A New Super-Wide-Angle Lens for Projection Plotters

S. MALCHOW,
Dipl. Ing., Wild Heerbrugg Ltd., Heerbrugg, Switzerland

(*Abstract is on page 1047*)

EIGHT years have passed since Wild Heerbrugg of Switzerland introduced the Super Aviogon super-wide-angle lens in the new RC9 Camera especially developed for it, and the A9 Autograph at the VIII International Congress for Photogrammetry in Stockholm in 1956. There has been enough time to have proved the instruments and the super-wide-angle method practically and to have demonstrated their advantages. To mention it briefly once more, the advantage of the super-wide-angle system is that for a given heighting accuracy a considerably larger area is covered per photograph. The number of photographs required, and consequently also the number of control points to be fixed, is thereby reduced. Both these factors are of great importance as far as time and costs are concerned.

In the course of the past years the B9 Aviograph has developed in completion of the system, providing an instrument for small-scale mapping at a particularly favorable price.

At the request of our U. S. customers and also in consideration of the number of plotters with double optical projection presently in use in the U.S.A., it was decided some time ago to develop a projection lens which would allow, because of its optical characteristics, optimum plotting of super-wide-angle photographs in projection type plotters.

This lens was computed by Dr. L. Bertele, the famous designer of other Wild lenses. By the following I introduce it to you and inform you of its optical properties.

Basically, the new Wild super-wide-angle projection lens is similar to the Aviogon type lenses. This is a logical consequence considering the advantages offered by this type of lens.

The projection lenses which have been used up to now in the various projection plotters are based more or less on the Topogon, a lens developed out of the Hypergon by R. Richter more than 30 years ago. Its most important characteristics are the symmetrical half-spherical lens elements (Figure 1).

All these lenses show a marked decrease in illumination into the corners of a magnitude of worse than $\cos^4$. The reason for this is that, due to the condenser effect of the front lens, the inclined bundle of rays passes through the aperture with a larger inclination to the optical axis, resulting in vignetting caused by the aperture. In addition to this, a further loss of illumination is caused by the vignetting effect of the lens mount.

By contrast, in lenses of the Aviogon type the inclination of the rays to the aperture plane is *reduced* by the introduction of negative front lenses, thus avoiding the reduction of the incident bundle of light by the aperture. Further, the losses in luminance at the image edges caused by vignetting are reduced by designing the front negative lens with a large diameter in comparison to the aperture. These two precautions together have the

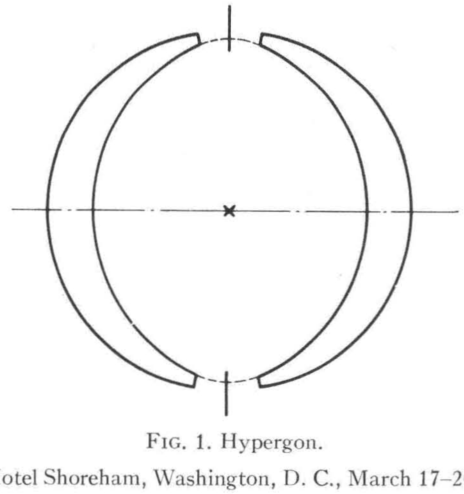

FIG. 1. Hypergon.

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effect that the reduction in illumination is proportional to only about $\cos^3$.

Since good illumination of the corners of the projection image is an important criterion for the quality of a projection lens, it was appropriate to use an Aviogon type of lens for the new super-wide-angle projection lens.

Of course, the requirements for the projector lens are of quite a different nature as compared to those for an aerial camera's lens. A good projector lens should have the following properties:

1. Minimum loss of luminance to the edges.
2. High resolving power not only in the corners, but also within a certain range of enlargement.
3. Distortion should be as small as possible.
4. The projection center should be free of aberrations.

An additional difficulty is presented by the characteristic anaglyph projection with blue and red light for image separation. It was, therefore, necessary to design two types of lenses to obtain optimum correction for each color. On the other hand, the distortion of the two lenses must be practically identical in order to allow interchangeability of the aerial photographs to be projected.

