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Balanced Light Output (BLO),method and circuit for maintaining constant light output for LED luminaires.

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I. Introduction

For LED luminaires, it is difficult to accurately predict the lifetime or the light output degradation due to the diversity of LED technologies and the particular contribution of the system's components to this process such as lens, driver, heatsink, etc..The life of a LED luminaire is the combined effect of gradual light output degradation caused by material degradation and abrupt light output degradation mostly caused by LED components failure.There are a set of standards defining how LED luminaires can be tested to determine their performance over time such as:

- LM-84-14 and TM-28-14
- IEC 62772 luminaire performance

According to IEC 62722-2-1, the LED luminaires using modules in conformity to IEC 62717 definition, may be declared the lumen maintenance value for the module as the maintenance value of the luminaire.Basically IEC 62722 tolerate replacing LED luminaire lumen maintenance with LED emitting surface as long such a data is available.Most of the LED lighting system manufacturers are declaring luminaire lifetime based on thisacceptance despite the complexity of this matter. The latest generation of LED drivers are managing this problem by employing aConstant Light Output (CLO)operation. This CLO feature,increase the forward currentat specific time rate, disregarding overall luminaire performance. Ultimately based on a prediction supposedly applying to any LED technology and luminaire configuration.Unfortunately regardless of the CLO type procedure the method do not compensate real light output degradation of the luminaire even for same type of LEDs otherwise even the constant light output may not be achieved. In reality there are many factors which requires a different algorithm in terms of time rate and forward current values as to maintain a genuine constant light output.

Balanced Light Output (BLO)

To include all combined effects in aCLO operation should require a different procedure otherwise may not be any longer of a preset stepping type. Such a dynamic BalancedLight Output (BLO) method is maintaining the luminous flux over the lifetime of the LED luminaire, considering the real luminaire global light degradation instead of LED projected life.The process starts by establishing a reference, respectively an equivalent value number allocated to the initial luminous flux, may also be called a preset flux, together with an equivalent value number of the light transmission through the diffuser or the optical system (transparency or transmittance) as measured by a sensor. Therefore the reference is a numerical value that is in a mathematical relation to the metrological value of these characteristics. Ultimately these reference values of transmittance and luminous flux areused through a mathematical processto determine the overall level of light degradation of the apparatus. The photometric performance, respectively, the maintenance of the luminous flux over the operating time, is analyzed in relation to the reference values in real time.Finally, the result control the LED's supply current, trough the dimming feature of the power supply, in order to balance the difference in respect to the overall initial light output performance.

Light degradation process

Decreasing the light output of a luminaire during operation is mainly caused by depreciation of the light source, the diminution of light transmission through the transparent screen (otherwise diffuser), the reduction of the power of the power supply and the ambient temperature conditions. Short term light depreciation is mainly caused by LED's reaching the thermal balance (Fig.1). Since the forward voltage varies with temperature, the output power delivered to LEDs is decreasing toward balance and may be observed if record the input power variation of the LED luminaire. Practically, a well-designed luminaire,has a very low variation (perhaps 2-3% is acceptable), as aright balance between total LED‘s power and the heatsink size/shape.

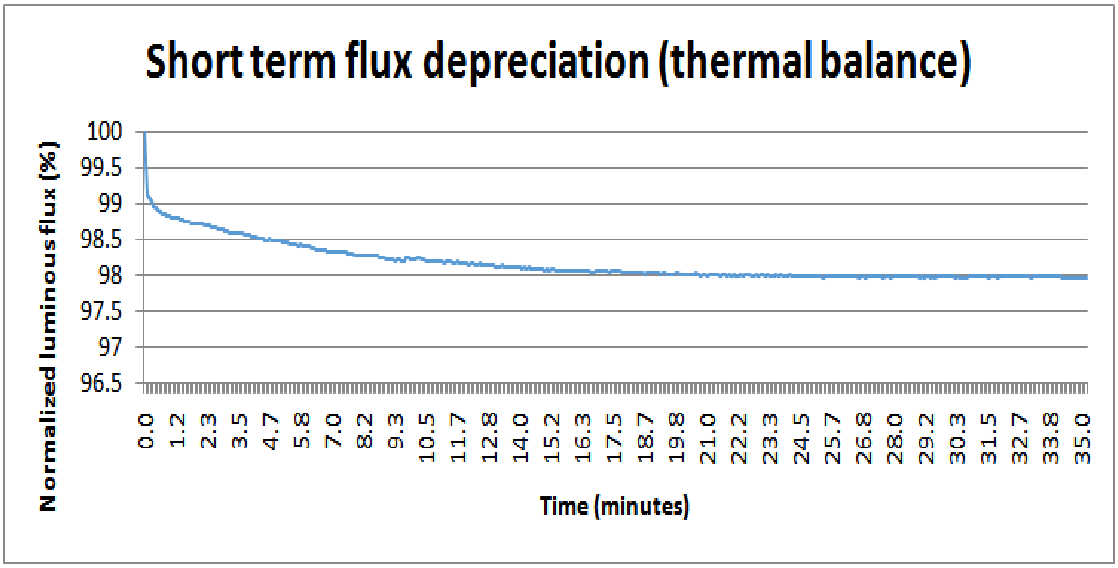

Fig 1. Flux depreciation due to the thermal balance

Long term light output degradation beyond thermal balance is caused by LED’s,the optical material and electronics aging. Measurementsof the luminaire’s long term light degradation are carried under strict controlled condition (basically in a laboratory) in respect of procedures as specified in standards. For lamps and luminaires data collection procedure is specified in LM 84-14 and projection for luminous flux method stated in TM 28-14. Both these normativeis considering the luminaire‘sall components contribution, insteadof single LED test data as a proxy.

