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Condensers, Their Contour, Size, Location and Support

By C. Francis Jenkins

Surprisingly little literature has been written on the subject of condensing lenses, and none at all with regard to their use in motion picture projecting machines. Investigators outside our own art have so far failed to observe that the problem is not the same in a motion picture projecting machine that it is in a stereopticon lantern, a difference resulting from the necessity for the use of a shutter with the motion picture projector. I shall confine my remarks practically wholly to the problems of the illumination of the picture aperture of a motion picture projecting machine and its result on the canvas, rather than to the subject, generally.

Condensing lenses are employed because it is practically impossible to illuminate the film directly. When we get a cold light it may perhaps be feasible, though this is debatable. But for the present, condenser lenses, for gathering the diverging rays of the luminant and converging them on the picture aperture, continue to be used.

Two lenses are usually employed in combination for the reason that to get the same gathering power with the same convergence in a single lens there would be too great a loss of light by reflection from the curved surfaces. So lantern makers usually take two plano-convex lenses and mount them with the curved surfaces together, which puts a flat side next the light source.

As a simple but rather interesting experiment showing the loss of light by reflection, hold up your next glass of water and try to look upward through the surface of the water at about [a] 45° angle. You will not be able to see anything above the water until it actually touches the surface. This total reflection phenomena is usefully employed in many ways, e.g., in engraving plants to reverse the picture for etching; in binoculars to give a large field and long-range telescope in short, compact form; in periscopes to see without being seen; in the Graphoscope for mechanical simplicity and convenient operation.

But this same reflection, when from the surface of a single condenser, is a very decided loss. For this reason it is usual to employ two lenses in a condenser system. The first lens, the lens next [to] the source of light, an electric arc usually, is popularly described as gathering the diverging rays and paralleling them, the second lens then converging them on the aperture plate. Lenses of 6 1/2 and 7 1/2-inch focus are usually employed for short projection distances, with the arc lamp 2 1/2 to 3 inches from the surface of the arc lens.

To parallel the light rays with these two lenses the arc should theoretically be 6 1/2 inches from the lens. But this is not best, for at the closer position more than four times as much light at the aperture results. If the rays could be paralleled by the first lens, the arc lens, then the converging lens might be any distance away. Because the arc lens cannot do this, the second lens, the converging lens, is brought up close to the arc lens in order to catch as large a portion of the rays as possible and concentrate them on the picture aperture.

Authorities on lenses have heretofore recommended that these converging light rays cross in the center of the projecting lens, but their conclusions have been based upon the old lantern slide assembly, which had the pictures just in front of the converging lens and did not employ a shutter at all. Their recommendations are not therefore wholly applicable, nor is the arrangement proposed for the lantern the best for motion picture projecting machines.

It might be nearer right if we could get lenses made so that the shutter could cut across the rays at the narrowest part, that is, at the diaphragm location in the lens. But this is not practical because, among other things, a variety of focal lengths of projecting lenses are required for different projection distances, or "throw," as the operator usually terms it. The preferable arrangement is, therefore, to put the shutter in front of the lens, and then to have the rays of light cross at that point.

The principal reason for having the shutter at the narrowest part of the projected light beam is that the obscuring blade may be as narrow as possible, so that when the other two blades, the flicker blades, are added they may each approximate the width of the obscuring blade and yet give a 50-50 ratio of light to darkness,

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which is the ideal arrangement for a flickerless picture today.

To readily determine where the light beam is narrowest is not always easy, for the light cone is not readily discernible. If, however, a card is passed vertically through the light just in front of the lens, a shadow will cross the screen, say, from top to bottom; with the card farther out the shadow will cross from bottom to top — but at a median position the passing of the card causes a shadow to cover the whole screen at once. That is the proper location for the shutter. One should remember, however, that a shutter that is just right, that is, most efficient, at this point will show halation or streamers, both above and below the letters of a title, if the arc is moved very much either toward or away from the condensers.