The following comments will now show to what extent it was possible to satisfy these requirements in the case of the new lens. As in many technical fields, maximum compliance with one requirement is obtained at the expense of another. The art is, therefore, to find a compromise which satisfies all requirements as well as possible.

The lens (Figure 2) consists of 5 optical components separated by air spaces and comprising a total of eight lens elements. The relative aperture is f/8. The usable angular field is 120°. For a reduced picture format of 115×115 mm. and an average enlargement ratio of 1:8, the principal distance is 44.25 mm.

In sequence, distortion, resolving power and luminance of the lens will next be investigated.

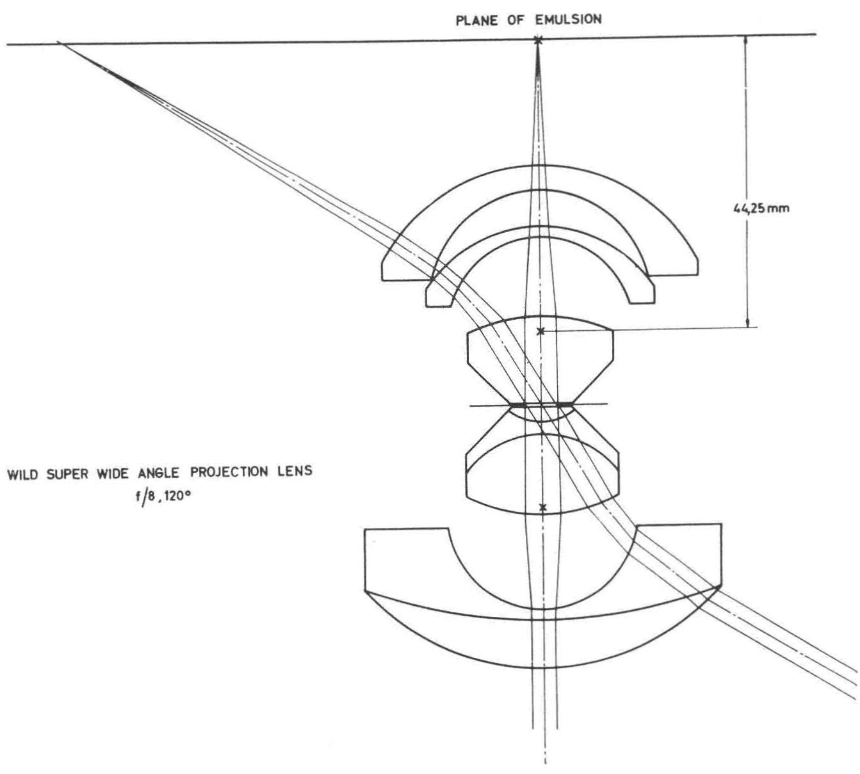
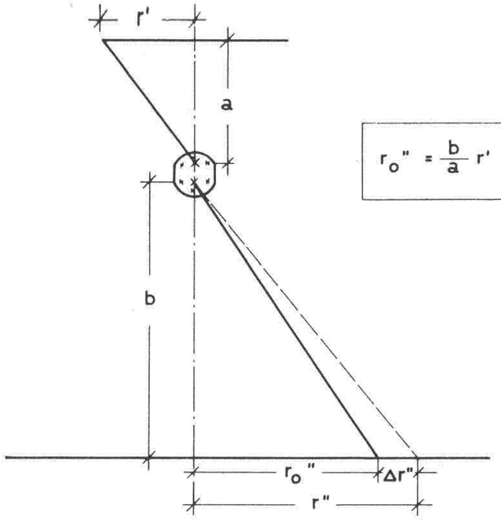


FIG. 2. Wild super-wide-angle projection lens, Cartogon f/8 120°.



$$r'' = r_o'' + \Delta r'' = \frac{b}{a} r' + \Delta r''$$

$$\Delta r'' = r'' - \frac{b}{a} r'$$

$$\Delta r' = r' - \frac{a}{b} r''$$

$$\Delta r_i' = r_i' - \frac{50\text{ mm}}{r''_{r'=50}} r_i''$$

FIG. 3. Principle of distortion measurement in finite projection range.

