THE OPTICAL-PHOTOGRAPHIC PRINCIPLES OF THE AGFACOLOR PROCESS*

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Summary.—*The physical and photographic properties of the lenticular screen process of producing motion pictures in color, as developed by Berthon, and later known under the name Keller-Dorian and commercialized in the 16-mm. field under the name Kodacolor, are briefly described. The author traces the development of the process from the earlier mosaic screen process, and after giving consideration to the technical problems involved, indicates that the situation obtaining at present may be regarded as one stage of a development leading up to the application of the lenticular screen process to the 35-mm. field as well as the 16-mm. field.*

Processes of making motion pictures in natural colors must satisfy at least the following principal requirements in order to be technically and practically successful:

(1) The photographic manipulation and apparatus must be simple.

(2) The process must provide sufficient color saturation and resolution; that is, the color elements must be small enough to be unobjectionable.

(3) It must be possible to make prints from an original exposure.

(4) The process must make efficient use of the available light, both in making camera exposures and in projecting the pictures on the screen.

It would be impossible, within a limited space, to mention all the processes that have been suggested and tested, or are still in the experimental stage, for producing colored motion pictures. A review of present methods is given by J. Eggert.[1]

This paper describes briefly the physical and photographic principles of the lenticular screen process as developed by the French optician, A. Berthon, in 1908. In 1913, Berthon and Keller-Dorian formed the "Société anonyme du film en couleur Keller-Dorian;" and, under the name of Keller-Dorian, this process is widely known. Out of this company, the "Société Cinechromatique" was formed in France, while Kodak took over the patents and commercially applied the lenticular screen process to 16-mm. film under the name

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of *Kodacolor*. Recently, Agfa has also produced a 16-mm. film based on the same principles, called *Agfacolor*.

Up to the present time, both companies have restricted themselves to the production of 16-mm. film only. The amateur usually takes his pictures outdoors, where he finds a large variety of colors and a wide range of light intensity; the lenses of amateur movie cameras have sufficient focal depth even at large apertures. Moreover, the lenticular screen process is so simple that only small and easily adaptable accessories are required in order to apply it to any existing camera. As to the photography, there is no difference between this process and the reversal process generally used in 16-mm. film technic. Therefore, the technical development of this field has not been retarded by unsolved problems of a satisfactory printing process. The 16-mm. picture is projected only to a limited size and brilliancy on the screen.

The fact, however, that this process is being applied only to 16-mm. film should not lead to the conclusion that it can not be applied to the 35-mm. standard motion picture film. The situation at present may be regarded as one stage of a development leading to the application of the lenticular screen process to the 35-mm. field as well.

In certain respects, the lenticular screen process in its photographic and optical principles is an extension of the mosaic screen process, long ago introduced into amateur photography. Indeed it might be regarded as a color screen process modified for motion picture purposes. Both the lenticular and mosaic screen processes are so-called additive processes; that is to say, the required colors are produced by blending three primary colors. A combination of red and green produces yellow; red and blue produce purple; blue and green produce bluish green. Red, blue, and green when properly combined, produce white. Conversely, it is possible to analyze any given color, with respect to the proportion of red, green or blue contained in it, simply by using filters of these colors. The color may then be reproduced by mixing light of these colors in the same proportions. This separation, or analysis, of the color can be accomplished photographically by exposing the film to the object through the color filters, either simultaneously or in succession, using one or several lenses. For reproduction, these exposures must be optically superimposed in perfect registration. With a color screen or lenticular screen, however, the tri-color analysis can be made in a single exposure, by dividing the photographic coating, in one way or another, into numerous small units, each unit being fitted with a red, green, and blue filter. The smaller the units, the higher the resolving power. Theoretically, these units should not be so large as to come within the resolving power of the eye (visual angle of 1 minute, corresponding to about 0.02 mm. at the natural viewing distance). Each area is fitted with a composite tri-colored window through which the light from each individual area of the object passes to the emulsion coating.

In the mosaic screen process we find the simplest application of this principle. Between the emulsion coating and the film (or glass), we find the color screen, an even blending of red, green, and blue transparent grains of starch or bakelite, irregularly dispersed. The mixture of the grains is never quite uniform, as the formation of small clumps of grains can not be avoided. The exposure of the emulsion is always made through the screen. Each group of differently colored grains forms a screen unit, in the sense already explained, and the light rays, passing through the grains, produce a photographic effect according to the primary-color content of the rays. In order to see the original in its true colors, it is necessary to subject the developed film to a reversal process, because the usual negative development produces only the complementary colors.

Unfortunately, the mosaic process can not be used for motion pictures. First of all, the enlargement necessary for motion pictures would magnify the grains of the color screen to a size within the resolving power of the eye, thus making the individual grains visible. Furthermore, on account of the random distribution of the color grains, local aggregations of similarly colored grains can not be avoided. A greater difficulty, however, is the fact that the random distribution of the screen elements over the entire image surface—their positions relative to the perforations of the film—changes with each and every frame of the film. On account of the intermittency of projection, these two effects cause a violent irregular movement of the colored grains, producing a disturbing visible effect particularly on larger areas of uniform color.

