Designing an Efficient Luminaire for a Fluorescent Lamp

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Abstract: In this paper, the successive stages of designing the shape of a mirror reflector for a VDU-safe fluorescent luminaire with a 55° cut-off are described. The first step was to determine the luminous intensity curve in the plane perpendicular to the lamp axis taking into account the limitations imposed by the low luminance of a fluorescent lamp. The method of calculating the reflector shape, which would give the required luminous intensity curve, is then presented. The reflectors calculated had an efficiency of up to 76.9% and a high uniformity of working surface illumination. The possible use of a discontinuous reflector, the upper part of which is so designed that the reflected rays pass by the lamp was investigated. This type of reflector was found to have an efficiency of 80.7% with only a slight decrease in uniformity.

1. Luminous intensity distribution of a luminaire

Fluorescent fixtures are commonly used today in internal lighting. They should ensure uniform illumination of the working surface and have a 50° - 60° cut-off angle. The first step of reflector designing is to determine the luminous intensity distribution of the luminaire. It can be done precisely on assuming the position of the luminaire and the working surface (Fig. 1).

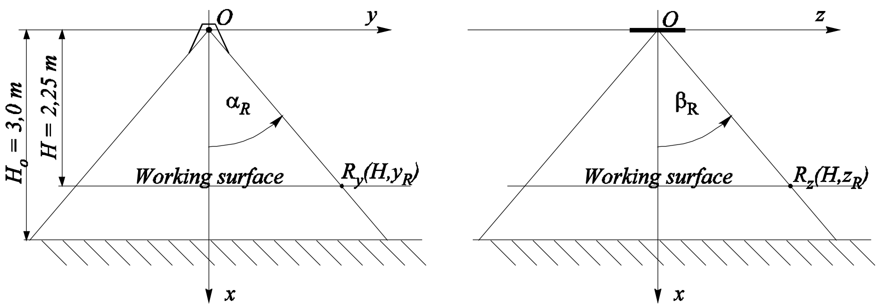

Fig. 1. Position of co-ordinate system, the luminaire and working surface

The centre O of the co-ordinate system is situated in the centre of the light source. The z axis is the light source symmetry axis. Fluorescent luminaires have a cylindrical reflector, which means that the luminous intensity distribution can only be changed in the plane Oxz. In the other directions, the luminous intensity distribution is the same as that of the light source and the b_R angle is limited by using louvers situated perpendicularly to the lamp axis (axis z).

It was assumed that the illuminance E_r on the working surface during the whole period of operation would be at least 300 lx, that is assuming a margin ratio of k = 1.3 the initial value E_p of illuminance on the working surface should be 390 lx.

For a zero-diameter linear light source, the effective luminous flux F_u falling on the working area equals

$$\Phi_u = \frac{a_R}{p}\Phi_0 + \left(1-\frac{a_R}{p}\right) r\,\Phi_0, \qquad (1)$$

where: F_0 - luminous flux of lamps (in the calculations - 4 x 1350 lm = 5400 lm),

r - reflector reflectance (in the calculations - 0.85)

a_R - cut-off angle in radian (Fig. 1 - in the calculations - 55°).

Therefore, theoretically the luminaire efficiency could be up to 89.6% (without considering the louvers). From F_u the value of uniform illuminance E_{Rm} of a working surface of a width of $2y_R$ can be calculated [2]

$$E_{Rm} = \frac{4\Phi_u}{p}\left(2y_R\sqrt{y_R^2+H^2} + H^2\ln\left(\frac{y_R+\sqrt{y_R^2+H^2}}{-y_R+\sqrt{y_R^2+H^2}}\right)\right)^{-1}. \qquad (2)$$

On the basis of (2) it was found that the maximum width y_{Rmax} of an illuminated area with an assumed illuminance E_p (390 lx) equals 3.2 m. The value y_{Rmax} calculated does not take into account the limitations imposed by the low luminance of a fluorescent lamp. The maximum illuminance E_{ymax} which can be produced at a given point on the illuminated surface by a single luminaire assuming that the light source is a cylinder with a constant luminance, the whole of which is visible from this point, is

$$E_{ym} = \frac{H}{\left(H^2+y_R^2\right)^{\frac{3}{2}}}\left[\left(\frac{B}{D}\frac{H}{\sqrt{H^2+y_R^2}}-1\right)\rho+1\right]I_m \qquad (3)$$

where: D - lamp diameter (in the calculations - 26 mm),
B - width of reflector (in the calculations - 140 mm)
I_m - maximum luminous intensity of a lamp (linear light source).
From (3) it can be found that one luminaire with assumed illuminance of E_p can illuminate an area of only 1.7 m. The rest of the surface should be illuminated by the next two luminaires (Fig. 2).