A. DISTORTION

Aerial camera lenses focused at infinity are usually calibrated by means of a goniometer or a collimator arrangement.

In the case of a projection lens, however, the distortion must be determined at the finite range of image formation.

A relatively simple way of doing this is to project a calibrated glass scale and measure its projected graduations. Figure 3 shows the principle.

The distortion measurements carried out according to the method described gave the results for the new projection lens as shown in Figure 4.

The "blue" and the "red" lenses have approximately the same distortion.

For many types of work, the height errors of the stereoscopic model resulting from this distortion will lie within the tolerance. The distortion of the photographic lens will, of course, also play a decisive part in this. The ideal case, where the distortion of the photographic lens and that of the projection lens are mutually compensating, is probably very rare. If correction plates are used to correct for the distortion of the photographic lens because of higher accuracy requirements in the plotting, then it is practical to correct also for the distortion of the projection lens with the same plate.

By means of a correction plate, which usually compensates also the effects of earth curvature and atmospheric refraction, the total distortion can be reduced to practically zero.

B. RESOLUTION

The next diagram shows the resolving power of the red and blue projection lenses

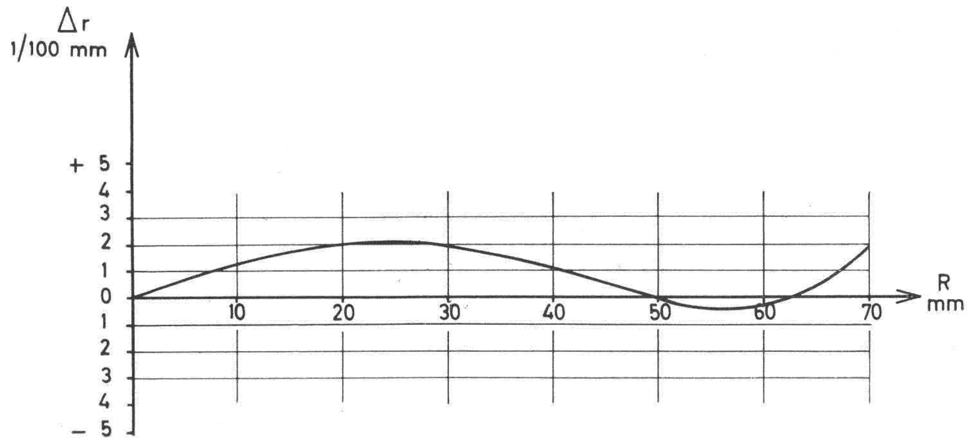


FIG. 4. Mean distortion curve of Wild super-wide-angle projection lens "Cartogon."

(Figure 5). This is referred to the reduced format of 115×115 mm and was determined in the plane of optimum image quality as well as in the planes 50 mm above and below that plane. A 10× magnifier was used to examine visually the test targets in the planes of projection.

The resolving power is almost the same in radial and tangential directions. Only in the plane of optimum sharpness, between the radii 10 mm and 50 mm radial resolution is about 25% better than tangential resolution. The curves represent the average of radial and tangential resolution. It can be seen that the lens resolves approximately the same number of lines from center to corners as is the case in aerial photographs. Since only the resolving power of the lens had to be determined, a lens condenser was used for the illumination to provide even distribution of the illumination of the pupil for all angles of incidence. If ellipsoidal reflectors are used for the illumination, the characteristics of the resolution are slightly different. As explained later, the pupil is not always completely illuminated with the latter system. Since that would correspond practically to projection with a smaller aperture, the resolving power is increased in such a case. On the other hand, the