EstimatingLight degradation

Hence CLO method is using data based on LM80 report provided by LED manufacturers, then,long term luminous flux maintenance for LEDs is basically estimated by a mathematical process as explained in TM 21, instead of the real one. According to the TM-21-11, values during minimum 6000 operating hours are processed by approximation exponential regression and then statistically estimating the light degradation six time beyond this period. Approximation by exponential regression is expressed by the equation:

$$_t = B \cdot e^{-\alpha \cdot t} \quad \text{(Eq.1)}$$

Where:

t - operating time (in hours)

Φ (t) - averaged normalized luminous flux at time t

B - projected initial constant by the least squares curve-fit of LM-80data

α - decay rate constantderived by the least squares curve-fit of LM-80 data

As test period is concluded, the dataare normalized for each device to a value of 1 (100%) at 0 hours and then averaged within the same data set (see Fig 2).

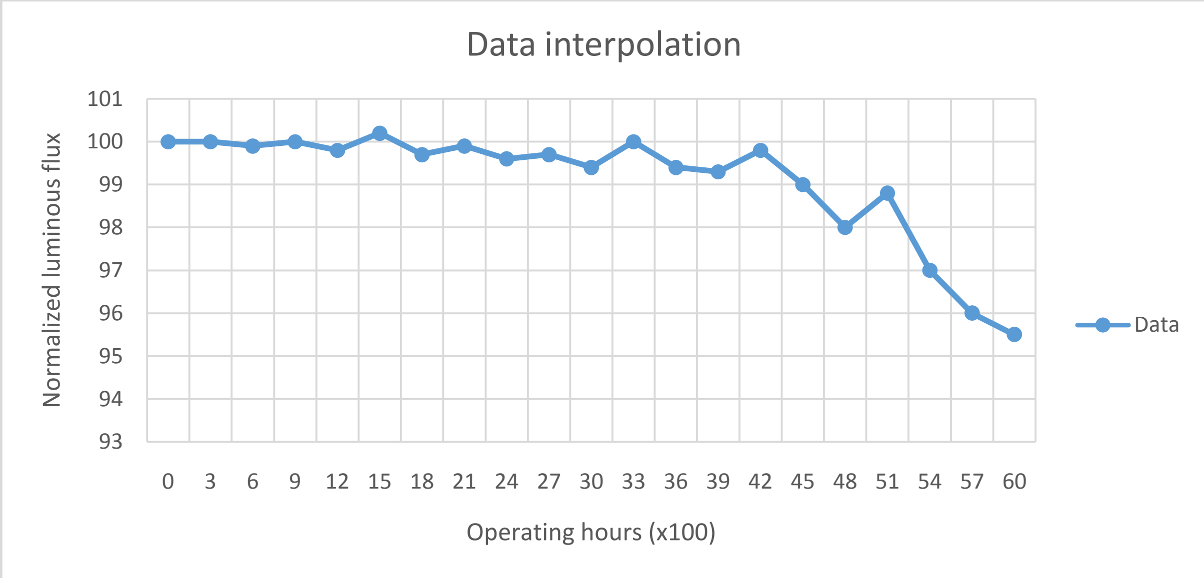

Figure 2

In order to acquire the decay rate for the test period, an exponential last squares curve-fit through the average values is performed (Fig 3), in accordance to the previousequation(Eq.1).

