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Optimization of light distribution (LD) for road lighting luminaries of different cross factor (C.F)

[1]Safaa K. El – Mahy and [2]M. M. EL Ganainy

[1]Department of Physics, Faculty of Women for Arts Science and Education Ain Shams University, , P.O11757, Cairo, Egypt.
[2]National Institute for Standards TersaSt El Haram, , P.O136, Cairo Egypt.

Address For Correspondence:
Safaa K. El – Mahy, Department of Physics, Faculty of Women for Arts Science and Education Ain Shams University, P.O11757, Cairo, Egypt .
E-mail: safaa.elmahy@yahoo.com

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ABSTRACT
To improve the quality of lighting installation in dry and wet conditions the luminaire maximum efficiency must be realized .Theoretically each C.F value of the luminaire corresponds to different values of both of m_t and m_l (the indices determined the L.D across and along the road surface. Respectively), this leads to different luminaire efficiencies. In this work we obtain the maximum luminaire efficiencies by optimizing the LD. So the values of the indices corresponding the optimum LD m'_t and m'_lshould obtained for each C.F value. The calculation have been carried out for luminaires having C.F values in the range(1.2-10) considering two cases . The results for the first case are useful in comparing the actual efficiency of the luminaire with its maximum by comparing the actual values of $m_t$and m_l with their optimum values for road lighting luminaire of different C.F values The results for the second case are useful in further developing of road lighting luminaires.

KEYWORDS: Lighting distribution, Luminaire Cross Factor, Illuminance,luminance.

INTRODUCTION

1.1-The luminaire L.D:

The luminaire L.D is the basic information in any lighting calculation .The fundamental technique in road lighting is to provide a bright reasonably uniform road surface .Each lantern produces brightness pattern. The overall brightness pattern of an array of lanterns depends on three factors: the reflection characteristics of the road surface, the light distribution of the lantern and the geometrical layout of lantern /column (their arrangement).

There is a convenient mean of describing L.D known as intensity distribution solid [1,2] ,it is a portion of space bounded by a surface constituting a geometrical locus of the end points of the position vectors that represent the luminous intensity in different direction.

It was found that the most suitable analytical expression for the intensity I_α versus the angle (α) between the axis of symmetry and the direction of the beam is expressed by the formula[3]:

$$I_\alpha = I_{o\,(\cos\alpha)}^{\;m} \quad (1)$$

Where I_o is the value of Iαin the direction of the axis of symmetry and m denoted by the L.D index

Using formula (1) the L.D below the horizontal corresponding the values of

m = o.5, 1 and 2 are shown in figure (1-a) [3]. Figure (1-b) represents the L.D of a luminaire achieved by means of reflection refraction and diffused transmission [4]. Of particular concern in road lighting is a luminaire

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downward light output ratio (d . l .o. r) [5] which means the flux emitted below the horizontal and thus in the general direction of the road as a fraction of the total lamp flux.

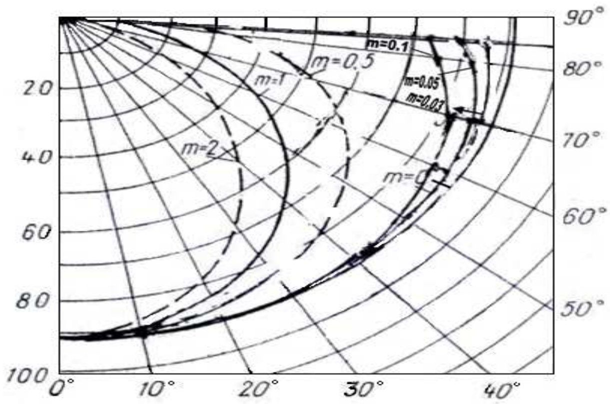

Fig. 1-a: the lighting distribution for the values of ms 0;03 ; 0.05 ; 0.1; 0.5; 1 and 2 according to formula (1).

