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DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS



TREMBACH, V.V.

T-1497

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9 tr pp

CATALOGED BY ASTIA
AS AD NO. 276801

U S Army
Engineer Research And
Development Laboratories



276 801

FORT BELVOIR, VIRGINIA

Translated for
U.S. Army Engineer
Research and Development Laboratories,
Information Resources Branch
Washington 25, D.C.

V.V. Trembach

Illuminants Equipped with Powerful Xenon Lamps. (Svetil'niki s moshchnymi ksenonovymi lampami) Svetotekhnika 8: 1-7. 1961. In Russian.

Translated by

ROYER and ROGER, Inc.

International Division

1000 VERMONT AVE., N. W.
WASHINGTON 5, D. C.



41 EAST 28th Street
NEW YORK 16, N. Y.

ILLUMINANTS EQUIPPED WITH POWERFUL XENON LAMPS

V. V. Trembach

Candidate in Technical Sciences Moscow Power Institute

Beginning in 1958, articles in foreign technical journals [1] began to describe the operating principles of superpower xenon lamps (from 10 to 65 kilowatt), their performance characteristics, and application in exterior lighting installations [2].

In April, 1960, the Moscow Electric Lamp Plant, under the supervision of I. S. Marshak, developed the first USSR xenon lamp of 20 kilowatt capacity [3]. An advantage of this domestic lamp is the fact that it can be used without ballast resistance as a result of its excellent volt-ampere characteristics.

Examination of test samples of 20 kilowatt lamps produced by MELZ [3] has shown that they have lighting engineering properties superior to lamps of foreign manufacture. Their luminous efficiency is 26-30 lumen/watts and over-all brightness in a direction perpendicular to the longitudinal axis of the lamp is in the range of 1 to 1.3 mnt. The power factor is close to 1, stability of operation is satisfactory, and the power of the individual samples fluctuates from 18 to 21 kilowatt. Table 1 presents the nominal values for characteristics of Type DKST20000 lamps manufactured by MELZ.

Light distribution in the plane that is perpendicular to the lamp's axis is practically uniform; in the plane of the lamp's axis, it corresponds to (a) in Figure 1; a distribution curve for over-all brightness of that plane is given in (b) of Figure 1. Deviation of the curve of light forces (Figure 1, (a)) from the law of cosines and, also, the increased values of over-all brightness for large angles β can be explained by the significant transparency of the xenon discharge. The photometric body of the lamp can be described as a globe with deep hollows along the lamp's axis. Further evidence of this is the value of the coefficient that combines the maximal light force of the lamp with its luminous flux, equal to 10.3-11.1 (its value for a cylinder of equal brightness is π^2 , for a globe - 4π).

Distribution of brightness along the tube may be considered to be approximately uniform (with exclusion of the regions near the electrodes). Brightness in the lateral section has an adequately expressed maximum in the center of the discharge canal and then diminishes to zero magnitude toward the tube's edges.

In association with the Administration of the Fuel-Power Plant and the Moscow Electric Lamp Plant, the School of Illuminating Technology and Light Sources of MEI conducted a study on the application, in exterior lighting installations, of powerful xenon tube lamps and on the development of efficient optical devices for illuminants employing these lamps.

In connection with the application of powerful lamps having a flux of 0.5 to 2 million lumens each, a significant reduction in the number of illuminants is achieved. The role played by the illuminant in this case assumes further importance, since the expediency of application of powerful lamps, in the final analysis, is determined by the possibility for effective redistribution within the space of their light flux. A 20-kilowatt lamp, mounted at a height of 30 meters provides illumination (along a line perpendicular to the lamp's

axis) of 63 lk below the support and 6 lk for a distance of 58.5 meters from the support. If the standard illumination is taken at 6 lk, one must note the non-uniformity of its distribution and, thus, the excessive electric power consumption. If the condition of uniform distribution of illumination is adhered to, the illuminant must have - in the direction of $\alpha = 75^\circ$ - a light force that is 62 times greater than under the angle $\alpha = 0$, while, in the range of angles $\alpha = 0-45^\circ$, the light force of the lamp exceeds the required force tenfold and threefold, respectively. The above leads to the obvious conclusion that it is important to achieve a significant redistribution of the light flux in powerful xenon lamps, and gives an indication of the considerable difficulties to be encountered in the achievement of such redistribution.