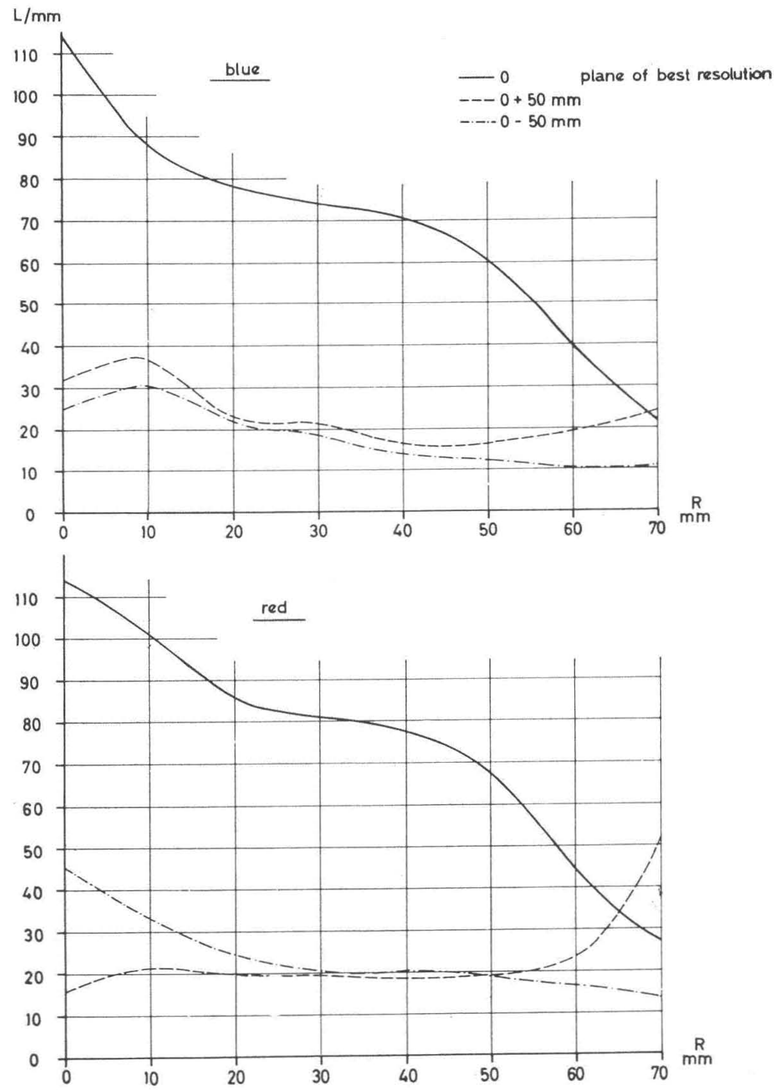


FIG. 5. Resolution of the "Cartogon."

structure of the filament, which is imaged sharply in the plane of the pupil, causes double images of the test targets in the plane of projection. This effect occurs only at the upper and lower limits of the range of sharp imaging, resulting in a decrease of the resolving power. This effect could be eliminated by using a frosted lamp or by introducing an opal glass filter: this would, however, lead to a loss of light.

C. LUMINANCE

The luminance of a projection lens must always be investigated in combination with the illumination system to obtain factual information on the illumination of the projection image. Since for various reasons the use of ellipsoidal reflectors is most satisfactory, particularly for super-wide-angle projectors, this case will be investigated more closely.

As is known, ellipsoidal reflectors are used in photogrammetric projection instruments in such a way that the lamp is placed in one focus of the rotational ellipsoid and the entrance pupil of the projection lens in the other (Figure 6). The illumination of the projection image is not rotationally symmetrical in this arrangement, but shows an asymmetry in the direction of the large ellipsoid axis.

The exact mathematical treatment of this problem would exceed the limits of this paper. The details have been published internally in the paper "Comments on the Ellipsoid Condenser" by R. David and the author in a Wild publication. A summary of this work will be given next, at least as far as is necessary for explaining the problems treated here.

The characteristic asymmetry of illumination of this system in the direction of the large axis of the ellipsoidal reflector has its cause in the variable scale of the image of the source of light. The image scale of the light source can be computed from the polar equation of the ellipse. The image scale λ of the light source as a function of the angle of direction of the ray α is:

$$\lambda\alpha = \frac{1 - \epsilon^2}{1 + \epsilon^2 + 2\epsilon \cdot \cos(\psi + \alpha)}$$

The curve of this function is shown in the next diagram (Figure 7).

