PERFORMANCE EVALUATION OF LED LAMP UNDER PULSE CURRENT MODE OPERATION

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Abstract:

There are measurement challenges in measuring the lumens output of LED lamps under pulse current mode operation to evaluate the performance of LED lamps. This paper describes and validates integrating sphere measurements for lumens flux of LED lamp under pulse current mode operation. It also evaluates the performance of LED lamp dimming operation using pulse current mode operation

Keywords: LED, Lamps; Integrating Sphere; Lumens; Junction temperature; Pulse power; LED dimming

1. INTRODUCTION

The technological development over the years in the Solid State Lightings (SSL) has made the Light Emitting Diode (LED) lamps to replace other lamps such as incandescent, florescent and compact florescent lamps (CFL) in the lighting applications due to its better efficiency and life. The LED lamps are based on semiconductor technology with P-N junction. Like any semiconductor device LED lamps performance depends on electrical and thermal parameters. The LEDs are current operated device and hence its light output is largely dependent on the current flows through the LED [1]. The P-N junction temperature of the LED also influence the light output significantly. The increase in junction temperature causes significant reduction in light output. The integrated sphere systems are used for measuring the total luminous flux and integrated optical measurements of SSL lamps. In integrated sphere system, the spectroradiometer detector is used for measuring photometric quantities such as total luminous flux, colour correlation temperature (CCT), chromaticity, etc. The total luminous flux (Φ_V) is obtained by

$$\Phi_V = K_m \int_{360nm}^{830nm} \Phi_e(\lambda).V(\lambda).d\lambda \quad (1)$$

where K_m = 683 lm/w, $\Phi_e(\lambda)$ is spectral radiant power and $V(\lambda)$ is spectral response function of the human eye [2]. In most of the home lighting application, a constant rated current is sent through the LEDs using power drivers. In applications where the dimming of light is required, the reduced constant current is sent through the LEDs and in automotive lighting applications dimming is achieved using pulse width modulation (PWM) of rated current [3]. At higher operating power, the LEDs exhibits excellent optical properties but also increases the junction temperature which degrades the optical performance [4]. The combined accurate measurements of junction temperature, electrical and the photometric parameters are essential for optimal design of LED derivers and to evaluate the performance of the LED lamps. The photometric, electrical and thermal characteristic of LED lamps are highly depends on one another.

An integrating sphere is used to spatially integrate the light and produce diffuse radiation to average the radiation emitted into the sphere, resulting in equal radiance at any point on the sphere wall. The distribution of radiance inside an integrating sphere would depend on the distribution of incident flux, the geometrical details of the actual sphere design, and the reflectance distribution function for the sphere coating in the integrating sphere. The integrating sphere is most often used in the steady state condition, i.e operating the LED lamps in constant direct current. The performance and application assumes that the light levels within the sphere have been constant for a long enough time so that all transient response has disappeared. If rapidly varying light signals, such as short pulses or those modulated at high (radio) frequencies, are introduced into an integrating sphere, the output signal may be noticeably distorted by the "pulse stretching" caused by the multiple diffuse reflections [5]. Hence there is a need for validating the integrating sphere measurement for the pulse current operation of LED lamps. The LEDs are getting heated up mainly by operating drive current during the operation. This heat comes from the recombination of electrons and holes in the semiconductor lattice. Ideally, the recombination results in a photon that exits the LED and contributes to the overall illumination. Unfortunately, much of the time that desired outcome does not occur. For example, sometimes the recombination results in a photon, but it fails to escape from the crystal due to internal reflection and is reabsorbed, generating a tiny amount of heat; and at other times a phonon (a quantum of energy analogous to a photon) results from the recombination leading to a vibration of the crystal lattice and yet more heat [6]. As the lumens flux and chromaticity (colour) of LED lamps are highly sensitivity to P-N junction temperature of the LED and just a few tens of degrees is enough to change the output spectrum, altering the chromaticity and hence the accurate real time measurement of junction temperature is essential for analysing the performance of LED lamps. Different methods are attempted to measure the junction temperature accurately. The forward LED voltage is measured at very low LED current to estimate the junction temperature [7]. Operating the LED at very low current during the measurement lead to flickering and in-situ temperature sensor are fabricated in the LED package to measure the junction temperature accurately without causing any flickering during normal LED operation [8]. In this work, we have measured the junction temperature of the LED without altering the operating conditions of the LED.

The research are done over the years to measure and evaluate the performance of different lighting systems. The measurement method using Integrating sphere and spectroradiometer is used to compare and analyze the performance of LED and CFL lamp technologies [9]. The thermal, optical and electrical characteristic of LED lamp under DC and pulse current are studied to evaluate the performance degradation of high brightness LEDs [10]. The simultaneous study of thermal and optical behaviors of LED are studied using integrating sphere and with attached temperature controlled holder [11], [12]. In this paper, thermal, optical and electrical parameters are measured to evaluate the performance of LED lamp under DC and pulse current operation.