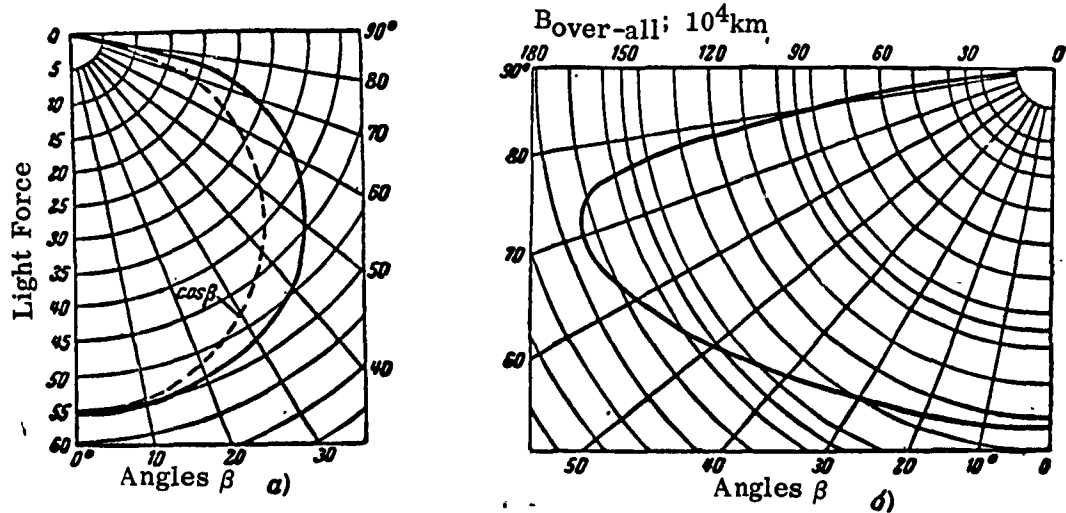


Figure 1.

- (a) Light Force Curve of Xenon Lamp (P=20 kilowatt) in the Longitudinal Plane;
 (b) Over-all Brightness Curve for the Lamp in the Same Plane.

Table 1
 Nominal Values of the DSKT 20000 Lamp.

P kilowatt	U_s w	U_1 w	i a	N lum/watt	F k/lum	I_{max} kilo/candle	l mm	L mm	d mm	B_{\perp} millihenry
20	380	380	57	29	580	56	1680	1980	27	1,235

Types of Optical Devices for Illuminants. Powerful xenon lamps are of cylindrical shape and have a ratio of length to tube diameter that equals 63 for type DKST20000. Thus, the luminescent body of this lamp practically constitutes a straight line. Such a shape of the lamp is inconvenient for the redistribution of light flux by means of an optical device that must also be cylindrical in shape. In view of the above, the sweep angle of the optical component cannot be wide; thus, in the longitudinal plane of the illuminant, it is always smaller than 180° . Owing to the cylindrical form of the optical part of illuminants for xenon lamps, the concentration of their light flux along the different directions in space is limited and is feasible only in the plane perpendicular to the lamp's axis.

A cylindrical mirror reflector with open light apertures serves as a primary optical component of illuminants equipped with powerful xenon tube lamps. A significant concentration of light flux under wide angles α in the profile plane evidently is based on the presence of a paraboloidal-cylindrical component in that reflector.

In view of the considerable irradiance of the surfaces, the temperature of an illuminant of acceptable dimensions can reach significant values (up to 300°C). Therefore, it would hardly be useful to employ glass shields and prismatic refractors that would cover the light aperture of the illuminant. It should also be noted that the radiation spectrum of xenon lamps contains a strong infrared portion that is well absorbed by glass.

