An accelerated test method for estimating LED system life

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Background

- Why LED system life?
  - How often to change the light bulb
  - Life cycle cost analysis

- Users buying a lighting system expects it to perform and last the same in all applications
Background

- **LED system life**
  - Presently, LED lighting product life is rated based on LED lumen maintenance (LM80/TM21)

- **A lighting system has many components**
  - Failure of any component can cause system failure

- **Therefore, whole system has be tested to obtain reasonable life estimate**
Background

- **IESNA LM84-14 standard:**
  - First attempt towards developing a system life test method
  - Test method is based on continuous operation.

- **In applications the lighting systems are turned on and off**
  - Typical use pattern:
    - A - Office: 12 hrs on, 12 hrs off
    - B - Home: 4 hrs on, 4 hrs off
Background

- Power cycling can cause component/system failure
  - Dynamic stress
  - LRC study (2013 – 2014)
    - COB LEDs
  - Testing conditions:
    - 700 mA; Tj = 150°C; Continuous vs. cycling (4 hours on, 2 hours off)
  - Results:
    - Catastrophic failures were only discovered in cycling test

<table>
<thead>
<tr>
<th>Product No.</th>
<th>Catastrophic failure (cycling test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4 out of 5</td>
</tr>
<tr>
<td>C</td>
<td>4 out of 5</td>
</tr>
</tbody>
</table>
Background

- The electronic industry has several rapid cycle test methods for failure testing
  - Example:
    - IEC 60068-2-14
    - Strife

- Some manufacturers have adopted similar methods for LED reliability testing
  - Test for 1000 cycles
  - Usually a pass/fail test (helps to identify early failures)

IEC 60068-2-14 Method

Strife method

STRIFE method is the most destructive among test method.
Study Objective

- None of the test procedures presently available are designed to project system life based on the environment temperature and the use pattern (on-off).

- Objective - To develop an accelerated test method that can predict failure of LED system based on factors such as:
  - Environment temperature (Tpin)
  - On-off cycling.
Initial studies

- To determine $T_{pin}$ of the LED lamp when placed inside a luminaire
  - 40W replacement lamps
    - Max $T_{pin} = 98^\circ C$; Delta $T = 75^\circ C$
  - 60W replacement lamps
    - Max $T_{pin} = 118^\circ C$; Delta $T = 95^\circ C$
    - $T_j \sim 20^\circ C$ higher than $T_{pin}$

- LRC preliminary studies identified the following acceleration parameters:
  - $\Delta T$, Max. $T_j$, Ramp rate, Dwell time
Failure Testing

- Some standards have very fast cycling of LED products to test for failures.
  - Very small delta T
  - May not cause damage

- Generally there are two types of failures:
  - Parametric
    - Lumen depreciation or color shift
  - Catastrophic
    - Ceases to produce light
Study 1

- **Objective:** To understand failure modes and their relationship to test parameters:
  - Delta T (70, 95 C);
  - Dwell time = 1 to 9 hrs

- **Over 14,000 hours of test time**

- **Results:**
  - Cycling without dwell time did not show any degradation or failure
  - Delta 70, no failure
    - catastrophic or lumen depreciation
  - Delta 95, no catastrophic failure but lumen depreciation

System tested
G25 LED lamp
(40W incandescent replacement)
Results: Delta 95°C study

Light output pattern
Results: Delta 95°C study

- No catastrophic failures but lumen depreciation was observed
- Failure assumption:
  - 70% light level
- Cycles to failure
  - Correlated well with
    - time averaged temperature

Multiple degradation mechanisms

- Slope 1 = -0.05%/day
- Slope 2 = -0.52%/day
- Slope 3 = -0.13%/day

Cycles to failure vs. time averaged temperature

\[ y = -4949 \ln(x) + 23035 \]
\[ R^2 = 0.9549 \]
Analysis

- Lumen depreciation was due to electrical and optical degradations
  - 40% light loss due to electrical
  - 13% light loss due to optical

<table>
<thead>
<tr>
<th></th>
<th>New sample</th>
<th>D95 Aged sample</th>
<th>D95 aged sample with original current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current (mA)</td>
<td>193</td>
<td>117</td>
<td>193</td>
</tr>
<tr>
<td>Light output</td>
<td>100%</td>
<td>47%</td>
<td>87%</td>
</tr>
</tbody>
</table>

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Data Extrapolation

- Extrapolating the 6000 hr data can lead to erroneous results
  - Projected life = 25,000 hrs
  - Actual life = 8,000 hrs
Study 1 Summary

- For the selected product (40W incandescent G25 replacement)
  - Cycling without dwell time did not show any degradation or failure
  - Cycling with dwell time showed no catastrophic failure, but showed lumen depreciation due to multiple failure modes
    - Electrical / Optical (Electrical degradation much greater than optical)
  - Cycles to failure correlated well with time-averaged T
  - Need to be careful when extrapolating system data
    - multiple degradation mechanisms
STUDY 2
Study 2

- **Objective:** To understand the effect of different delta temperate and dwell times on failure time
  - Lamp used: A 60W equivalent LED lamp

<table>
<thead>
<tr>
<th>ΔT</th>
<th>60°C</th>
<th>70°C</th>
<th>80°C</th>
<th>90°C</th>
</tr>
</thead>
</table>

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Study 2 Results

- For the system tested
  - Delta temperature increase results in shorter TTF
    - Catastrophic failure
  - Dwell time increase
    - Results in longer time to failure at delta T 95 C
    - Data is still being collected at other delta T temperatures
Results

- For the system tested, time to failure has a good correlation with time averaged temperature.
  - Dominant failure mode: Solder joint failure

![Graph showing the correlation between time to failure and average temperature](image.png)

\[ y = 3.0325x^2 - 721.68x + 44932 \]

\[ R^2 = 0.83 \]
Study 2 - Summary

- Failure acceleration to predict system life
  - Higher Delta T, shorter time to failure
  - Dwell time also influences time to failure

- For the system tested, time to failure has a good correlation with time averaged temperature
Final Remarks

- Failures can be parametric (lumen depreciation) or catastrophic (complete failure)

- Life testing of LED systems must include on-off cycling
  - Very fast cycling may not show failure
    - Not a suitable test for stressing system

- Over accelerated life testing may result in additional failure modes

- In an LED system lumen depreciation can be due to several factors (Electrical and optical)
  - Simple function extrapolation for systems may lead to erroneous results

- Failure acceleration using delta T and dwell time is showing promise in predicting the failure of LED systems under different operating conditions
  - Time average temperature correlates well with time to failure
  - However, more products need to be tested to validate test procedure
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