THE PROJECTION OF LENTICULAR COLOR-FILMS*

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Summary.—*In the projection of lenticular color-films a large portion of the incident light is lost by absorption in the tricolor filters. To determine the feasibility of satisfactorily showing these films in large theaters, an experimental projector was set up embodying the few simple changes in standard theater equipment that were necessary to obtain the required large increase in screen illumination.*

Successful demonstrations with the apparatus at Loew's Rochester Theater at Rochester and the Center Theater at New York have proved that it is quite possible to secure enough screen brightness to give a satisfactory showing of the lenticular films in the majority of theaters.

The principal changes made in the standard projection apparatus in order to obtain the greatly increased illumination were as follows:

(1) Increased Relative Aperture.—By substituting an f/1.6 projection lens for the f/2.4 lens commonly used, and by increasing the working relative aperture of the 65-ampere high-intensity reflector arc so as to take full advantage of the increased aperture of the projection lens, it was possible to get 2.25 times the screen illumination obtained with the regular equipment.

(2) Reduction of Shutter Loss.—A further increase was obtained by the use of a quicker pull-down and a corresponding reduction in the angle of the shutter blades; this may not, however, be feasible in practice.

(3) Increased Filter Transmission.—As a result of numerous practical tests it was found to be possible to increase the transmission of the tricolor projection filters by 33 per cent, without undue loss of color values.

(4) Lower Print Density.—The excellent tone reproduction obtained in the process, together with a modification of the optics of the lenticular film, makes possible a substantial lowering of the print density. The resultant increase in the brightness of the projected image amounts to some 25 per cent.

The large increase in the radiant energy directed upon the film has made it necessary to employ a heat filter in the condenser system.

Refinements in the present system are expected to produce additional small increases in illumination, and it is believed to be possible to develop other special equipment to take adequate care of the few (special) cases where it is necessary to project upon an unusually large screen.

The lenticular film color process, in common with other additive color processes, involves a large loss of light by absorption in the color filters necessarily used in the projection system. Therefore,

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it requires so much more illumination than is needed for projecting black-and-white pictures that it was believed until recently by many persons in the industry that it was impossible to show these pictures properly even in the average theater, not to mention the *de luxe* houses having screens from 25 to 35 feet in width. To illustrate the seriousness of the problem, it was estimated that about ten times the normal amount of light would be needed. The color filters used for projection during the earlier experimental work had a transmission of only 12 or 13 per cent, and the intensity was further reduced by the lenticular surface of the film support. The Kodak Research Laboratories recently undertook to make a systematic

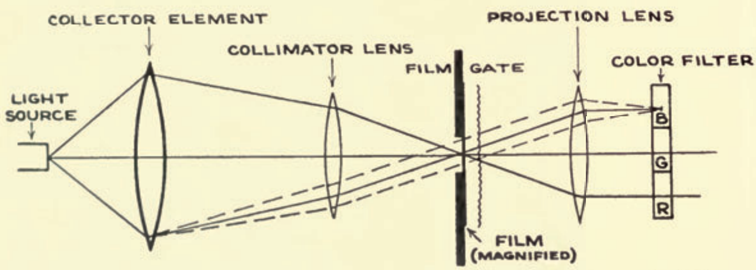

FIG. 1. Diagram of projection optical system for lenticular color-film.

investigation of the possibilities of lenticular film projection and to give an actual demonstration in a *de luxe* theater.

A preliminary survey of the problem indicated quite a number of possible ways in which the screen illumination could be increased. Some of these, which were temporarily laid aside for practical reasons, will not be mentioned except in the concluding remarks. With a desire to limit the investigation to the use of already existing projection equipment with only minor alterations, the work was pursued along the following lines:

(*1*) Reduction of the absorption loss in the color filters.
(*2*) Modification of the optical system to increase its relative aperture.
(*3*) Recovery of part of the light lost because of the shutter.
(*4*) Reduction of the density of the prints.
(*5*) Improvement in the operating conditions of the illuminating system.

EXPERIMENTAL

Filters

Since the greater part of the light is lost due to absorption in the color filters, the problem of screen brightness becomes progressively easier as the filter transmission is increased. After a certain point, however, the colors of the projected picture begin to lose saturation, and appear "washed out." The color reproduced upon the screen can be of no higher degree of purity than that of the projection filters. As the red filter is made lighter, it soon begins to transmit yellow, and becomes an orange-red. With such a filter a good red can not be represented properly upon the screen. After considerable experimental work with dyes, and a number of observations with filters of different densities, a standard filter was finally adopted that was thought to have the highest transmission it was possible to get without too noticeable loss in color saturation. The transmission of this filter, when used with the high-intensity arc system to be described later, was 22 per cent. This multiplied by the 80 per cent transmission of the lenticular film support gives an overall transmission of 17.6 per cent. Therefore, the factor by which the normal illumination needs to be increased is 5.8 times.