The use of diffusion cylindrical reflectors cannot be considered practical since the maximum intensification (by a factor of 3) offered by such reflectors, is inadequate for purposes of effective redistribution of light flux. The profile curve of a mirror reflector must have a paraboloidal portion that is capable of assuring the necessary strengthening ($k_v = 8-15$), and further circular zones that distribute the light flux in directions that do not require strengthening; for example, for $\alpha = 0$, the illuminant requires a light force that is considerably smaller than that at the lamp itself. Shown in Figure 2 (a) is a diagram of rays in the profile plane of a single-pencil cylindrical

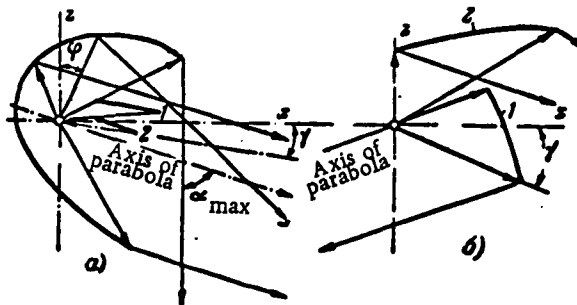


Figure 2.

- (a) Diagram of a single-pencil mirror illuminant for the lighting of large areas;
- (b) Diagram of a bi-reflecting mirror illuminant for street lighting.

mirror reflector used to light large areas. For the direction $\alpha = 0-30^\circ$ the direct light of the lamp appears excessive and therefore, along these directions, the upper circular portion of the reflector is operative, distributing light flux at wide dihedral angles, a circumstance that makes it possible to obtain a light force of small magnitude. The necessary concentration of light flux in the direction of angle α_{max} is provided by the lower paraboloidal portion of the reflector. To prevent the light flux from radiating into the upper hemisphere and, also, to make sure that the illuminant has the proper protective angle in the profile plane, the reflector must be supplemented by flat mirror inserts (1 and 2).

An illuminant for street lighting purposes must have an optical device near its center support that will reflect the light flux in two directions along the street. For this reason, the optical component of such an illuminant has been designed in accordance with the principle of a bi-reflecting, wide-angle radiation illuminant [4]. The ray diagram from its symmetrical half is given in Figure 2 (b). The strengthening coefficient of such an illuminant may reach a value of $4 \div 8$. The profile curve of formulas [5]. For the paraboloidal portion of the reflector:

$$r_{\varphi} = \frac{2r_0}{1 + \cos \varphi}, \quad (1)$$

where r_0 - the focal distance of the parabola (the radius-vector of the profile curve that coincides with the axis of the parabola at angle α_{\max});

φ - the angle formed by the actual radius-vector and the axis of the parabola.

For the circular portion of the reflector,

$$r_i = r_{i-1} \frac{\cos(\varphi_{i-1} - \delta_{cp_i})}{\cos(\varphi_i - \delta_{cp_i})}, \quad (2)$$

where φ_{i-1} , φ_i - polar angles, read from the vertical axis z , which orient radius - vectors r_{i-1} and r_i ;

δ_{av_i} - the angle constituted by the normal, passing through the center point of the i -zone, with axis z .

Using these equations, one can compute the required profile of the reflector by the method of completing the given curve of light forces by means of zonal curves [5].

The optical devices described above provide non-symmetrical light distribution. When it is necessary to obtain circular-symmetrical light distribution from an illuminant with xenon lamp (for example, when a support tower has to be placed in the center of a circular area), the illuminant's optical system must be slightly different. In this case, bent xenon lamps must be used which, together, can be combined to form a ring-shaped illuminating body (for example, 3 Type DKST20000 lamps form a ring of 955 mm radius). The mirror reflector of such an illuminant [6] is formed by rotation of the profile curve around the axis of the support tower (Figure 3).

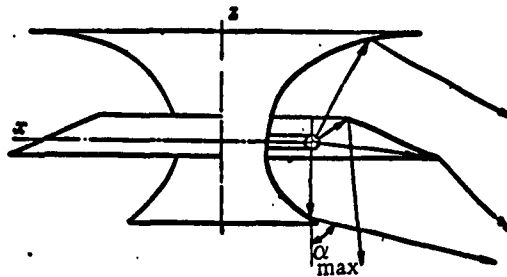


Figure 3.