2. MEASUREMENT CHARACTERISTICS

2.1. Integrating Chamber For Pulse Luminous Flux Measurement

The total luminous flux of LED is directly proportional to the LED forward current under constant temperature and can be expressed as

$$\Phi_V = kI \tag{2}$$

where Φ_V is the total luminous flux, k is the constant and I is the DC current through the LED.

If the pulse forward current with duty cycle (D) is send through the LED then the average current can be written as

$$I_{av} = \frac{1}{T}\int_0^{DT} I_p \, dt = I_p D \tag{3}$$

where I_p is the peak value of the LED current and $\frac{1}{T}$ is the frequency of the pulse waveform.

Average total luminous flux can be written as

$$\Phi_{Vav} = \frac{1}{T}\int_0^{DT} \Phi_{Vp} \, dt = \Phi_{Vp} D \tag{4}$$

where Φ_{Vp} is the peak total luminous flux of the LED.

Normally, the total luminous flux of the LED is measured with integrating chamber at the continuous current mode i.e 100% duty cycle. Here we validated the total luminous flux measurement of the LED at different duty cycle.

2.2. Junction Temperature Measurement

The junction temperature of LED is measured by placing the white LED in the environmental chamber at different temperature steps. The LED is energized with the constant current (normal operating current) pulse for the short duration of few milliseconds. The resulting forward voltage is measured for each temperature steps. The relationship between environmental chamber temperature and the forward voltage of LED is obtained during this calibration measurement. The junction temperature of the LED is obtained by measuring the forward voltage of LED during normal operation.

2.3. Pulse Power Measurement

The average power P_{av} can be measuring the pulse current and the forward voltage and it is expressed as

$$P_{av} = \frac{1}{T}\int_0^{DT} I_p x V_f \, dt = I_p V_f D \tag{5}$$

where I_p is the peak LED current and V_f is the LED forward voltage

3. EXPERIMENTAL VALIDATION

In order to validate the pulse luminous flux measurement a prototype measurement system is fabricated as detailed below

3.1. Control system for pulse operation

The electrical measurement and control setup for pulse operation of LED is indicated in the schematic diagram shown in Figure1. The luminous flux generated by the LED is directly proportional to the LED forward under constant temperature. In the pulse current operation, the LED peak forward

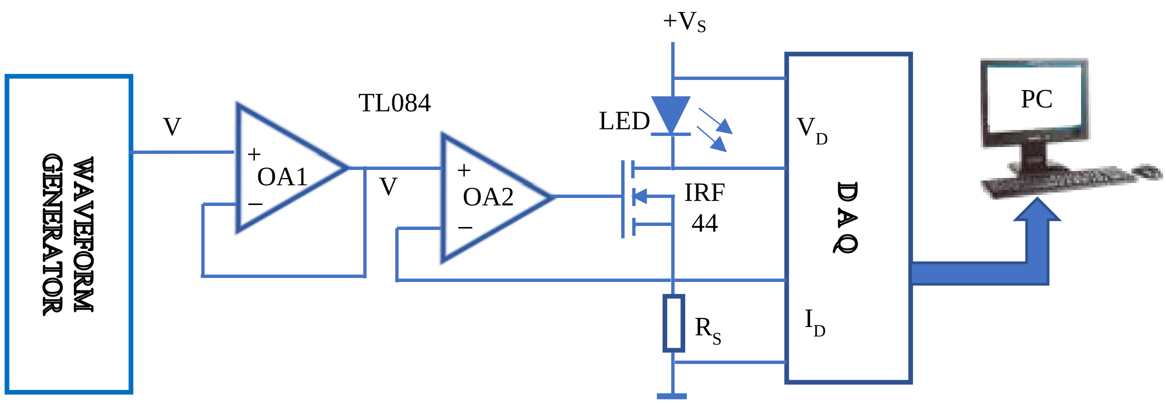

Figure 1: Block diagram of measurement setup for pulse operation of LED

current is kept constant and the average LED forward current is altered by varying the duty cycle of LED forward current. The average total luminous flux is directly proportional to the average LED forward current. Here, the waveform generator is used to generate the different duty cycle of a pulse waveform. The operational amplifier OA1 act as the buffer. The operational amplifier OA2 with the MOSFET IRF44 configuration act as the current controller. The amplitude of the pulse waveform set the peak LED forward current and it will be equal to $\frac{V}{R_S}$. The data acquisition system (DAQ) will capture the LED current and voltage data and connected to PC through USB cable. The illustration of the LED operation under pulse current mode is shown in Figure 2.