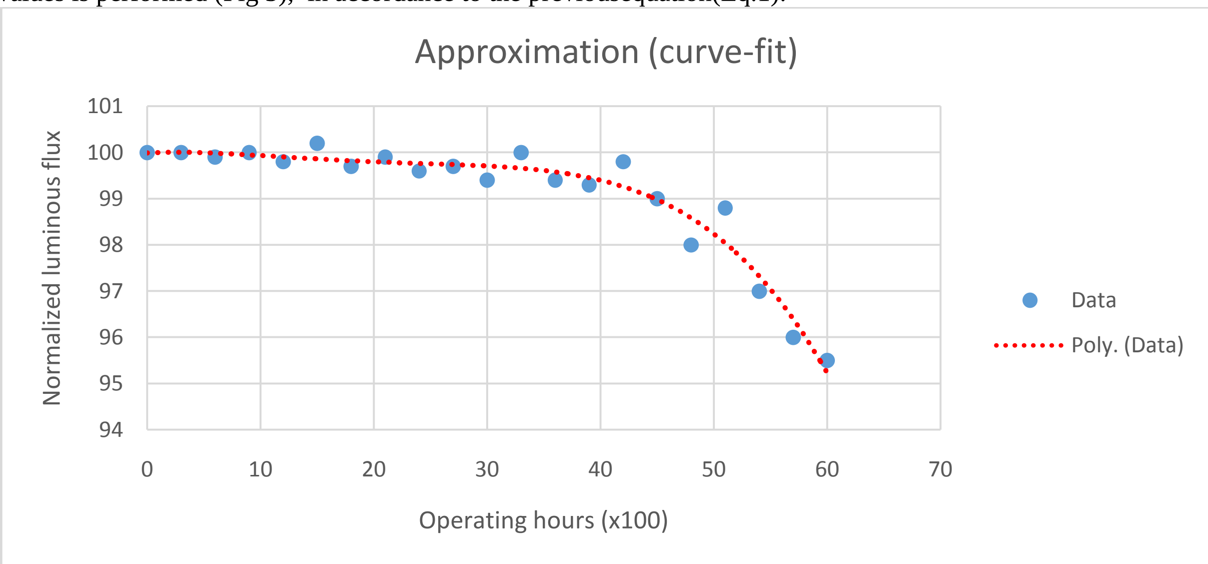

Figure 3

To project the luminous flux maintenancebeyond test period (6000 hours),TM-21 state the following equation:

$$L_{70} = \frac{ln\left(\frac{B}{0.7}\right)}{\alpha} \qquad \text{(Eq.2)}$$

Example of such result:

Test Condition - 85°C Case Temp	
Sample size	10
Number of failures	0
DUT drive current used in the test (mA)	150
Test duration (hours)	6000
Test duration used for projection (hour to hour)	1,200 - 6,000
Tested case temperature (°C)	85
α	6.49255E-06
B	1.013505744
Reported L70(6k) (hours)	>33000

Otherwise, the results estimate an 80.23% depreciation level for luminous flux after 36 000 hours operating time (Fig 4).

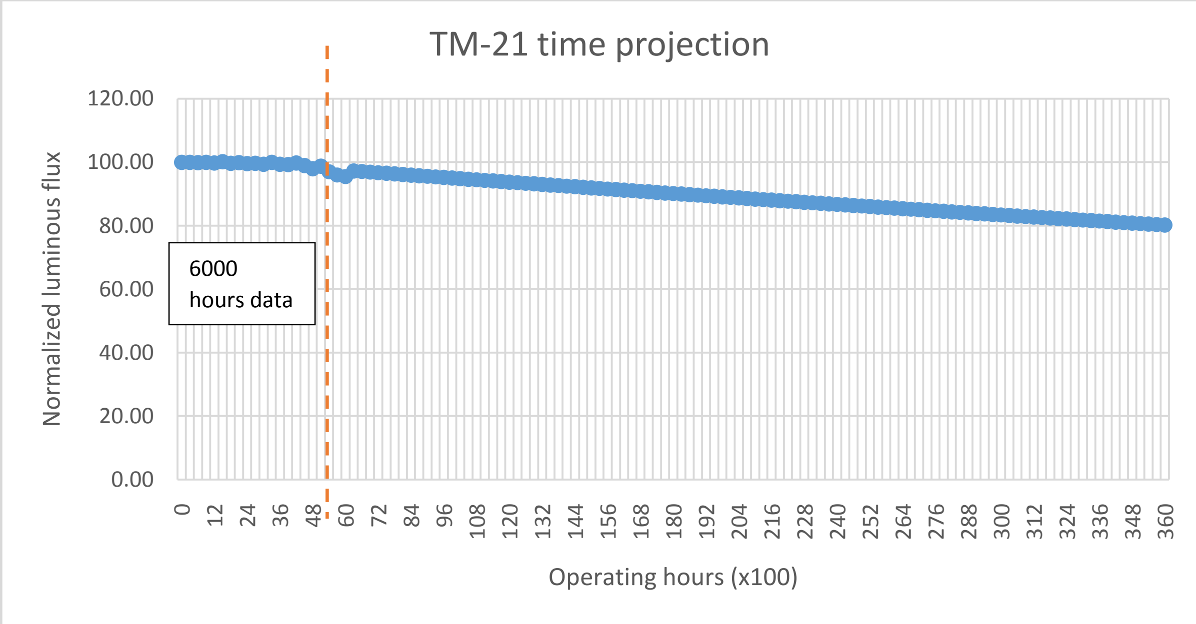

Figure 4

Unlikely the real behavior during operating hours of the luminaire, in real condition is known either be predicted beyond a certain range. Obviously light output depreciation of the luminaires, is mainly caused by the thermal stress of the LED emitters, but may also be caused by aging or messing up the transparent screen or the optical system. These two combined depreciation processes are difficult to predictotherwise the resultis reducing the level of illumination andaffect function of which was employed(Ex.: the safety and security of users in applications such as street lighting). The implementation of a solution to offset these processes is therefore justified especially for street lighting.