Optical System

Fundamental Conditions.—As shown in Fig. 1, the essential elements of a projection system suitable for lenticular color-films are: light-source, collective element, collimator lens, film-gate, projection lens, and color filter. A detailed discussion of the optical relations involved in the use of lenticular films is not within the scope of this paper, and therefore a mere statement is made of the necessary conditions to be observed in practice:

(*1*) The light-source must be imaged at the film-gate.
(*2*) The collecting element must be imaged at the color filter.
(*3*) It is essential that all elements be centered upon the optical axis.
(*4*) The color filter must be located at the front focus of the projection lens.

It will be obvious that the first three of these are the identical conditions for optimal screen brightness and uniformity, even in black-and-white projection. The fourth condition comes about as a result of a particular optical property of the lenticular color-film itself, and is dependent upon the optical arrangement used in printing.

Projection Lenses.—The greatest single gain in illumination promised to come from increasing the relative aperture beyond the $f/2.5$ systems commonly used. In view of the successful use, in the 16-mm. field, of lenses having relative apertures of $f/1.6$ or better, it was thought that it should be possible to set up a 35-mm. system that would be equally efficient. Two $f/1.6$ lenses were obtained having focal lengths of 120 and 160 millimeters. Except for the somewhat inferior definition of one of them, these lenses were entirely satisfactory for the purpose. On account of the much larger diameter of the lens barrel, it was necessary to make a new lens mount for the Simplex projector.

Illuminating Systems.—Before the increased relative aperture could be fully realized, it was necessary to modify the existing illuminating system so as to fill an angle of $f/1.6$ and at the same time to fulfill the

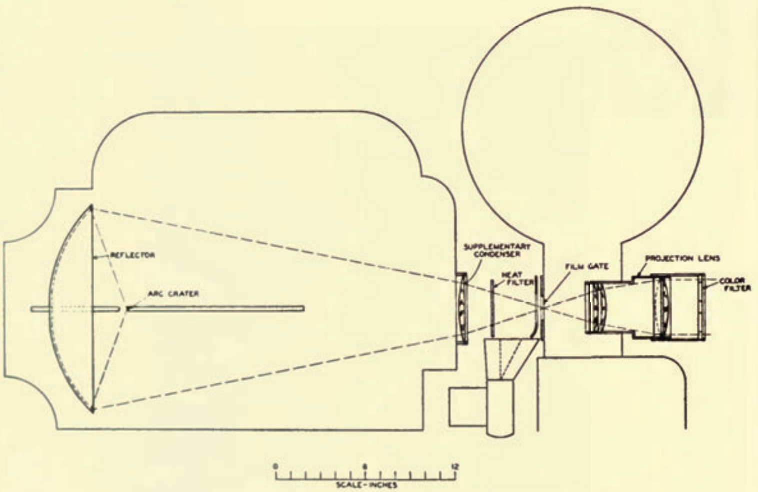

FIG. 2. Scale drawing of experimental projection system.

conditions necessary for use with lenticular films. The lamp selected for the first experiments was the Peerless "Magnarc,"* which appeared to be a good example of a high-efficiency reflector system. After a number of optical arrangements had been tried, using reflectors of various focal lengths, it was apparent that the only change necessary was the addition of an inexpensive condenser lens at the front of the lamp house. To avoid breakage due to the extreme heat, this lens was made of Pyrex. The complete optical arrangement as it was finally used is shown in Fig. 2, which is drawn approximately to scale. The regular "Magnarc" reflector is 14 inches in diameter, and

* Other lamps on the market similar to this one should be equally suitable.