There are other factors also which have a bearing on the location of the various elements of the projection system. For example, a longer projection for the same size picture requires a projection lens of longer back focus. This again requires a longer cone of light from the converging lens. This lens must, therefore, be changed for one having less curvature. But when this is done the light spot on the aperture is too large, and the lamp house must be moved back. This draws the apex of the light cone back within the projecting lens barrel, so that another change is required. By repeated trials one would probably find the proper lens and best lamp-house position, but the easier plan is to advance the arc a little when an approximately correct lens and lamp-house position is found, and this is usually done.

When the lamp-house is moved back for the long "throw" it is not unusual to change the arc lens to a 7 1/2[-inch] lens, making the combination two 7 1/2[-inch] lenses. The resultant light loss is considerable, however, 50%, perhaps. This loss of light has given rise to an erroneous idea that the longer throw requires a correspondingly greater amount of current for a given size screen. Another plan is to let the 6 1/2[-inch] arc lens alone, and substitute an 8 1/2[-inch] lens for the 7 1/2[-inch] converging lens. This will give the same amount of light on the same screen at the longer distance, without increasing the current consumption. A 6 1/2-inch and 8 1/2-inch lens combination has practically the same equivalent focus as two 7 1/2-inch lenses, though the reciprocals are not exactly identical in both cases. However, the distortion of poor lenses sometimes prevent getting an even, white-lighted screen.

This brings us very naturally to the consideration of a better lens arrangement for the lens next [to] the arc, for, if this can be made a fixed factor, then the matter of adjustment for different lengths of throw is simplified.

Taking up the consideration of the arc and the theoretically best adjacent lens surface, it is at once apparent that if a curved surface could be employed, the same safe distance might be maintained between the arc and the lens at its center; while the outer edge of the lens, by reason of its enveloping curvature, would gather very much more light. But to make a single lens of this conformation having the same 6 1/2-inch focal length as the plano-convex usually employed gives the opposite or convex surface of the lens a disastrous curvature. A better plan is, not to attempt the total light refraction with the one lens, but set another close thereto having such a curvature that the sum of the two will give the focus desired. A lens of (-1 1/2 and +6 1/2 (dioptric measurement), say 8-inch focus, in combination with a 10-inch, either bi-convex or a plano-convex, is about correct for a 3-inch arc location and is an ideal arrangement, but unfortunately, it is only ideal. A meniscus of 6-inch focus would have to be about a +7, which obviously is not practical. The use of a (-1 1/2 and +5 1/2 lens, about 10-inch focus, in combination with either a bi-convex or plano-convex lens of 10-inch focus, is good, being approximately the equivalent of a 5-inch lens. This combination used with a 7 1/2, 8, or 8 1/2-inch plano-convex, seems to make a very satisfactory three-lens meniscus set.

There is still another factor to be taken into consideration — namely, the liability of condenser breakage. But, as has been explained, if the arc can be kept close to the lens very much less current is required for the same screen illumination. And right here a Kelvin law helps us very materially, i.e., "the light of an arc lamp increases directly as the increase in current, while the heat increases as the square." Obviously, therefore, if we can employ such an arrangement as will require but half as much current as another we get but one-fourth as much heat.

But at best the heat is such that the condenser gets very hot, though the heat of itself alone does not crack lenses. In actual practice I have found that if the arc lens is held in a nonconductive ring it will never break, no matter how hot it gets. Lenses crack because of unequal stress in the glass, and this comes about because something has carried away heat from a limited area and not from the whole mass evenly. Thus, if one should touch a very hot lens with a piece of metal, say, a screwdriver, the lens will crack, because the metal being a better conductor of heat than the glass robs the glass of its heat at the point of contact and the equilibrium of stress is disturbed and the glass cracks. I have had the glass crack across between my thumb and finger when I attempted to pick up a hot lens by its edge (without knowing before that it was hot). If the lens is heated evenly and remains so, that is, is not robbed of any part of its heat by a conducting or convecting medium it will never break. A complete understanding of this phenomena, and its proper recognition by the operator, would enable him to get a much more brilliant screen picture with much less current consumption.