Optical Diagram of a Circular-Symmetrical Mirror Illuminant with Xenon Lamps.

The type of surface of a mirror reflector may have considerable influence on the light distribution of the illuminant, since the filaments of the xenon lamp and the possibility of their bending during operation may cause difficulties in focusing, which is important for the paraboloidal-cylindrical portion of the reflector. An illuminant having a smooth-surfaced reflector will always have a certain amount of diffusion of light flux as a result of defocusing, the presence of the reflected diffused component, or lack of precision in manufacture.

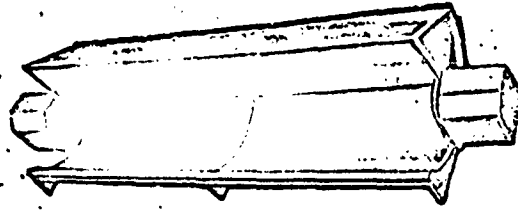


Figure 4.
Mirror Cylindrical Illuminant for Street
Lighting (experimental sample).

To obtain a smoother light force curve, the use of a bevel reflector, or a reflector with a wavy surface is recommended. Methods for the computation of the light force curve and zonal curves of mirror reflectors of the types indicated can be found in the literature [5, 6, 7].

To reduce glare, the illuminant must have protective angles both in the profile (Figure 2) plane ($\gamma = 10-20^\circ$) and in the longitudinal plane ($\gamma' = 15-25^\circ$). The protective angle in the longitudinal plane is formed, as in the case of luminescent illuminants, through the use of lateral protective screens.

The exposure to comparatively high temperatures of the illuminant must be taken into account in the selection of the material for its optical component. If a continuous reflector is desired, only metal can be used as the light-reflecting material. Due to the high temperatures and the lack of protection of the reflector from dust and the action of atmospheric conditions, a corrosion-resistant material should be selected. For check purposes, reflectors were made of polished aluminum, Alzac-aluminum, and stainless steel. The reflector made of stainless steel, having a general co-efficient of reflection of $\rho = 0.6$, and a mirror coefficient $\rho_3 = 0.5$, withstood operational tests particularly well. A glass mirror, having a coefficient of $\rho_3 = 0.85$, can be used in the form of individual platelets (facets) of small dimensions (500 x 100 mm); the glass should be tempered and should be capable of withstanding substantial temperature fluctuations.

Examination of an Experimental Sample of an Illuminant. In the course of checking the efficiency of proposed designs of optical installations of illuminants with xenon lamps, the study of their temperature patterns, and the precision of manufacture of theoretical forms of reflectors, we designed, and the Administration of Fuel-Power Plant of Mosgorispolkom constructed and developed an experimental sample of a mirror cylindrical illuminant. Its reflector was made of stainless steel (Figure 4), based on the diagram shown in Figure 2 (a) ($\alpha_{\max} = 75^\circ$). The sweep angle of the cylindrical reflector in the profile plane equals 210° . The flat mirror insert has a sweep angle of 60° and reflects light flux from $\alpha = 15^\circ$ to $\alpha = 70^\circ$. Overall dimensions of the reflectors are: height - 537 mm, depth - 404 mm, length - 1,700 mm. The computed maximum light force equals 360 kilo/candles ($k_y = 8$), while the angles of radiation were: 110° in the profile plane and 170° in the longitudinal plane. The results of photometric measurements are given in Figure 5 (a) and (b). From the light force curves one can see that, as a result of low-precision manufacture of the reflector and its buckling during operation, the maximum of the photometric curve was reduced to 282 kilo/candles ($k_y = 6$), while the curve became wider both in the longitudinal and the profile planes. Estimated and actual values of the efficiency differ but slightly and equal 0.66 and 0.70, respectively. The low precision of manufacture of the flat mirror insert of the illuminant affected the appearance of a second maximum ($\alpha = 110-150^\circ$), since, in that zone, the lamp is not covered by reflectors. However, in spite of the shortcomings noted, investigation of the experimental sample indicated that the proposed design solutions for the optical portion of illuminants for xenon lamps were adequately effective. Temperature measurements of the illuminant made it possible to select the reflector dimensions on a sound basis. To eliminate the excessive heating of the optical components, their