Constant Light Output (CLO)

As explain previously, lumen maintenance beyond test period is based on a statistically calculation, otherwise called projection method. There are not too many methods as to compensatethe light output degradation caused by a combination of elements. The CLO method, simply increaseperiodically the current through LEDs in order to compensate a presumedluminaire's light output degradation.This system compensate a predicted depreciation of luminous flux through a fixed algorithmirrespective to LED technology or environmental condition, asto ensure a predefined lighting level during the luminaire's useful life. One of the algorithm may be expressed by the equation:

$$I_t = I_N(1 - e^{-\frac{t}{\tau}}) \text{ (Eq.3)}$$

Where:

I_t,forward current at time t

I_N,nominal forward current

t,operation time

T, time constant

Without a remote management, this means simply increasing the initial power upon installation in order to make up for luminous depreciation. By precisely controlling luminous flux, by means of forward current trough LEDs can control the energy necessary as to reach the required level (Fig 5).

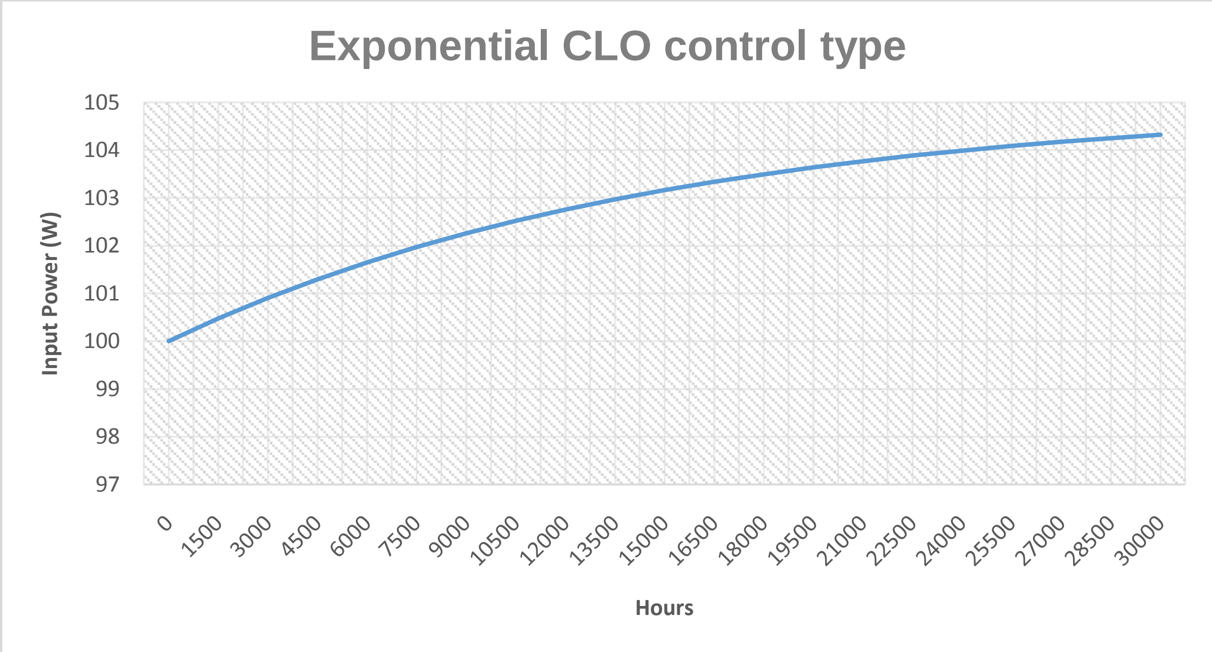

Figure 5. Example of CLO control type

Anotherwayis to compensate at a fixed rate, as for example 1% for every 7500 operation hours (Fig 6). Obviously both methoddo not consider LED type/technology, optics degradation power supply as a complete system and also environmental condition.