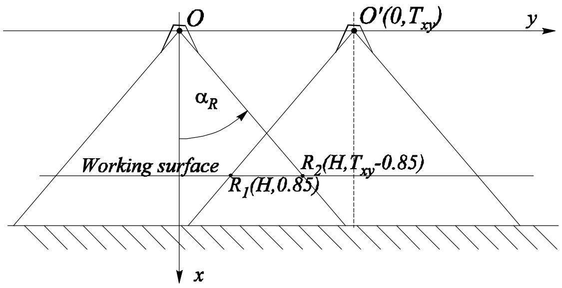

Fig. 2. Position of two luminaires and working surface

In the case of two luminaires, the distance between which equals T_{xy} (Fig. 2), their optimum luminous intensity curve can be calculated precisely only for the part of the working surface lit by one luminaire and at the point half way between the two luminaires. At this point each luminaire has to give an illuminance equal to half the assumed value E_p (145 lx). At the other points of the illuminated surface, lit by the two luminaires, the luminous intensity curve may have various forms, on condition that the illuminance, which is produced by one luminaire, is lower than the maximum possible value E_{ymax} given in (3). Fig. 3 presents various types of luminous intensity curves of luminaires.

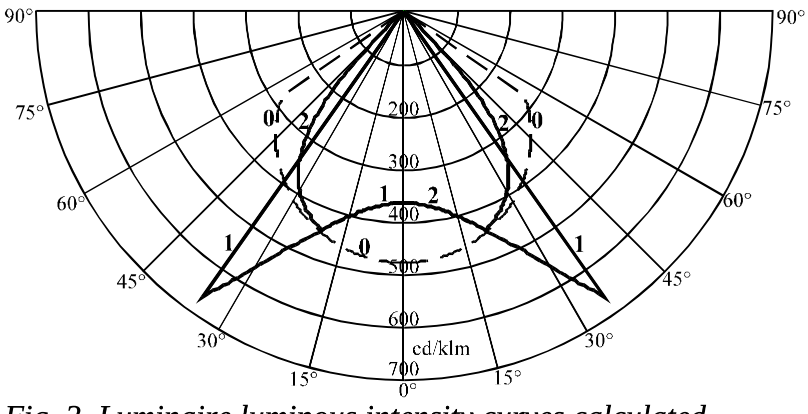

Fig. 3. Luminaire luminous intensity curves calculated
0 - curve of maximum luminous intensity which can be obtained for a real luminaire (E_{ymax})
1 - luminous intensity curve ensuring uniform illuminance from one luminaire (unobtainable)
2 - luminous intensity curve ensuring uniform illuminance from the next two luminaires

2. Determination of reflector profile

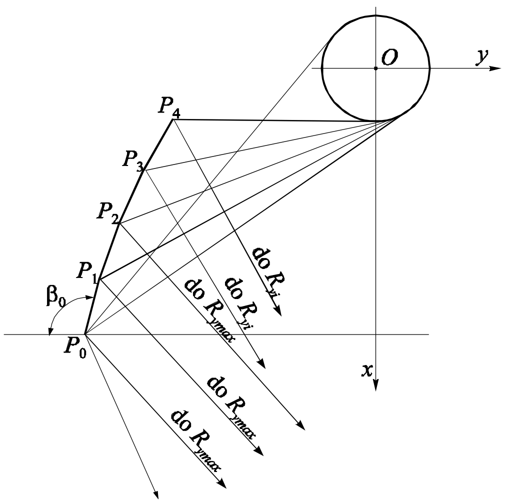

Fig. 4. Diagram of determination of a cylindrical reflector profile by the filling method

The synthetic method of designing an asymmetrical cylindrical reflector profile proposed here can be called the filling method [3]. It consists in filling the luminaire luminous intensity curve by the luminous flux sent by the consecutive reflector elements, starting from farthermost direction in which the reflector starts to operate (Fig. 4 - R_{ymax}). The synthetic method assumes that a reflector will consist of flat elements. The use of flat elements is not at variance with the fact that the reflector is later constructed with a smooth profile since this depends only on the size of the flat elements. In the methods used at present for optical calculations, e.g. in the well-known inverse beam method, the reflecting surface is divided into elements characterised by their size and normal vector (constant for the whole element). Smoothing of the broken line of the reflector profile leads to smoothing of the luminous intensity curves of the luminaire. Therefore, if a reflector composed of the flat elements ensures the assumed uniformity of the illuminance, so does a smooth reflector.