$5^1/_4$ inches from the arc crater. The plano surface of the auxiliary condenser is 28 inches from the center of the reflector, and $5^1/_4$ inches from the film-gate. This condenser is $4^7/_{16}$ inches in diameter and 15 inches in focal length. The addition of this condenser to the "Magnarc" brings the image of the reflector into the plane of the three-color projection filter. The filter is located near the front focal plane of the projection lens, a necessary condition for lenticular film projection. In order to allow the larger cone of illumination from the modified illuminating system clear access to the film-gate, it became necessary to enlarge the apertures in the shutter housing and in the masks back of the aperture plate on the Simplex projector. When the full $f/1.6$ relative aperture is filled, there should be 2.31 times the screen brightness that is obtained with a corresponding system of relative aperture $f/2.5$. The actual screen brightness obtained with this system was slightly less due to mild imperfections in the quality of the reflector. Certain dark zones appear upon the reflector surface when viewed from the film-gate. This modified "Magnarc" system was used for a great part of the experimental work and for the demonstrations that are to be mentioned presently.

Magnification of the Arc Crater.—It will perhaps be contended that the increase in the relative aperture attained in this way is at the expense of the crater magnification at the film-gate, and that the uniformity in screen brightness will be unsatisfactory. Of course, the crater of the high-intensity arc is not uniform in brightness, being brighter at the center than at the border. For this reason, and also in order to provide some tolerance in the position of the arc, present illuminating systems are made to have a higher magnification than would be necessary just to fill the aperture. However, when the lenticular color-films are projected with the above-described system, the corners of the picture do not appear to be more poorly illuminated than is the case with the average black-and-white system. The reason for this lies in a particular requirement of the camera and projector lenses used in the lenticular film process. The lenses used in black-and-white work, both in the camera and, to a somewhat less extent, in the projector, cause a falling off in the marginal illumination due to the fact that the lens aperture can not be completely filled for oblique angles.[1] With some of the camera lenses ordinarily used in black-and-white work, this becomes so bad that the corner illumination falls nearly to zero, and results in a print having higher density at the corners than at the center of the picture. When this print is projected, the additional density at the corners adds considerably to the deficiency of corner illumination already present in the projection system.

This property of the lenses becomes objectionable in the lenticular color-film process, but for a different reason, as seen in Fig. 3, which shows different views of the lens and color filters as they would appear when viewed from different points of the screen. Disproportionate areas of the color segments are illuminated for different

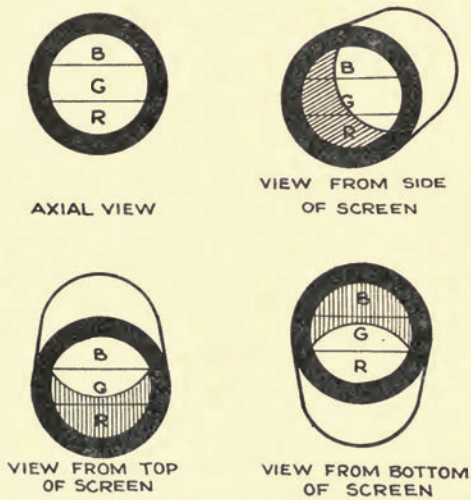

FIG. 3. Projection lens and color filters seen from different points of the screen showing cut-off of the filter zones.

positions around the margin of the screen, a condition that leads to an uneven distribution of color on the screen and can not be tolerated. Thus, because of the choice of lenses that this makes necessary, one can afford to use a lower magnification of the crater. However, it may be desirable to have a slightly larger crater image than that used in the present system, which could be accomplished by substituting a 9- or 10-mm. carbon for the 8-mm. one now used.

The Heat Problem.—Considering that there are already reports from theaters when using improved black-and-white equipment of too much heat at the picture aperture, it was not surprising to find in the preliminary trials with this more efficient optical system that the film was badly damaged by the terrific heat. Attempts to cool the film by a jet of compressed air were insufficient. Clearly some sort of heat filter had to be used. Previous experience with water cells did not favor their use in the theater projection booth, so heat-absorbing glass was tried. Used in a single sheet, it broke repeatedly even though it was of the heat-resisting type. Cutting the glass into $^3/_4$-inch strips and mounting the strips side by side prevented breakage, but it was found that the glass would soon melt unless subjected to a current of air. Since too much color in the glass would have been objectionable, it was necessary to use a density only just sufficient to reduce the heat to a safe value. The filter finally adopted was in the form of several $^3/_4$-inch strips of Corning *Extra-Light Aklo,* 2 millimeters thick, held loosely side by side in a rectangular metal frame, and cooled by a gentle current of air from a small furnace blower. The location of the filter in the optical system must be such that the edges of the glass strips are not visible upon the screen. In the present instance, the glass was mounted upon the front of the shutter housing at a distance of approximately $3^3/_8$ inches from the film-gate. No trace of the edges of the strips has ever been noticed upon the screen. The air was directed upon both sides of the glass by appropriate baffles With this filter, which transmits only 25 or 30 per cent of the total heat energy, the heat at the aperture is actually less than that occurring with some of the better projection lamps now in use. The familiar "biscuit" appearance of projected prints is entirely lacking. Part of the air from the blower is directed upon the film-gate, which gives slight additional cooling to the film and to the metal parts around the aperture.