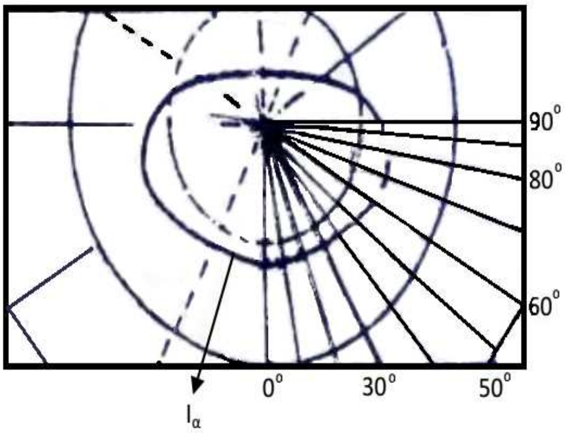

Fig. 1-b: Control of luminaire light output by means of (a) reflection (b) refraction, and (c) reflection and diffuse transmission, with resulting luminous intensity diagrams:

1.2-The cross factor (C.F):

Van Bommel defined C.F of the luminaire [4] as intensity ratio I_t /I_l

Where: I_t the luminous intensity of the luminaire in the direction 45^0

$^{(}$ tan $^{-1}$1) from the downward vertical in the plane at right angle to the road axis (cross wise direction) I_l the luminous intensity of the luminaire in the direction $63.5^{0(}$ tan $^{-1}$2) from the downward vertical in the plane parallel to the road axis (longitudinal direction) as shown in figure (2)

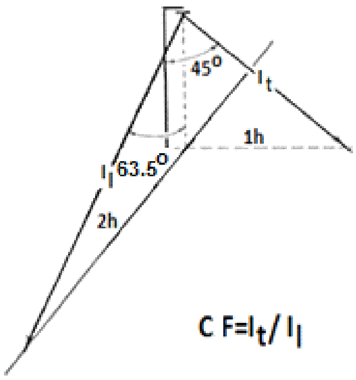

Fig. 2: Definition of cross factor(CF), a figure of merit for a luminaire indicating its suitability for use in the wet conditions.

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Theoretical:

2.1 The dependence of the illuminance E at any point on the road surface on L.D (index m) in the cross and longitudinal directions:

Considering a point source S the illuminanceE at any point P on a horizontal plane (see figure 3) is given by the formula [2].

$$E_\alpha = I_\alpha \frac{\cos \alpha}{r^2} \quad (2)$$

From equation (1) we have $E_\alpha = E_o (\cos \alpha)^{m+3}$ (3)

Where $E_o = \frac{I_o}{h^2}$,m is the index of L.D

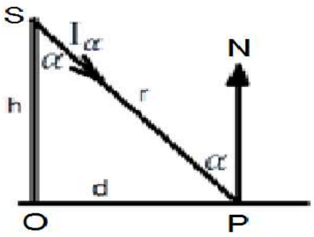

Fig. 3: The illumination of a point source on a horizontal plane.

In this work we consider the fact of symmetry which approved by N.N. Ermolenske and G.M.Knopping[3] Due to such fact L.D in the inclined longitudinal planes are similar

Takaing the .point o (direct below the luminaire) as the origin,ξ, ή

as the axes of coordinates figure(4) .Then (ξ - ή)plane represents the road surface and the fact of symmetry can be expressed by the formula [3]

$$\frac{I_\alpha}{I_{\alpha l}} = \frac{I_{\alpha t}}{I_o} \; or \; \frac{I_\alpha}{I_{\alpha t}} = \frac{I_{\alpha l}}{I_o} \quad (4)$$

whereI_o,$I_{\alpha t}$,$I_{\alpha l}$ and I_α are the luminous intensity of the beams incident at the points 0,A,B, and P such values given by the cross and the longitudinal luminous intensity curves). The coordinates of such points are); (0,0), (0, $ή_0$) ,(ξ,0) and (ξ , ή) respectively . The angles α_t ,α_l and α are the directions of the beams incident at the points A,B and P from the downward vertical

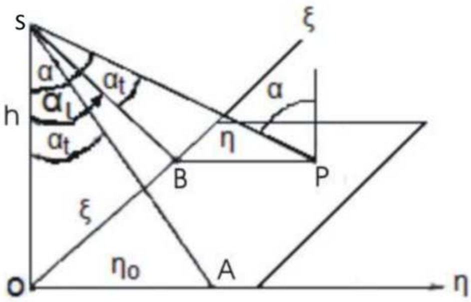

Fig. 4: The localization of the point (P) on the (ξ ,η) planes.