Determination of the reflector profile starts from the point P_0 of co-ordinates calculated on the assumption that the cut-off angle is 55°. The light ray tangent to the light source after reflection at point P_0 should fall on point R_{ymax} (Fig. 4). In this way the whole luminous flux falls on the illuminated plane. The methods used at present are based on the direction of the centre ray, therefore half of the luminous flux of the beam falling on the lower edge of the illuminated area is wasted. On the basis of the law of reflection, the inclination angle b_0 of the first reflector element can be determined. Assuming a constant width ***dl*** (in the calculations - 0.5 mm) of the reflector flat element, the co-ordinates of the end point P_1 can be calculated. The next step consists in determining the illuminance E_{2yi} distribution on the working area illuminated by the next two luminaires, with a specified frequency ***dy*** (in the calculations - 0.05 m). If at any point R_{yi} of the following condition is satisfied

$$E_{2yi} \geq E_{max} \qquad (4)$$

where E_{2yi} - value of illuminance at point R_{yi} produced by the elements calculated so far,

E_a - assumed value of illuminance on the illuminated surface,

the next element of the reflector should send the luminous flux in the same direction as the previous element. Otherwise the next element should send the luminous flux in the direction of the point R_{yi} which meet the condition (4) and has the lowest i value. Determination of the reflector profile is ended, when for each point of the illuminated surface, the condition (4) is met or when the assumed dimensions of the reflector are obtained.

Fig. 5 presents the reflector profiles calculated and Fig. 6 the illuminance distribution on the working surface calculated with a distance between the luminaires of 3.2 m. The calculations were made for four values of the assumed illuminance E_a - 0.85; 0.8; 0.75 and 0.7 of the E_p value (390 lx). There are several reasons for the decrease in the E_a value, the main one being that the dimensions of the luminaire are too small (in a luminaire type 4 x 18 W about 140 mm) in relation to the lamp diameter (26 mm) as a result of which the rear part of the reflector is obscured by the lamp. This leads to inter-reflections and a decrease in luminous flux output.

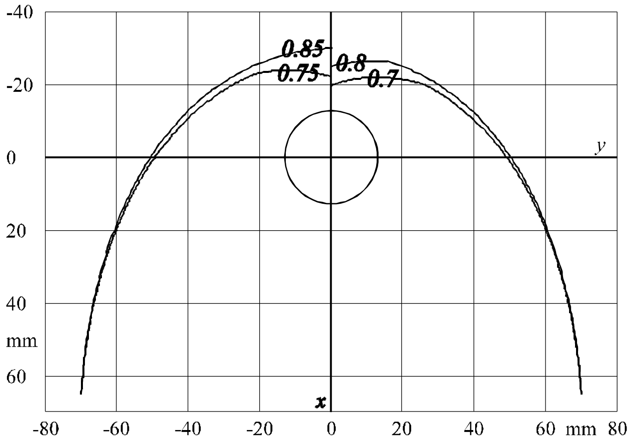

Fig. 5.Reflector profiles giving the assumed illuminace E_a of the working surface

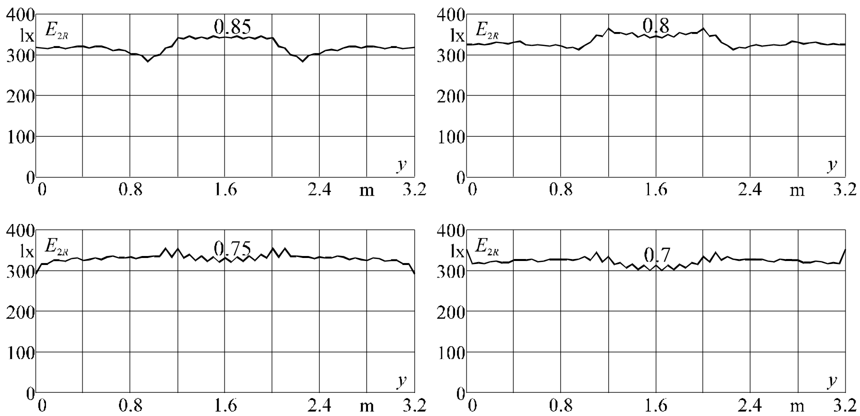

Fig. 6. Illuminance E_{2R} distribution of the working surface illuminated by the two luminaires 3.2 m apart