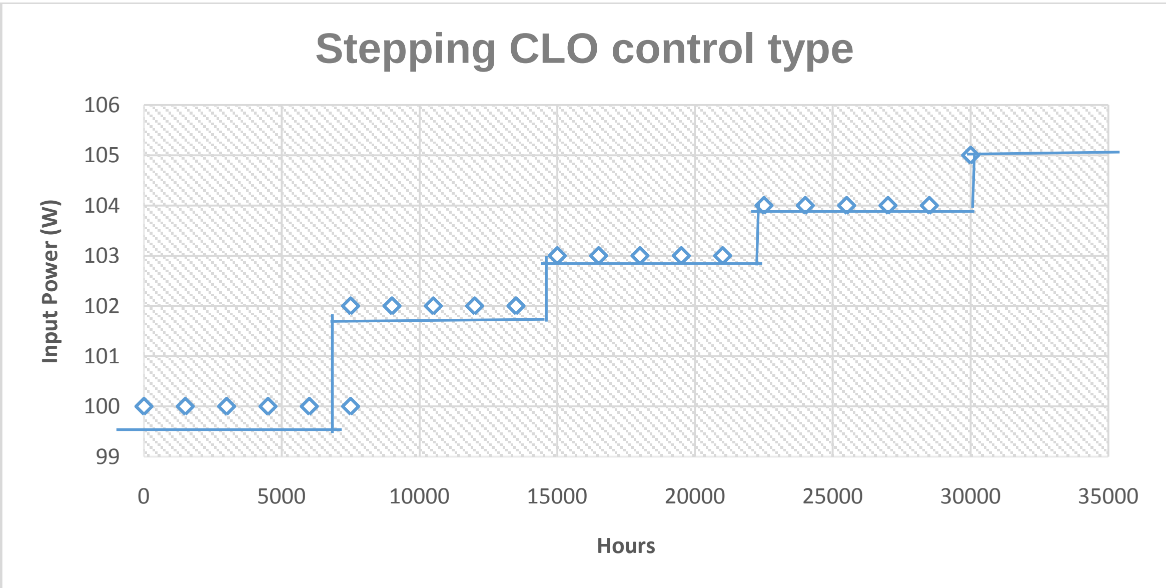

Figure 6. Example of stepping of CLO control type

Unfortunately, regardless of the procedure type, the CLO method do not compensate real light output degradation of the luminaire even for same type of LEDs. Considering that other system elements behaves similarly as power supply, lenses, etc., the luminous flux for the LED type degrades differently, mainly as a result of T_j difference.

Dynamic Balanced Light Output (BLO)

Balanced Light Output method is maintaining the luminous flux, therefore the level of illumination, over the lifetime of the LED luminaire, considering the luminaire'sglobal light degradation instead of LEDs projected.Obviously increasing in luminous flux is the result of forward current increase through LEDs and consequently precaution needs to be taken in regard of thermal management. In this regard the heatsink should be design as to accept the maximum LED output power when reach maximum balance light output, in order to avoid LED's junction overheating. For example a 100W LED luminaire should have a thermal capability of a 120W luminaire equivalent to a L80 lumen maintenanceat the end of life.

Such a BLO system could be employedinside of a LED luminaire, consisting in principleof a body / assemblyas the luminaire's heatsinkhaving a transparent screen or light diffuser and a LED light source (Fig 7). The light generated by the LED emitters is monitored by a sensor assembly that ultimately controls the power supply driver via a microprocessor. The sensor assembly consists of an IR-infrared emitter-receiver pair, which together detects the transmission through the screen/diffuser. Measurement of the light output generated by the LED emitters inside of the luminaire is performed by a visible VIS sensor.

The sensors assembly is mounted on the surface of the radiatorat some distance from the screen / diffuser (Fig 8). Between the transmitter and the receiver is a technologically distance and the VIS sensor is facing indirectly the LEDs (Fig. 9).

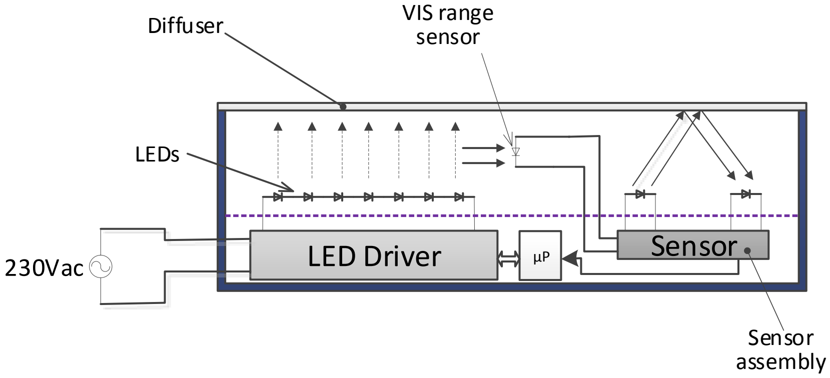

Figure 7. BLO system assembly

Suitable arrangement for sensor assembly depend on the mechanical characteristics of the luminaire, respectively the height of the LED emitters, space availability and the type and size of the optics.

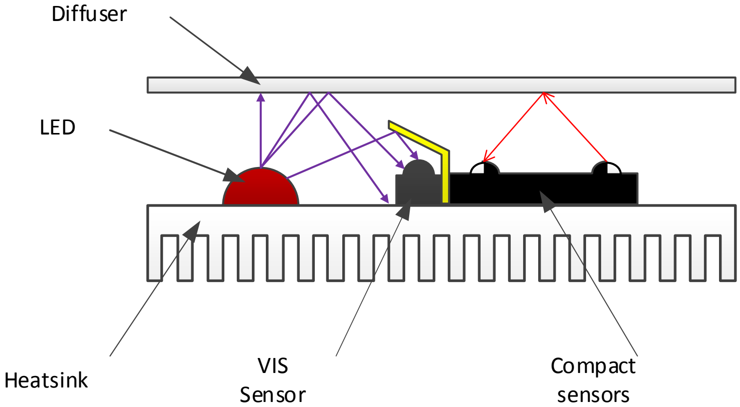

Figure 8. Sensor assembly side view.

The VIS sensor, which isindirectly facing the LED emitters will perform the function of measuring the equivalent value of the total luminous flux. Sensor's position should allow only the detection of light generated by the LED emitters,whichis accomplished by using a reflective wall as in Fig. 9.

Figure 9. Reflective wall (left)and the sensor assembly (right).