A Relay Condenser System.—To see what could be done with the 120-ampere, high-intensity arc used with a condenser system, a Hall & Connelly lamp was set up with a set of 7-inch condensers and a relay system. In a relay system full advantage can be taken of the entire crater surface because it is not imaged at the aperture. Furthermore, advantage can be taken of the fact that the entire crater area emits red light of practically uniform intensity. Since in color work, the limiting color seems to be red, use can be made of the entire crater surface. The measurements of screen brightness made with this set-up show that it is possible to get equally as bright a screen with the "Magnarc" system, and it becomes somewhat easier to maintain the screen uniformity. Therefore, where there is sufficient space in the projection room to accommodate the increased length of a relay system, this type of lamp would serve very well. The remarks about to be made about adjustment and operation of the optical system apply equally well to condenser systems and reflector systems.

Adjustment and Operation.—A great number of observations were made with the best types of black-and-white illuminating systems at present in use, in order to determine, if possible, what effect the operating conditions and the adjustment and alignment of the optical system had upon screen brightness. Based upon these observations, it is believed probable that the average theater projection machine often does not deliver much more than half the screen illumination it is capable of delivering. Losses occur in many ways: accumulation of dirt upon the screen lowers the reflecting power; the reflector or condenser surface facing the arc becomes clouded with smoke, pitted by flying particles, and has to be cleaned constantly in order to preserve the light transmission. Because of the imperfections in the commercial mirrors and condensers, the screen uniformity is not at its best when the system is adjusted to provide the maximum of screen brightness.[1] The projectionist, therefore, has to sacrifice a considerable amount of screen brightness in order to improve the uniformity. Errors in centering condenser systems can be responsible for appreciable losses of illumination. Some projection lenses are in use that have a lower transmission than is desirable. Carbon arcs are somewhat erratic in behavior. The crater sometimes burns unevenly, and the crater brightness varies from time to time. Substantial improvement could be made in all these operating conditions. Possibly new equipment would have to be designed in order to free the projectionist from the necessity of constantly attending to the adjustments of the various manual controls found upon the present lamps. If the arc operation could be sufficiently stabilized, and the arc crater accurately held to the optical axis, the entire system could be set up and adjusted once for all, and the projectionist would then be required to make only the single adjustment of keeping the arc crater in the correct position along the optical axis. There is no reason, furthermore, why an arrangement using photoelectric cells could not be devised that would make even this adjustment automatically.

Reduction of the Shutter Loss

Since 50 per cent or more of the incident light is lost at the shutter, it seemed worth while to attempt to recover some of this loss by speeding up the pull-down movement, and using shutter blades of the narrowest possible angle. No originality is claimed for the method used. Inside the housing of the Geneva pull-down mechanism used on all Simplex machines there is a pair of small spur gears, through which the intermittent assembly is driven. By substituting a pair of elliptical gears, the intermittent movement was accelerated so that the pull-down period occurred in 52 degrees of the cycle instead of the usual 90 degrees. Using this in combination with a 45-degree covering blade and a 30-degree flicker blade, a gain of 59 per cent was made in screen illumination. However, it was thought that this was too severe for the film, and a second pair of elliptical gears was prepared that gave a more moderate acceleration to the pull-down mechanism, and accomplished the movement of the film in a 68-degree interval. Using with this a covering blade of 60 degrees and a flicker blade of 40 degrees, a gain of 44 per cent was realized. However, unless there are certain changes made in projector design that will compensate by reducing the stresses occurring during the pull-down operation, it is doubtful whether application of even this mild degree of acceleration to the Geneva movement is practicable. The Powers movement, however, because of the smooth acceleration, offers possibilities for a quicker pull-down.

The proper size for the shutter blades was arrived at empirically by progressively increasing the width until there was no noticeable flicker or travel-ghost upon the screen at the ordinary brightness level. Advantage was taken in these experiments of the fact that the perceptibility of both flicker and travel is less as one proceeds to lower levels of illumination. If it should later be found necessary to increase the shutter blade slightly, it would represent a loss of only a few per cent. A further discussion of the subject of projector mechanisms is believed outside the scope of the present paper. Although the work done so far must be regarded as merely preliminary, there seems to be ample ground for believing that more can be done in a practical way to recover a considerable part of the light lost at the shutter. In this connection, moving the shutter to a position very near the film plane so as to effect quicker cut-off of the light-beam would be a worth while step. However, in the small neighborhood theaters, probably no change in projector mechanism would be needed in order to get sufficient light.