Table 1. Selected illumination parameters of the working surface illuminated by the two luminaires 3,2 m apart

E_a [lx]	E_m [lx]	E_{min} [lx]	E_{min}/E_m	E_{max} [lx]	E_{max}/E_m	h_t
0.85 E_{Rm} = 331.5	320.1	283.6	0.886	346.2	1.082	74.0%
0.80 E_{Rm} = 312.0	333.1	313.5	0.941	365.3	1.097	76.9%
0.75 E_{Rm} = 292.5	329.8	292.3	0.886	354.1	1.073	76.1%
0.70 E_{Rm} = 273.0	322.0	301.0	0.935	351.4	1.091	74.0%

The reflectors calculated for different E_a values have similar parameters of working area illumination (Table 1). The mean value of illuminance E_m in the plane perpendicular to the lamp axis changes from 320.1 lx to 333.1 lx. All the reflectors ensure high illumination uniformity (minimum E_{min} or maximum E_{max} illuminance vs. mean value E_m). The values of the luminaire output ratio h_t (without considering the louvers), ranged from 74.0% to 76.9%. The efficiency was greater than that of the luminaires used at present but much lower than the theoretical value 89.6%.

4. Increasing luminaire efficiency by using a discontinuous reflector

In the method presented above such undesirable effects as that of the reflected luminous flux falling once again onto the light source and reflector are not taken into account. It appears that the secondary reflectance of the luminous flux by the reflector is to be preferred to the luminous flux falling once again onto the lamp since in the former case even with a reflectance of 0.85, an efficiency of 0.722 was noted whereas in the latter, the luminous flux falling on the lamp is diffusely reflected in 40 - 50% and then is lost in inter-reflections. These studies show that an increase in luminaire efficiency can be achieved by using a discontinuous reflector with the upper part so contoured that every point along the curves reflects the beam exactly where desired and not once more onto the lamp and the reflector [1]. However, because of the wide diameter of the fluorescent lamp and the small width of the luminaire, it is not possible to eliminate the undesirable effects completely since the height of the luminaire would have to be at least 160 mm, that is too high to be applied in practice. A partial solution to the problem is to use a discontinuous reflector, the upper part of which is so designed that the rays pass by the lamp while the lower part constitutes a LID in other directions. Fig. 7b shows the profile calculated of a discontinuous reflector. The lower reflector is a part of the most efficient of the reflectors previously calculated (Fig. 5 - 0.8). Although this discontinuous reflector is marked by a slight decrease in the uniformity of illumination (E_{min}/E_m = 0.917, E_{max}/E_m = 1.129), the efficiency is increased by about 4%, that is to 80.7%.

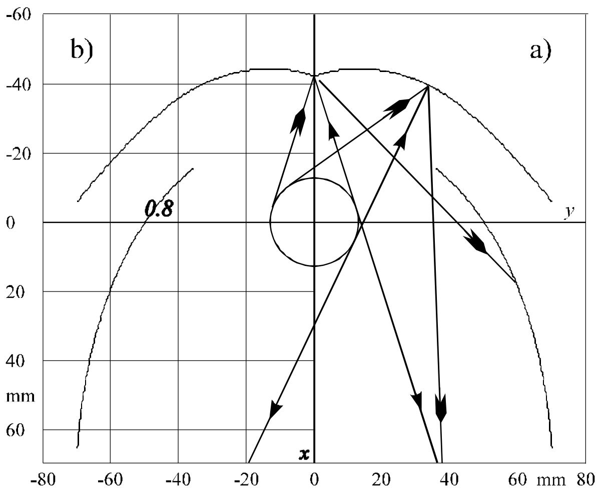

Fig. 7. The method of calculating a discontinuous reflector

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6.

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