Thus, a ratio between the total lumen output of the luminaire and the electrical signal generated by the VIS sensor can be established for system calibration. The value of this signal is equivalent to the luminous flux value or the reference value for assessing the level of light degradation.

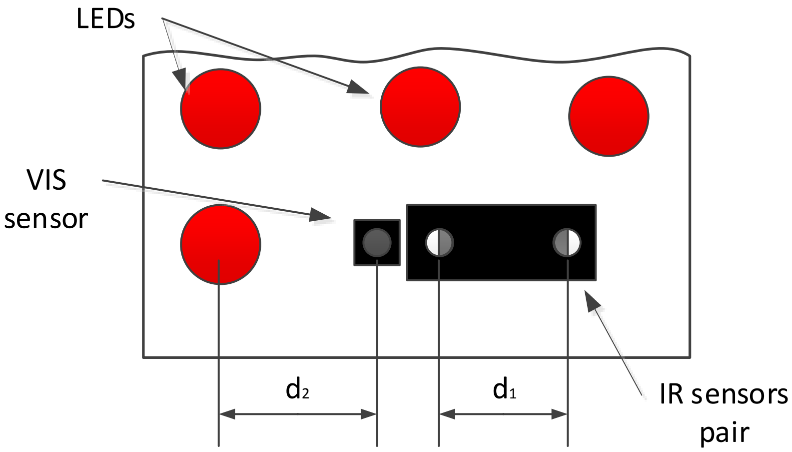

Figure 10. Sensors assembly top view

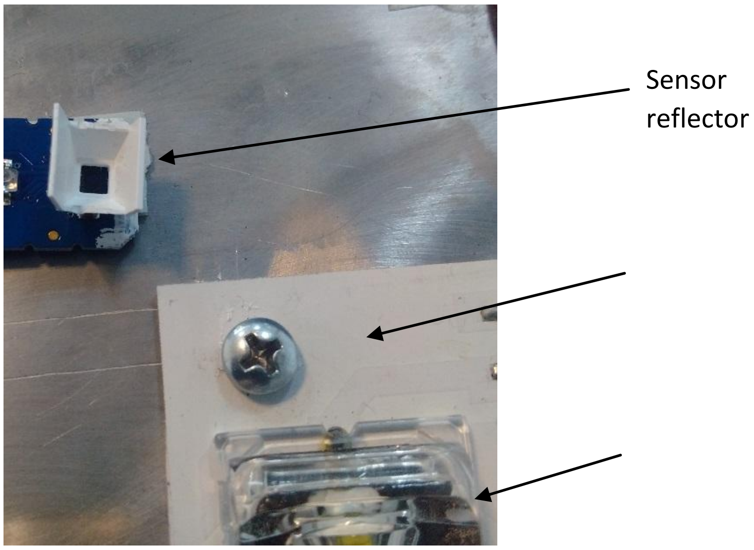

Figure 11. Actual sensors assembly

Transmission of light through the transparent screen (transmittance) is determined by the IR sensors pair.The IR beam generated by the emitter is projected onto the diffuser at the angle α (Fig 12). The intersection with the viewing angle β of the IR sensor on the surface of the screen takes place over the distance D. The intersection surface of the projections of the two cones, respectively, of the sensor, on the surface of the screen is represented by the intersection of two circles corresponding to α and β (Fig. 13). When the distance between the transmitter and receiver tends to 0, then L ~ h therefore the projection of the generated beam is practically covered by the viewing angle.

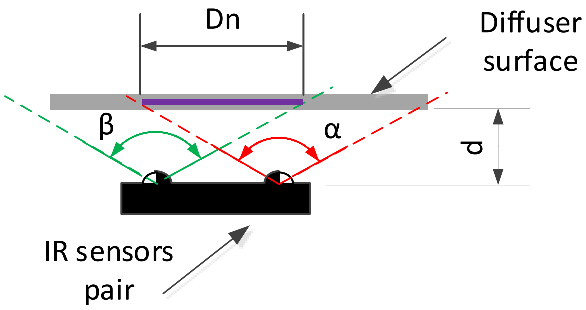

Figure 12. Transmittance measurement

In Fig. 14 shows the trajectory of the IR beam through the transparent diffuser material. The light transmitted by the IR transmitter is reflected in the A direction by the inner surface of the diffuser, but travels in the C direction towards exterior, throughout the material to the air.

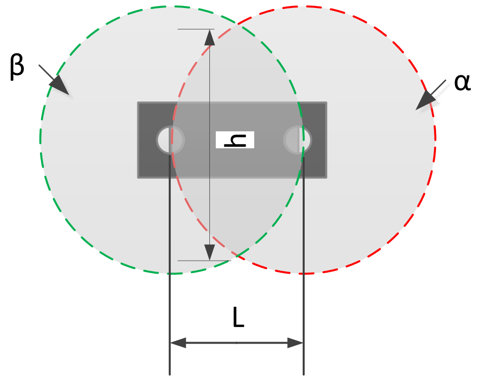

Figure 13. Projected areas on diffuser for larger L distance between sensors

When the diffuser's material deteriorates, the component in C direction is increasing(Fig. 14) and redirected inside diffuser's material, heading the IR receiver.The damage process is caused by the aging of the transparent material, dirt, deformation, or breakage. The degree of damage may be calibrated by a reflection reference materialas applied on the surface of the screen. Such a reference material, also known as the "gray card", should allow developing a relationship between the degree of damage and the signal produced by sensor. When the diffuser is new,in the very beginning, the level of the signal is recorded and used in the calculation process as a reference value.