Assuming an approximately *point-shaped source of light*, the luminous flux is $\Phi = I \cdot \omega$.

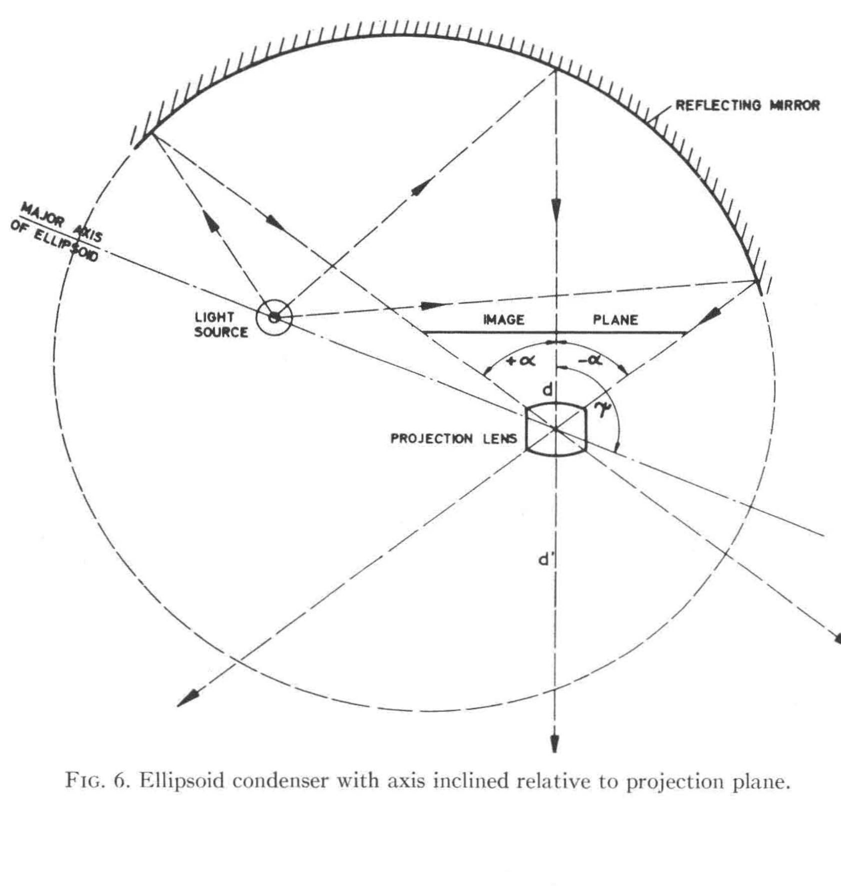
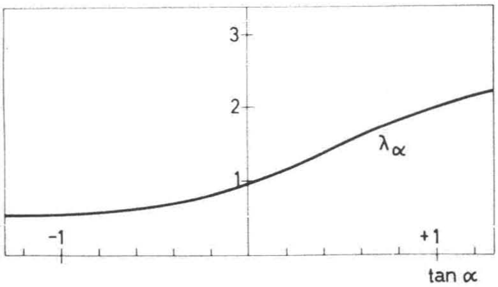


FIG. 6. Ellipsoid condenser with axis inclined relative to projection plane.



$$\lambda_\alpha = \frac{1-\varepsilon^2}{1+\varepsilon^2+2\varepsilon\cos(\gamma+\alpha)}$$

FIG. 7. Image scale λ of the light source as a function of the angle of direction of the ray α (for eccentricity of ellipse $\epsilon=0.4$ and $\psi=112°$).