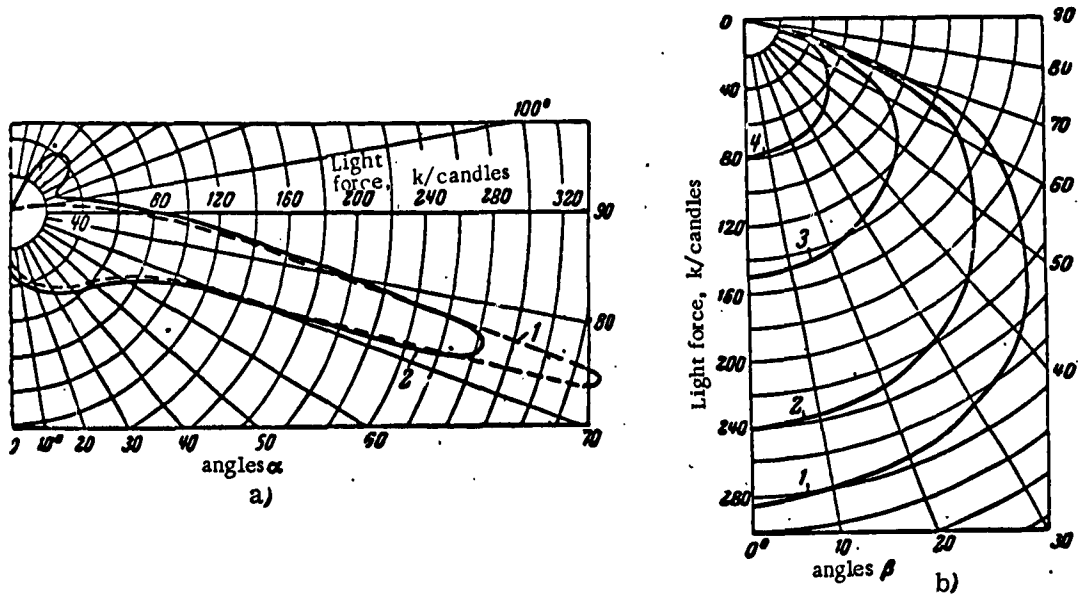


Figure 5.

Curves of Light Forces of An Experimental Illuminant With Xenon Lamps.

- a - in the profile plane $\beta = 0$ (1 - theoretical, 2 - photometric);
- b - in the longitudinal plane (1 - $\alpha = 75^\circ$, 2 - $\alpha = 72^\circ$, 3 - $\alpha = 70^\circ$, 4 - $\alpha = 60^\circ$).

minimum distance from the xenon lamp ($P = 20$ kilowatt) should be 150 - 200 m.

Design Characteristics of Illuminants with Lamps of the DKST20000. Examination of the experimental illuminant made it possible to select, on a sounder basis, the design, and to perform the computation for the optical portion, of illuminants for xenon lamps. The illuminant for purposes of lighting city squares was computed on the basis of its proposed installation on support towers 20 to 30 m high. The light force curve on which computations were based was determined from the expression

$$I_a = \frac{E_H H^2}{\cos^2 \alpha},$$

where E_H is the standard value of illumination and H is the height of the installation.

Angle $\alpha_{\max} = 70^\circ$. The curve not coinciding with that of the light forces was not standardized.

The optical component of the given illuminant (Figure 2, a) consists of mirror cylindrical reflectors and flat inserts made of stainless steel ($\rho_3 = 0.5$; $\rho = 0.6$). The cylindrical reflector has a paraboloidal profile with a sweep angle of 190° (from $\varphi = +10^\circ$ to $\varphi = -180^\circ$). At its upper portion, the parabola joins a portion of the periphery. The overall sweep angle of the cylindrical reflector equals 230° . The axis of the parabola is inclined at an angle $\alpha_{\max} = 70^\circ$, as a result of which the illuminant has its maximum light force in that direction.