It is exactly the same with many other improvements which might be attempted if we had graduate engineer operators to handle our machines. So the best we can do is to make a compromise machine and wait until the public grows up to our ideals. In this category is an adjustable shutter and the three-lens condenser system I've just been talking about; and, to come closer home, a multiple negative carbon arc with its single unshadowed crater in the exact axis of the optical system, an ideal arrangement which we had to give up because we couldn't take the time to teach each operator where such a lamp was installed, if, indeed, he were teachable.

Much of what is here explained could be calculated with exactness and applied by rule if the source of light were an infinitely small point, and condensers were as carefully ground and annealed as projection lenses; which, however, isn't the case. Also, the condensers and light source area have a definite bearing on the sharpness and brilliance of the screen picture aside from the question of illumination. The optical system of motion picture machines is a makeshift, and I hope that some of us will undertake a systematic investigation of it looking to a more definite knowledge and resultant improvement.

In conducting experiments with motion picture machines it is desirable, on occasions, to take the heat out of the light so that the light may shine on the film continuously for an indefinite time without igniting or puckering the film. The usual plan is a tank of water, located between the condensers and the picture aperture, through which the light must pass. This is a help, perhaps, but not wholly effective. Alum is sometimes added to the water, but, so far as my experiments go, adds nothing to its heat-absorbing property.

After repeated trials and finding that the water cell did not furnish the required protection, I set about to find out what would, and developed some surprises. Our first surprise was the discovery that ice water was less effective than warm water. Next I found that a plurality of thin glass plates, spaced apart, served the purpose admirably. The only trouble encountered was the breaking of the plates through which the light first passed. This, because the plates were heated in the region of the light spot faster than the glass could conduct it to the parts of the plate lying outside the path of the light.

To overcome this difficulty, a water cell was made into which glass plates were put, the water serving the purpose of equalizing the heat over the whole surface of each plate. No more breakage was then encountered. In order to dispel any doubt in your mind about the true reason for the results, I might add that after the cell was filled with water, but before the spaced glass plates were put in, the film ignited in from 32 to 35 seconds, but that after eight or ten plates were put in, the film was not ignited, or even puckered, after repeated tests of 25 to 30 minutes duration. This device cuts off some light — I have not yet had time to measure the loss — but a 50% loss is permissible and still [will] have as much screen illumination as results from the running of the machine without it but with the usual 50-50 shutter.

In this connection it may not be amiss to caution any of you who may wish to construct such a cell that the cell must be not less than about three times the width of the beam of light. I am not yet ready to say just why a narrow cell is not as good as a wide one in preventing the ignition of the film, and so will reserve a positive statement until from repeated experiments I can be certain of it.

Another thing which is interesting is that the same number of plates in surface contact with each other will not prevent ignition. A mica cell with spaced sheets is also effective, but the color of the mica and the flimsy, thin sheets are objectionable.

Another observed phenomena which gives further evidence of the complexity of the projected light is that:

There is a point between the condensers and the aperture plate at which a pencil, screw driver or other slender object held in the cone of light does not cast a shadow on the screen.

This seems incredible, but comes about probably because the heat rays, the light rays, and the color rays, which had, therefore, been more or less separated, so criss-crossed and mixed-up at this point that there are not enough directed rays to carry a defined image to the screen.

Further investigation of the light in this region is being made and will perhaps be presented in another paper following this primer presentation of the subject of condensers in motion picture projecting machines.

In concluding, let me encourage you to [do] original research, for the field is full of opportunity for profitable investigation. Stop a moment and think of it; no material change has been made in the mechanism, and no change whatever in the principle involved in projecting machines since the first projecting machine was deposited in the U.S. National Museum 20-odd years ago. It had the same arc lamp used today, the same two condenser lenses, the same aperture with tension plate, the same upper and lower sprockets, the same left-handed construction, and the same noise of an intermittently moved film. Here is abundant opportunity for original research work and improvement.

Nor have facts relating to lamp-house setting, lamp location, condensers, or other similar factors, been tabulated — not even the averages of the thousands of machines in use today. I think it should be done.

A condenser lens which I believe would be worth while to experiment with is the corrugated principle employed in lighthouse lenses. I hope that at our next meeting someone will be ready to read us a paper on lenses of this character.