The illumination in the *projection plane* is therefore:

$$E_\alpha = \frac{I\cdot\lambda_\alpha{}^2\cdot\cos^3\alpha}{\beta^2\cdot\alpha^2};$$

$$\left(\beta=\frac{d'}{d}\right)$$

The relationship of the illumination under the angle of inclination to the illumination at the center of the image, where $\alpha=0$ is then

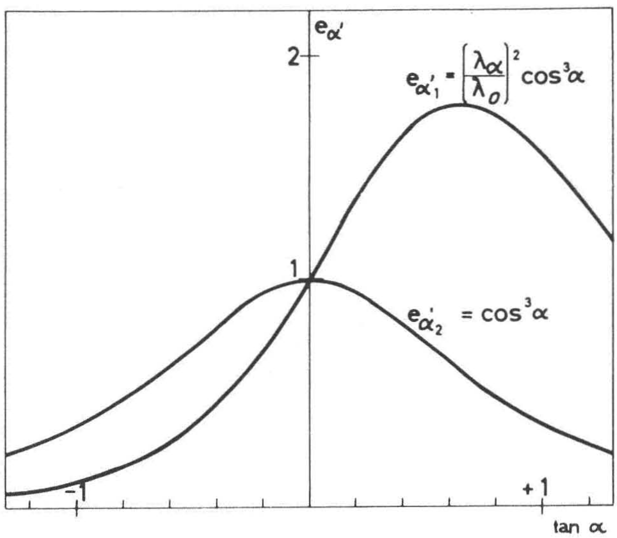
$$e'_{\alpha 1}=\left(\frac{\lambda\alpha}{\lambda_0}\right)^2\cdot\cos^3\alpha \qquad (1)$$

The next diagram shows the nature of this curve (Figure 8).

One recognizes from this that an approxi-

1. FOR POINT SOURCE OF LIGHT e'_{α_1}

2. FOR NON POINT SOURCE OF LIGHT e'_{α_2} (PUPIL FULLY ILLUMINATED FOR ANY α)



$$E'_\alpha = \frac{I.\lambda^2_\alpha . \cos^3\alpha}{\beta^2\ \alpha^2}$$

$$\frac{E_\alpha}{E_{\alpha-0}} = e'_\alpha = \left[\frac{\lambda_\alpha}{\lambda_0}\right]^2 \cos^3\alpha$$

E ILLUMINATION IN PLANE OF PROJECTION

$\beta = \frac{d'}{d}$ IMAGING SCALE OF PROJECTION

FIG. 8. Illumination in the projection plane at different angles of inclination α related to axial value unity.

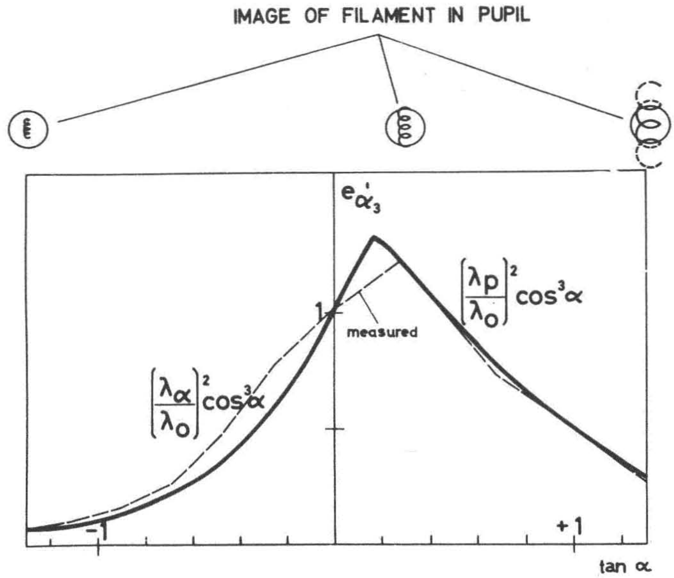


FIG. 9. Relative illumination in projection plane with given size of filament (3 mm).

mately point-shaped source of light is not as ideal for this arrangement of the illumination as one might think at first. If for example *the source of light were chosen so large that the pupil would be fully illuminated for all inclinations*, then the above equation would take the form

$$e'\alpha_2 = \frac{P\alpha}{P_0}\cos^3\alpha \qquad (2)$$

Here P represents the area of the pupil. In modern wide-angle lenses such as that described here, one can substitute $P\alpha/P_0=1$, since the pupil area seen from any angle is the same or even larger than that in the optical axis where $\alpha=0$. The equation can, therefore, be written

$$e'\alpha = \cos^3\alpha$$

This curve is also shown in the diagram. In practice, the use of such a large source of light is not possible without complications since it might lead to the generation of too much heat in the lenses.