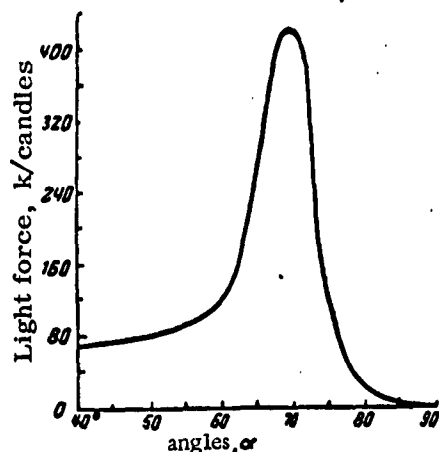


Figure 6.

Curve of Light Force $I_{\alpha} = f(\alpha)$ in the Profile Plane ($\beta = 0$) of a Single-Pencil Illuminant.

light forces in the profile and longitudinal planes are given in Figure 6 and in Tables 2 and 3. The maximum light force $I_{\max} = 460$ kilo/candles ($k_y = 10$), the light flux of the illuminant $\Phi_{il} = 380$ k/lum, $\eta = 0.65$.

Depending on the height of the support tower and the dimensions of the area to be lighted, the direction of the maximum light force and the magnitude of protective angle γ of the illuminant may be varied by rotation of the latter around the axis of the lamp. The design of an illuminant with the optical component described above was worked out by D.M. Budarin. Illuminants of this type were developed and used by the Administration of Fuel-Power Plant of the Mosgorispolkom for the purpose of lighting the area of the British Exhibit at Sokol'niki.

The illuminant can be installed both on the roof of a structure and on a support tower. When required, two such illuminants can be mounted on a support tower back to back, three - in the form of a triangle, four - in the form of a square, etc. In the latter two cases, the light distribution of the combined illuminants will be approximately symmetrical.

To determine the quantity and arrangement of illuminants equipped with powerful xenon lamps, it is convenient to use curves of identical values of illumination. For this reason, curves of identical values of relative illumination (Figure 7) were computed

In addition to the cylindrical reflector, the illuminant has two flat mirror inserts that cover the light flux of the lamp at angles from $\varphi = 50^\circ$ to $\varphi = 110^\circ$ which reflect it into the lower hemisphere along directions from $\alpha = 10^\circ$ and $\alpha = 70^\circ$. These inserts provide a protective angle in the profile plane, $\gamma = 17^\circ$. The radiation angle of the illuminant in the same plane 90° ($\alpha = 0 - 90^\circ$).

In the longitudinal planes the illuminant has a radiation angle $\beta = 160^\circ$ (from $\beta = 0^\circ$ to $\beta = 80^\circ$ in both directions). For the planes indicated the illuminant has a protective angle $\gamma' = 20^\circ$. It is assured by five lateral screens and the ends of the illuminant. The screens have a sector form with a radius $R = 173$ mm and are 70 mm from the lamp, with a distance of 300 mm between them. Over-all dimensions of the reflector and inserts are: height - 627 mm, depth - 441 mm, length - 1,700 mm.

The theoretical curves of the illuminant's

Table 2
Curve of Light Force $I_{\alpha} = f(\alpha)$ of an Illuminant for Lighting of Squares (profile plane $\beta = 0$).

α , deg	0	10	20	30	40	50	60	65	70	75	80	90
I_{α} , k/lum	29	52	64	65	68	80	116	250	420	135	20	0

Table 3
Curve of Light Force $I_{\beta} = f(\beta)$ for Longitudinal Plane $\alpha = 70^\circ$.

β , deg	0	10	20	30	40	50	60	70	80
I_{β} , k/lum	420	410	405	392	312	298	195	60	0

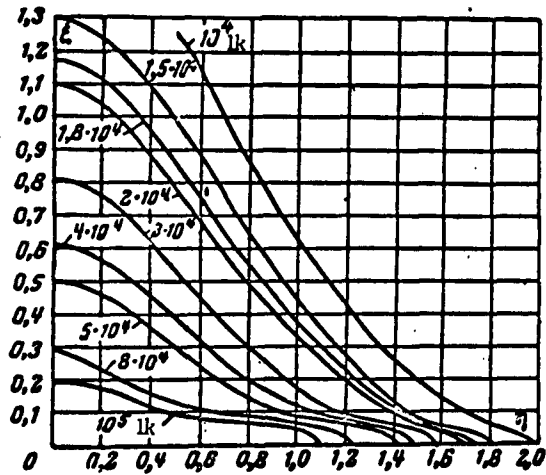


Figure 7.