Note : Due to the fact of symmetry ,the angle between the beams incident at the points B and P should equaled to α_t .Such condition can be satisfied if we have : [3]

$\eta_o = \eta \cos\alpha_t$ (5)

From equation (1) we can write equation (4) in the following formula:

$$\frac{I_o (\cos \alpha)^m}{I_o (\cos \alpha_l)^{m_l}} = \frac{I_o (\cos \alpha_t)^{m_t}}{I_o} \quad (6)$$

Where m_t and m_l are the indices of L.D in the directions across and along the road surfaces respectively.

Equation (6) can be written as follows:

$$(\cos \alpha)^m = (\cos \alpha_t)^{m_t} (\cos \alpha_l)^{m_l} \quad (7)$$

Referring to figure (4), the angles $\alpha_t , \alpha_l \; and \, \alpha \; can be \; given by$

$$\alpha_t = \cos^{-1}\frac{h}{\sqrt{h^2+\eta_o{}^2}}, \alpha_l = \cos^{-1}\frac{h}{\sqrt{h^2+\zeta^2}}\ and\ \alpha = \cos^{-1}\frac{h}{\sqrt{h^2+\eta^2+\zeta^2}} \qquad (8)$$

Such angles can be determined knowing the values of h, η_0 , η and ξ,

using equation (8) .Also giving the values of m_t and m_l ,the value of m can be calculated using equation (7). Hence the relative illuminance at the points A,B and P can be defined as

$$\varepsilon_A = \frac{E_A}{E_o}, \varepsilon_B = \frac{E_B}{E_o}\ and\ \varepsilon_P = \frac{E_P}{E_o} \qquad (9)$$

which can be determined from equation (3) as $\varepsilon_A = (\cos\alpha_t)^{m_t}$ $\varepsilon_B = (\cos\alpha_l)^{m_l}$, ε_P = $(\cos\alpha)^m$

also from equation (3) , equation (7) can be written

$$\varepsilon_P = \varepsilon_A . \varepsilon_B \qquad (10)$$

2-2 **.**The dependence of C**.**F on the ratio m_t/ m_l**:**

From the definition of C**.**F and equation (1) ,we have**:**

$$C.F = \frac{I_o\,(\cos 45)^{m_t}}{I_o\,(\cos 63.5)^{m_l}} \qquad (11)$$

Hence we have**:**

$$Log\ C.F = \frac{m_t \log\cos(45)}{m_l \log\cos(63.5)} \qquad (12)$$

The magnitude of the quantity $\frac{\log\cos(45)}{\log\cos(63.5)} = 0.43$

Then we have

$$\log C.F = \frac{m_t}{m_l}\times 0.43. \qquad (13)$$

Note: from equation (13) It is clear that each value of C.F corresponds to different values of both m_t and m_l.

3- The determination of the illuminanceLp and the relative illuminance L^-p at a point on the road surface:

The calculation of L is made somewhat easier if the so called reduced luminance coefficient r is used, where r depends upon the nature of the road surface material and upon the positions of the light source and the observer relative to the element under consideration.

From the definition of r we have $L_P = rE_p$ (14) [4]

Putting $L_P^- = r\varepsilon_p$ (15)

Then from equation (9) we have $L^- = L / E_o$ (16)

Hence both the values of L and L^- are corresponded to certain value of luminaries efficiency and can be considered as a measure of such efficiency.,i.e the maximum luminaire efficiency corresponds to the maximum values of L or L^-.

Note: L^- can be defined as the relative luminance, the values of which will applicable for different kinds of lamps and luminaries heights.

4- Calculations and results of ε_p and L_p^-:

Prior to the determinationof ε_p and L^-_p at a point on the road surface, we must carry out the following calculations:

a . Using formula (1) the L.D corresponding the values m= 0.03, 0.05 and 0.1 are obtained and illustrated in figure (1-a)

b. It is found that the L.D corresponding to m=0.05 is a good approximation for the actual typical L.D shown in figure (1-b) with maximum deviation less than 20% at the angle $\alpha \geq 70^o$. This can be approved as $\alpha < 70^o$in the cross direction. For the longitudinal direction the beams for which $\alpha \geq 70^o$ have a neglected contribution in road surface lighting.

c. The determination of the optimum L.D indices:

Since equation (13) can be verified by different values of both m_t and m_l, the luminaire of certain C.F value will have different L' levels. Let m'_t and m'_l are the indices of the optimum L.D corresponding to the maximum value of ' L'. Then for a group of luminaires having different C.F values and provide different L' maximum values, the values of m't and m'_lmust satisfy the following conditions:

1- The values of both m'_t and m'_lforlumunaires of different C.F values must be different.