Instead, light sources are, therefore, used which are neither point-shaped nor so large that the whole pupil area is illuminated at every angle.

For each light source there is an angle α_m which depends on the size of the source, at which the light source will just fill the area of the pupil. It is here that the maximum illumination lies. For the case where $\alpha < \alpha_m$ the Equation 1 will, therefore, be valid, and for $\alpha < \alpha_m$, the Equation 2.

The diagram which follows shows, as a concrete example, the curve of illumination distribution in the direction of the large ellipse axis both as measured and as found theoretically from the Equations 1 and 2 (Figure 9). α_m is here $+10°$. The width of the lamp filament was assumed to be 3 mm. The broken line represents the results of light measurements with white light. It agrees well with the theoretical computation. The deviations on the left side are explained by the fact that we have a light source of finite size but not spherical in shape. As a result of this the image of the filament in the pupil is altered in its perspective form, in addition to the size variation mentioned above.

The next diagram shows the lines of equal light values found from 153 light measurements in the plane of projection with white light at an enlargement ratio of 1:8 (Figure 10).

This diagram indicates that, in spite of some shortcomings which are inherent in such a system, a satisfactory illumination of the diapositives can be expected. While in some respects other systems may have advantages

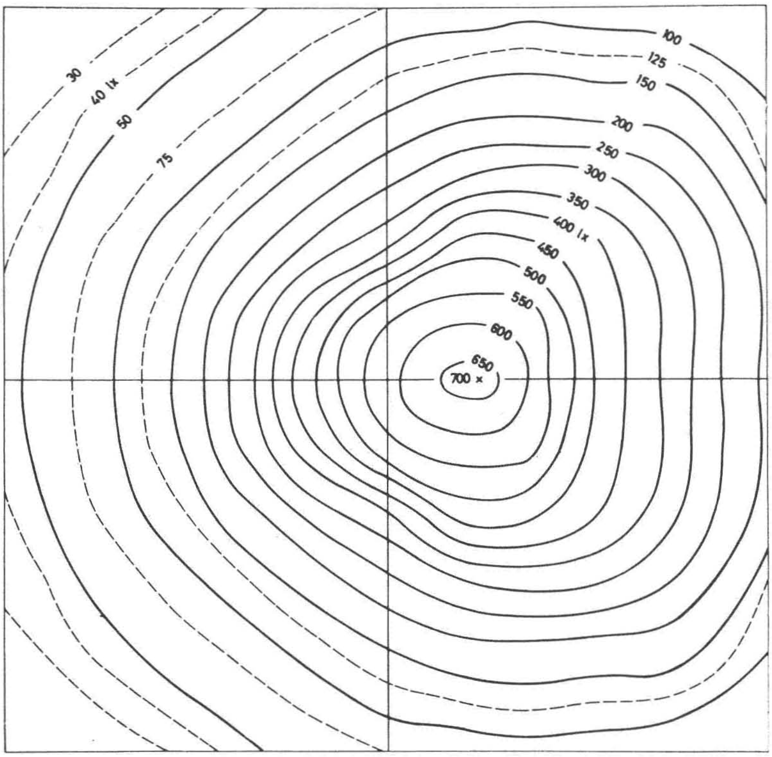


FIG. 10. Lines of equal lux values in the plane of projection with white light and an enlargement ratio of 1:8.

over the ellipsoidal reflector systems, the latter must still be regarded as the method of illumination for projection-type instruments offering the greatest technical simplicity, lowest cost and trouble free operation.

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*A Study of Rear Projection Screen Materials**

REX R. McHAIL,
Bausch & Lomb Incorp.,
Rochester, N. Y.

(*Abstract is on next page*)

IN THE last ten years, there has been an ever increasing demand for photo interpretation equipment which utilizes the rear projection method of image display. The advent of this requirement was somewhat concurrent with the shift in emphasis from photographic prints to transparencies as the interpretative media. Similarly there has been an advance

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