a luminaire do not depend only on the LED and can result from degradation in the secondary optics, reflectors or diffusers, and changes in the electrical parameters from the electronic circuits that typically are needed to control LED current. For this reason, it is important to test luminaires as a system. Additionally, LRC research has shown that power cycling (i.e., on-off cycling) introduces failures that are usually not present during continuous-on operation. It is worth noting that while there are several rapid cycle test methods for failure testing of electronic devices, these tests often result in differences in operating temperatures (temperature when the device is on minus the temperature when the device is off) that are too small to cause sufficient damage due to cycling. Moreover, these tests are primarily used to identify early failures in a usually small number of cycles, for example 1000 on-off operations. With this in mind, LRC researchers have been working on the development of an accelerated test method to predict LED system failure based on operating conditions, including temperature of operation and power cycling. Different studies have been conducted under this effort, and in all cases LED lamps designed to replace A19 incandescent lamps have been used because these lamps have, in a reduced volume, all the components that would be included in a larger luminaire (e.g., secondary optics, reflector, electronic driver).

During initial tests, it was determined that the main accelerating parameters included the maximum operating temperature of the LED junction (max Tj), the difference in temperature between the on condition and the off condition (delta T), the speed at which the temperature rises from the off condition to the maximum temperature (ramp rate), and for how long the maximum

temperature is maintained during each cycle (dwell time). Figure 1 shows these parameters graphically. For the studies conducted, maximum and delta temperatures and dwell times corresponding to conditions found in residential or commercial applications were determined in advance so that the results could be meaningfully related to realistic patterns of use.

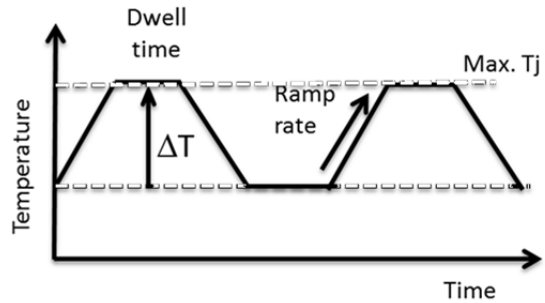

Figure 1. Accelerating parameters in the LED test method under development by the Lighting Research Center.

In one of the studies, after over 14,000 hours of testing, the LRC found that power cycling without sufficient dwell time resulted in no failures (catastrophic or light output depreciation) for a delta temperature of 70°C but resulted in light output depreciation for the condition with a delta temperature of 95°C. Two important observations were made from this study. The first confirmed that the light output depreciation rate correlated well with the time average LED operating temperature. The second observation was that the light output depreciation was primarily due to electrical changes in the LED driving circuitry. From these observations it can be concluded that estimating system life by extrapolating the data measured for the LED packages during an LM-80 test, which typically lasts 6000 hours, can lead to misleading expectations because those data do not account for the additional light output losses due to electrical changes in the driving circuits and optical degradation of reflectors or secondary optics.

A follow-up study was designed to test the effect of different delta temperatures and dwell times on the failure rate. Using similar LED-based replacement lamps, the LRC found that increasing the delta temperature from 60°C to 90°C resulted in a shorter time to failure (measured in hours of on time). For the test condition with the highest delta temperature (95°C), preliminary results show a good correlation between increasing dwell times and longer time to failure (measured in hours of on time). As in the first study, the time average LED operating temperature was found to have a good correlation with time to failure, but in this case the dominant mode was solder joint failure. Other conditions are under test and final results will be reported as they become available. Finally, a continuation of the long-term photometric performance test of LED-based airfield luminaires was started in late 2013 using power-cycling conditions. That study is also ongoing and results will be reported as they become available.

CONCLUSIONS

A definition of useful lifetime for airfield LED luminaires is needed so that informed decisions can be made with respect to selection and maintenance of lighting equipment. A definition that incorporates both parametric and catastrophic failures and takes into account the operating conditions of complete systems under realistic conditions would provide meaningful

information. This paper presents the findings of research supporting the development of such a definition. Importantly, in addition to a definition of useful life and test methods to estimate it, field evaluation methods may need to be developed to monitor and determine when airfield luminaires no longer meet the required photometric criteria.

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