Print Density.—Another loss of light occurring in the ordinary projector is caused by the minimum photographic density allowable in making the print. Because of the excellent tone reproduction attained with the lenticular process, it is possible to make the print density lower than that of a corresponding black-and-white print by approximately 0.10. This gives a 25 per cent increase in picture brightness.

Summary of the Gains Made.—It was pointed out above in connection with the filters that the maximum filter transmission, combined with that of the lenticular support, was in the neighborhood of 17.6 per cent, which corresponds to a factor of 5.8. This is the factor by which the screen brightness must be increased in order to equal that of corresponding black-and-white projection. The gains made and discussed above may be summarized as in Table I:

TABLE I

		Factor
(*1*)	Increased relative aperture ($f/2.5$ to $f/1.6$)	2.31*x*
(*2*)	Reduction of shutter loss 60° to 40° shutter, 68° pull-down	1.44*x*
(*3*)	Lower print density by 0.10	1.25*x*
	Product of all the above gains	4.32*x*

This is somewhat short of the required 5.8, which is necessary to balance the filter loss. In addition to these gains, the authors are of the opinion that the screen illumination can be doubled if sufficient improvement can be made in the operating conditions of the arc and the optical system. The product of this and all the gain factors given above leaves ample margin for the projectionist in operating the projector when compared to the loss factor of 5.8 mentioned above.

DEMONSTRATIONS

The complete experimental projector was used to give two demonstrations in the Loew's Rochester Theater in April, 1936. On both occasions the 52-degree accelerated pull-down was used. After the 68-degree pull-down was substituted, the machine was used to give a demonstration in the Center Theater in Radio City on July 9, 1936, before some 200 guests. Many of the audience commented upon the show, but no one expressed any feeling that there was a lack of screen brightness. Some said they actually believed the screen brightness was greater than necessary.

Although many measurements of the screen illumination were made throughout all these experiments, a simple statement of the values in foot-candles attained would have little meaning in view of the conflicting reports already published both as to the screen brightness actually prevailing in theaters and as to the actual level of screen brightness that is to be desired. To give some indication, however, of the amount of light obtained on the screen of the Center Theater, the value measured with a Weston illumination meter, model *603*, without the color filters or lenticular film, but with the shutter running, was 33 foot-candles at the center of the screen. The screen picture was 22 feet wide, and the projection angle was approximately 28 degrees. If the heat-absorbing glass filter had been removed, the value would have been more than 40 foot-candles.

FURTHER POSSIBILITIES

Of course, every precaution was taken in both the demonstrations to assure optimal operating conditions. It is probably too much to hope that optimal conditions could be thus maintained at all times. With this in mind, other possibilities will now be discussed, by means of which still more light might be obtained. If the regular high-intensity carbons were used, instead of the Suprex carbons, in connection with a reflection type of lamp of most efficient design, there would be an increase due to the higher intrinsic brightness attained with the regular high-intensity carbons. The possibilities that a new type of arc source will be developed having still higher intrinsic brightness can not be excluded. In this connection, carbon manufacturers express the belief that developmental work now in progress will produce a carbon that, with the proper optical system and lamp mechanism, will give the desired intensity, color, and uniformity of light, and, at the same time, keep the energy input into the arc within reasonable limits. There are some improvements yet to be made in the present experimental optical system that will make it possible to eliminate some of the glass-air reflection losses. A desirable further improvement in the optical quality of commercial reflectors would reduce losses arising from the imperfect formation of the crater image at the film-gate. The belief has already been expressed that improvement in projector design could be made that would further reduce the shutter loss. Another consideration is the possibility of a slight reduction of the screen size. Even for black-and-white projection, a reduction of screen size is being advocated by some in the industry. It is difficult to find any objection to doing this, since, with the present sizes of screens there is always a large block of seats near the front of the theater that the patrons avoid because of the discomforts of so large a viewing angle. There would seem to be no loss of desirable seating space by making conditions more comfortable for those in the front even at the expense of some loss in the rear of the house. Since the screen brightness would vary inversely as the square of the screen width, a considerable gain in illumination ought to be made possible by only a moderate reduction of screen size. The use of the ordinary specular screens would, of course, be limited to the long narrow houses, in which the seats are distributed within an angle of some 20 degrees. The design of equipment to take care of the few large houses having exceptionally large screens must be considered as a separate problem.