Curves of equal values of relative illumination of a single-beam illuminant.

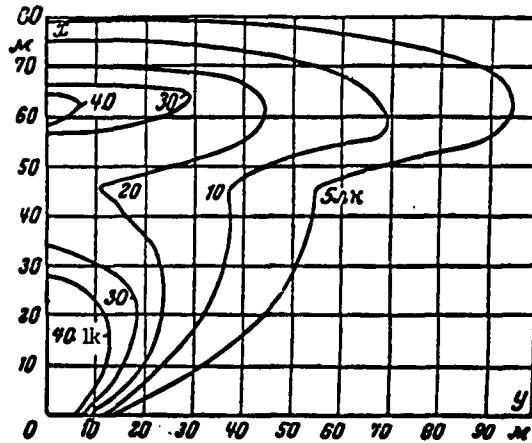


Figure 8.

Curves of equal illumination of a single-beam illuminant
 $H = 23$ m, $\theta = 20^\circ$.

for the illuminant under discussion with the aid of which one can, on the basis of known methods [8] determine the isolux for a given height of installation of illuminant H and angle θ , composed of the direction of the maximum right force with the horizontal. As an example, Figure 8 presents curves of equal illumination, computed for $H = 23$ m and $\theta = 20^\circ$.

An illuminant for street lighting has the optical device shown diagrammatically in Figure 2 (b). The lower portion of the illuminant consists of two paraboloidal-cylindrical reflectors that send the maximum light force in the direction $\theta = 70^\circ$.

The upper reflector of the illuminant, for simplification of manufacture, was designed in the form of two flat mirror inserts inclined at an angle of 8° to the horizontal. Width

of the mirror strips includes 350 mm. They are joined at a distance of 140 mm from the center of the lamp. The protective angle of the illuminant in the longitudinal planes equals $\gamma' = 20^\circ$. It is equipped with lateral screens in the same quantities and dimensions as used in the first illuminant. Specifications are: $I_{\max} = 232$ kilo/candles, $k_\gamma = 5$, $\eta = 0.68$, and the light force curve is analogous to that of the experimental illuminant (Figure 5).

Design and Manufacturing Requirements for Illuminants. Experimental and theoretical investigation of mirror illuminants for high-powered xenon lamps permit the formulation of the following requirements:

1. The material for the reflector must have a reflective coefficient of not less than 0.65. It is important that $\rho_3 = (0.85 \div 1) \rho$. The material of the mirror reflector and the flat inserts, in addition to the value of ρ_3 noted above, must be corrosion resistant and must be able to withstand high temperatures (up to 300°C).
2. In the design of illuminants, the problem of cleaning, and restoring the mirror properties of, the reflector during operation must be taken into account. It is recommended that screens be made of ordinary steel (without luminescent covering) and that reinforcements be provided against buckling.
3. The illuminant must be equipped with a spare lamp that switches on automatically when the original lamp burns out. The light aperture under the lamp must be covered by a protective screen that furnishes protection against splinters should the lamp break.
4. The design of a single beam illuminant must provide for its rotation both around the vertical axis (support tower) and relative to the axis of the lamp. Precision of the end surfaces of lateral bearing planes that constitute the surface of the reflector must be not less than 0.5 mm with relation to the theoretical profile. To reduce the danger of the reflector's buckling, it must be made of individual sheets whose one dimension must be equal to the length of the profile curve, and the other - not more than 500 mm.

The author expresses his gratitude to all students who participated in the above work in the course of performing study-research assignments, course and diploma projects. Thanks are also expressed to the collective of the "Mossvetstroy" Trust and to A.A. Veprintsev, who have made active contributions to this effort.

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