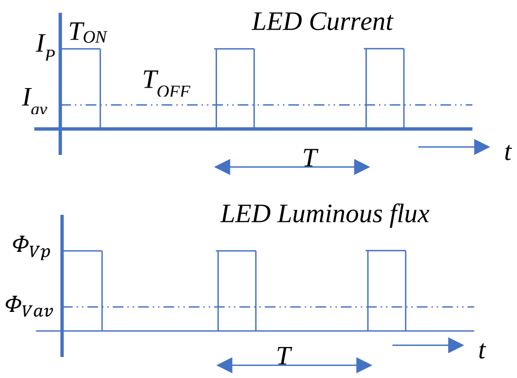

Figure 2: Illustration of LED luminous flux under pulse current with 25% duty cycle

3.2. Integrating Sphere Measurement

The LED is placed inside the Labsphere 2m integrating sphere and operated under pulse current mode as well as continuous current mode operation. The Labsphere spectral light measurement system (spectroradiometer) CDS 2100 is used for measuring the total luminous flux and spectral characteristic for the validation. The spectral light measurement system with the integrating sphere was calibrated with the NIST traceable reference tungsten lamp. The integrating sphere used for the measurement is shown in Figure 3. The waveform generator Tektronix AFG1022 and DAQ Agilent 34970A is used for electrical measurement. The circuit shown in Fig.1 is fabricated and used for the experimentation.

Figure 3: Labsphere 2m integrating sphere used for the measurement

3.3. Experimentation

The experiment is conducted with connecting eighteen high power white LEDs in series for continuous and pulse current mode operation. The total luminous flus (lumens) measured for the continuous operation and pulse mode operation of LEDs is tabulated in Table 1.

Table 1: Validation of pulse current mode

Continuous Current mode		Pulse Current mode (I_P=1500mA)		Error in %
Current	**Lumens**	**Average Current**	**Lumens**	
250mA	2.31E+03	250mA	2.46E+03	-6.41
500mA	3.90E+03	500mA	4.10E+03	-5.13
750mA	6.14E+03	750mA	5.83E+03	5.16
1000mA	7.78E+03	1000mA	7.51E+03	3,36
1250mA	9.21E+03	1250mA	9.04E+03	1.81

The lumen output of the LED under pulse current is compared with the calibrated lumen output of LED under normal (continuous current) operation. The error in % is calculated using the equation (6).

$$e\% = \frac{\Phi_V - \Phi_{Vav}}{\Phi_V} x100 \quad (7)$$

It was found that the increase error at lower duty cycle under pulse mode operation is due to difference in the operating temperature of LED. Further experiment planned with operating the LED with constant junction temperature and will be reported in the extended version of this paper.

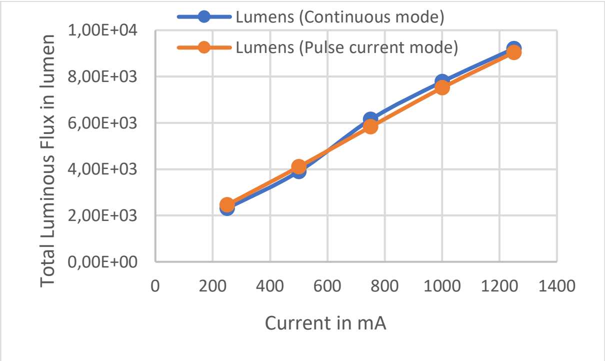

Figure 4: Lumens versus forward current

The Figure 4 shows the linear variation of lumen output for the pulse current mode operation of LED and hence the brightness control of LED will have linear relationship with the duty cycle of the pulse current.

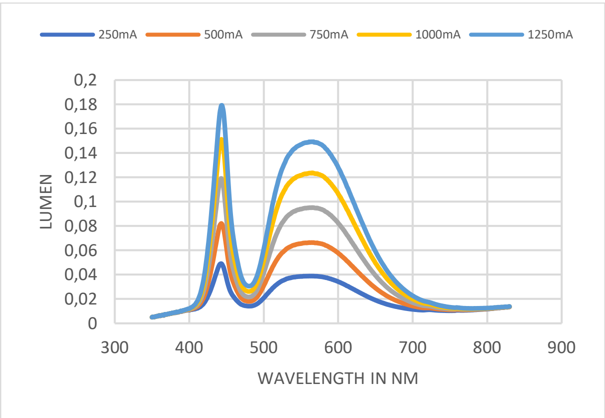

Figure 5: Spectral characteristic under pulse current

The Figure 5 shows the spectral characteristic of the high bright LED under pulse current operation. The variation in spectral characteristic of high bright LED under influence of junction temperature is being studied and will be reported in the extended version of the paper.

4. CONCLUSION

The lumen output of high power LED is analysed under different duty cycle of the pulse current and the measurement indicate the linear variation of lumen output with the duty cycle. The lumen output with the pulse current operation is compared with the standard calibrated continuous current operation of the LED and found with the maximum error of 6.5%.

5. REFERENCES

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