CONCLUSION

Although not all possibilities have been utilized in this preliminary investigation of the problem, it is seen from the foregoing experiments that lenticular color-films can be projected satisfactorily in the average theater without the necessity of making major alterations in the present equipment.

REFERENCE

[1] COOK, A. A.: "A Review of Projector and Screen Characteristics and Their Effects upon Screen Brightness," *J. Soc. Mot. Pict. Eng.*, **XXVI** (May, 1936), No. 5, p. 522.

DISCUSSION

MR. RICHARDSON: Is it not possible, by means of the additional lens, to parallel the light-beam between the aperture and the projection lens, and thus have more uniform screen illumination?

MR. MILLER: Arc lights do not radiate with equal intensity in all directions. Something could probably be done by using a shorter focal length reflector. Unfortunately none were available at the time, and we wanted to incorporate a minimum number of changes in the lamp.

MR. TASKER: The review room screens at Universal Studio are measured daily, in view of the fact that they vary considerably. We find that it is possible by daily readjustment of the arc to get such results as 16 foot-lamberts at the center, $14^1/_2$ to 15 at the edges, measured horizontally across top and bottom. Within a day's time the lamp is out of adjustment, and may be off as much as 15 at the center, 15 on one side, and 11 on the other.

MR. KURLANDER: A ratio of $1^1/_2$ to 1 from the center to the corners is considered excellent. That is about the limit one can get and still maintain good efficiency. It is comparatively easy to get evenness if one wants to sacrifice intensity.

For 16 years or more we have been trying to get even a 10 per cent increase in screen illumination. Mr. Miller has just told us how he obtained a 400 per cent increase. In view of some of the methods used to attain this 400 per cent increase, I should like to see it analyzed a bit more. The mechanical efficiency of the projector, over a period of 16 years, has been increased from about 4 per cent to 8 per cent—a 100 per cent increase over a period of 16 years. Here, over night, we have another 400 per cent.

MR. MILLER: We got 2.3 times as much light by increasing the relative aperture. It was a few per cent less than that when the aperture was increased from *f*/2.5, which is about what is used on the average now, to *f*/1.6. I purposely omitted discussing the optical principles, particularly because they were so well treated by A. A. Cook in the JOURNAL of last May.

MR. MCAULEY: What is the distance from the vertex of the mirror to the aperture? How much did you move up the projector?

MR. MILLER: The projector was moved up only very slightly. The distance from the vertex of the reflector to the lens was 28 inches; from there to the aperture was $5^1/_4$ inches, making a total of $33^1/_4$. I believe a distance of 34 inches is recommended by the lamp manufacturers.

MR. MCAULEY: Was it necessary to change the reflector?

MR. MILLER: No.

MR. MCAULEY: In order to get the increase of speed? It would seem that you would hardly fill the lens at a distance of 33 inches.

MR. MILLER: If the light-rays are drawn backward after passing through the auxiliary condenser, it seems from the aperture as if the mirror were bigger.

MR. BRENKERT: Did you say that with the same mirror that was furnished with the lamp, and by adding the collimating lens, you filled an *f*/1.6 lens?

MR. MILLER: Yes.

MR. BRENKERT: And obtained more light upon the screen than by using an *f*/2.3?

MR. MILLER: Yes.

MR. BRENKERT: How did you get more light out of the arc, through the aperture and from the mirror, without changing any mirror specifications?

MR. MILLER: The fact is that the spot upon the aperture plate in the regular machine is much larger than the aperture itself, due to imperfections in the optical system, and also to the fact that the lamp manufacturer is desirous of giving a broad tolerance to the projectionist for keeping his arc focused properly. The magnification of the lamp without the condenser was six times.

MR. BRENKERT: You reduced the size of the spot by means of the auxiliary condenser, and that is your sole mention of greater angle and more light.

MR. MILLER: Yes, but we could use a larger carbon and a little more current, and thus increase the size of the spot. We use an 8-mm. carbon; but I think a 10-mm. would be better.

MR. BRENKERT: What became of the illumination at the corners?

MR. MILLER: If a black-and-white film was projected, the corner illumination was not good; if a lenticular film, the corners were no worse than for the black-and-white, with normal projection as occurring in theaters.