2-The values of both m'_t and m'_l should be higher for lower values of C.F according to equation (13).

3- The increment of m'_t value between any two luminaires having two successive C.F values must be constant and equaled to 0.02 (the least m'_t difference in practice), as we are dealing with the optimum values.

4- As the typical L.D for road lighting luminaire can be approximated by that obtained for m=0.05 (as shown in figures (1-a) and (1-b). We can assumed that corresponding C.F = 10, we have m'_l =0.05. as for C.F=10 the luminaire has its maximum actual efficiency. Hence the corresponding value of m'_t =0.115 using equation (13) .Then apply condition (3), we can obtain m'_t and hence calculate m'l, this can be repeated to obtain m'_t and m'_l corresponding to the other C,F values .

4-1. The method of calculations of $\varepsilon_p$and L'_P:

Consider the installation in figure (4) assuming that $h=\eta_o=10m$ then the coordinates of the point A is (0.10) and the angle $\alpha_t=45^o$. Assuming the coordinates of the point B is (20.0). then we have the angle $\alpha_l=63.5$ °then we have the coordinates of the point P is (20,14.2) and the angle $\alpha=68^o$ Hence knowing the values of m'_t and m'_l for different values of C.F one can obtain corresponding values of ε_p by substituting in equation (7) for the two following cases :[case (1) for C.F =10 ,we have m'_l =0.05 and case (2) for C.F =10 ,we have m'_l = 0.03 . The result of calculations are represented in tables (1) and (2).

To determine L'_P corresponding to C, Fvalue ,we assume that the angle between the plane of light incidence and the plane of observation equaled to 90^o and since α =68^o , from the tables of r for the standard road surface R2 ,We have r = 0.04 [3] , Then L_p^- can be obtained using equation (15).

Case :1

C.F	10	8	6	4	2	1.5	1.2
Log C.F	1	0.903	0.7782	0.602	0.301	0.175	0.0702
m'_t/ m'_l	2.3	2.1	1.81	1.4	1.7	0.407	0.1633
m'_t	0.115	0.135	0.155	0.175	0.195	0.215	0.235
m'_l	0.0500	0.0643	0.0856	0.1250	0.1929	0.5283	1.4578
ε_A	0.9609	0.9543	0.9477	0.94113	0.9346	0.9282	0.9217
ε_B	0.9599	0.9487	0.9323	0.9027	0.8539	0.6488	0.3032
ε_P	0.9223	0.9053	0.8835	0.8495	0.7980	0.6022	0.2795
L'_P	0.0369	0.0362	0.0353	0.0339	0.0319	0.0241	0.0112

Case :2

C.F	10	8	6	4	2	1.5	1.2
Log C.F	1	0.903	0.7782	0.602	0.301	0.175	0.0702
m'_t/ m'_l	2.3	2.1	1.81	1.4	1.7	0.407	0.1633
m'_t	0.069	0.089	0.109	0129	0.149	0.169	0.189
m'_l	0.03	0.0424	0.0602	0.0921	0.2129	0.4152	1.4578
ε_A	0.9764	0.9696	0.9629	0.9563	0.9496	0.9430	0.9366
ε_B	0.9757	0.9659	0.9519	0.9274	0.8400	07118	0.3829
ε_P	0.9527	0.9365	0.9166	0.8869	0.7976	0.6712	0.3586
L'_P	0.0381	0.0375	0.0375	0.0355	0.0319	0.0268	0.0143

Conclusions:

1- Formula (1): is a good approximation for the Typical for L.D of roadway luminaire.

2- For each C.F value of a luminaire ,there are different values of m_t and m_l which can verify equation (13) ,hence different luminaire efficiency .So it is required to obtain the values of m'_t and m'_l for the optimum L.D which corresponding to the maximum luminaire efficiency .

3- Since the obtained values of m'_t and m'_lin case (1) are the optimum values for the luminaires having different values of C.F , one can use such values for testing the road lighting luminaires ,by comparing the actual values of m_t and m_l with their optimum values .

4- Case (2) for which C.F =10 and m'l = 0.03. The obtained results can be considered as further development of the quality of the road lighting luminaire.

5- The quantities ε_A and L' calculated in the two cases are relative quantities independent on the types of the lamp used in the luminaire .so such results can be applied in wide range of different road lighting luminaire .

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