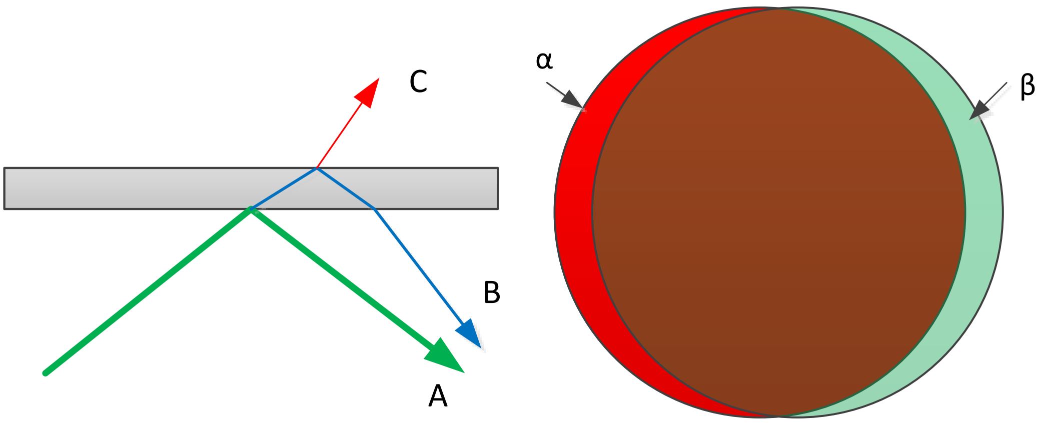

Figure 14. Projected areas on diffuser for smaller L distance between sensors

The photometric performance, respectively, the maintenance of the luminous flux over the operating time, is analyzed in relation to the recorded reference values. The variation of the luminous flux from the initial or reference value is expressed by the equation:

$\Delta\Phi_v = \Phi_{Ref} - \Phi_{Ech}$ (Eq.4)

Where $\Delta\Phi_v$ represents the luminous flux variation of the Φ_{Ech}measured and thereference flux value Φ_{Ref}. The variation of the transmittance from the initial value is expressed by the equation:

$\Delta T_v = T_{Ref} - T_{Ech}$ (Eq.5)

Where ΔT_v represents the transmittance variation between T_{Ech}measured and the T_{Ref} reference value. Maintaining the luminous flux is achieved by increasing or decreasing the forward currentthrough LED emitters in refer to the reference values of Φ_{Ref} and T_{Ref}. . For a LED current driver this action is equivalent to a dimming functionthis time relatedtothe light degradation.

In FIG. 15 illustrates the flow diagram of the BLO computing process.When the luminaire is switched ON, a pulse activatea timer in order to generate pulses every 60 min. Eachpulse increment by 1 the hour counter, for recording operating hours. When the hour counter has a value of 1 (n = 1), otherwise the very first operating hour, the initial flux Φ_{Ref} and transmittance values $T_{Ref}$are recorded from VIS respectively IR sensors. Recording these values (Φ_{Ech}, T_{Ech}) after first hour, it can be considered that the luminaire reached the thermal equilibrium and thus the stabilization of the parameters (variables) have been achieved. Moreover, thecounter (4) triggers every hourreading variables routine (7), in this order: Φ_{Ech} flux reading in (8), followed by reading transmittance T_{Ech} in (11). Signal value from the VIS sensor is recorded after each hour in (9). The very first value or the reference Φ_{Ref} is stored in (10), only if the block output (6) indicates as afirst operating time. Equivalent flux reading is accomplished in (8), every hour. Once the data is released in (9) triggered the block (11) for transmittance measurement whose value is recorded in (13). The mathematical processing, equivalent to thedegradation calculation in relation to the reference values (Eq 4 and Eq 5) are completed in (12). Therefore the resultsare:

$L_F = \Delta\Phi_V / \Phi_{Ref}$ (Eq 6)
$L_T = \Delta T_V / T_{Ref}$ (Eq 7)

If
$| L_F | \geq 0.2$
$| L_T | \geq 0.2$
When | LF | and | LT | are greater than 0.2, then an alarm signal is generated as the maximum dimming threshold of 20% is exceeding. Both ratios, relative to the reference values are summed in (14):

$R_{Dg} = L_F + L_T$ (Eq 8)

This represents the equivalent numerical value for the overall light output degradation, otherwise essentialinthe Balance Light Output process. Furthermore conversion to aPWM dimming signal, as required to control the power supply / driver,is completed in (15) and recorded in block (16), so that can be save as it changes withthe operating time.
It is advisable that power control not to exceed 20% over of the nominal value so that the luminous fluxincreasing action does not affect the thermal management of the luminaire,unless a thermal reserve was provided.

II. Conclusion

Unfortunately, regardless of the CLO type procedure, the method do not compensate real light output degradation of the luminaire even for same type of LEDs.The decrease of the lumen output is predicted with a certain tolerance with information LED luminaire manufacturers gathered from past products launched and marketed.
The Balance Light Output (BLO) option offers guarantied constantlight levels through luminaire lifetime.Hence, the driver's dimming feature, combined with the BLO platform, enables the environment to have a constant light output. The driver controls the power provided to the LEDs ensuring an equal lighting intensity throughout the lumen depreciation period.
BLO option now provides the possibility by adapting LED power supply to the lumen depreciation curve for the product's entire lifecycle.
Therefore BLO features take account of:
- Global depreciation curve of the luminaire, based on the real time measurement.
- Provides luminaire real lumen maintenancenot predicted by photometry during lifetime of the product.
- Avoids site over lighting situation that would be happening with standard LED lights for half of product's useful life.
- Autonomous, no input needed from the customer.
- Customized program.

Extra benefits:
- Precise and constant lumen output over the lamp life.
- Provides better management of light output and better lighting uniformity andintensity
- No installation or maintenance required
- Superior longevity

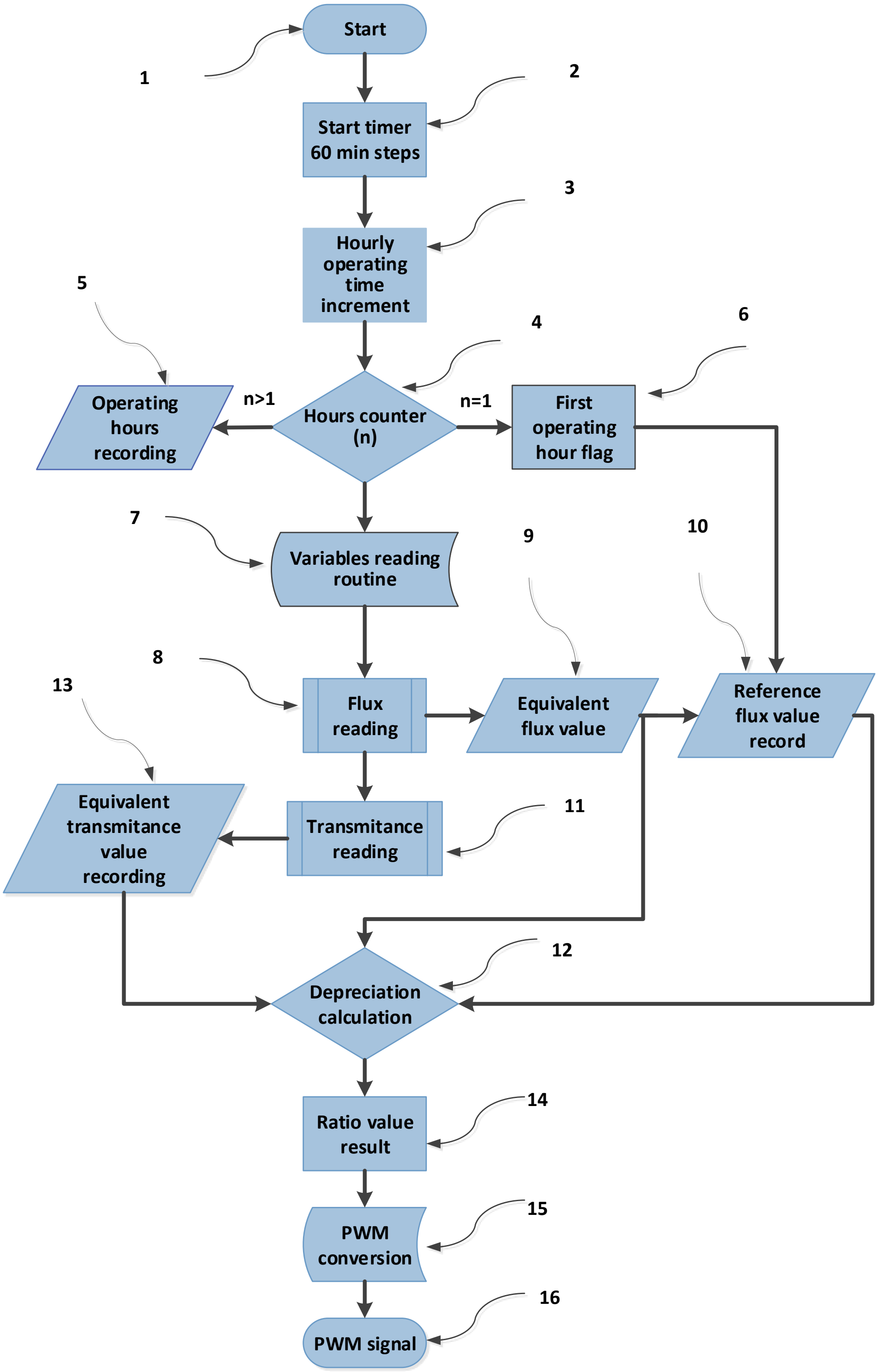

Figure 15. Flow diagram of the BLO process

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