In order to adapt the color screen process to motion pictures, it would be necessary to arrange the color elements in a regular pattern parallel to the edges of the film. Thus the elements would no longer be distributed haphazardly. Naturally, the manufacture of such an extremely fine screen involves many practical difficulties;

nevertheless, commercial experimentation has already been successful and is being continued.[2]

The lenticular screen process as developed by Berthon solved the problem by very simple and ingenious means. Berthon abandoned from the very beginning the idea of attaching the filters, corresponding to the different surface elements, to the film, and of providing the film itself with a real color screen. On the contrary, the screen is produced on the film optically during the exposure, and on the screen during projection. The film serves only as a support for an optical system of tiny cylindrical lenses embossed on the film base. The width of each lens is about 0.028 to 0.043 mm., the focal length being 0.1 to 0.14 mm. The lenticular screen is adjusted to the taking or projecting lens system, as shown in Fig. 1. A color filter having three colored areas—red, green, and blue—in three parallel sections, is placed either inside or outside the lens system. It does not matter where the filter is placed, so long as it controls the aperture. Furthermore, the filter diaphragm, or its virtual image, must not obscure the entrance pupil of the lens from any part of the film. The outer parts of the filter would be so obscured, viewed from the margins of the film area. This defect will be more fully described later. Once the position of the filter has been fixed for exposing the film, this position becomes an inseparable characteristic of that particular film, and controls the true color reproduction. The illustration shows the color filter (e,g,r) placed in front of the lens, as occurs in practice. Its virtual image appears at a distance F from the film, the width D representing the limiting diaphragm. Each of the cylindrical lenses embossed on the film produces a real, inverted, and reduced image of the tri-color filter in the focal plane of the embossed lenses, since the distance from the film to the filter, in comparison with the very short focal length of the embossed lenses, is practically infinite. The filter images replace the grains of the mosaic screen, each image corresponding to one of the previously mentioned screen units. The maximum width is equal to the width of one embossed lens, and its length extends over the entire height of each picture, in the direction of the axis of the cylindrical lens. However, the units do not carry their own real three-color screens, but look, so to speak, through telescopes to the one common color screen, placed in the limiting diaphragm of the lens. The film itself appears colorless under ordinary observation.

The development is the same as in the color screen process; *i. e.*

the original must be developed to a positive in order to obtain a direct reproduction in true colors. But while the color screen positive itself contains all colors, it is necessary to provide certain optical arrangements for projecting the lenticular films in true colors. This is not of particular advantage in motion picture work. The simplest arrangement would be to use for projection the same lens

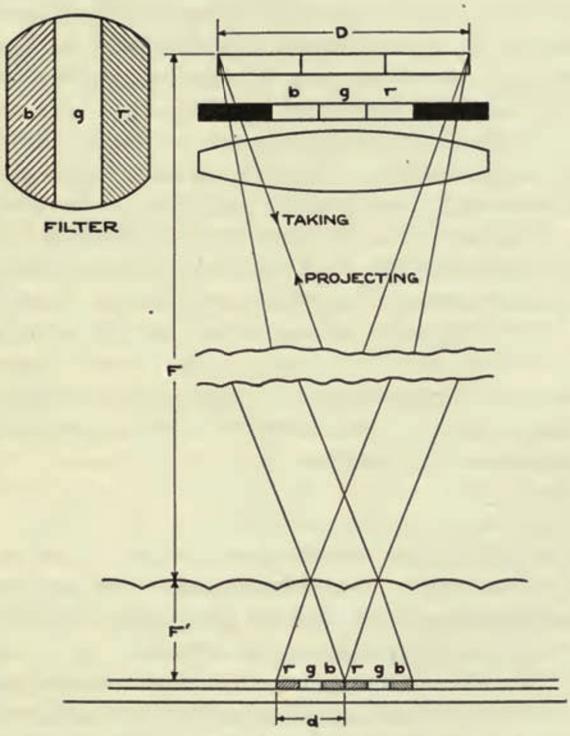

FIG. 1. Diagram of the optical system of the Agfacolor process. The cross-section of the film itself is shown at a much greater magnification than the objective and filters.

as used in the camera which would simply reverse the path of the exposing light. When lenses of other focal length and construction are used, care must be taken that the position and width of the color filter appear, from the point of view of the lenticular screen, identical to their relations during exposure. It is only then that, at the given focal length of the lenticular elements, the position and width of the filter images behind the lenticular screen are identical to those of silver images formed by exposure and development of the film.

If the color value of the projected image is to be at its best, the screen must satisfy certain requirements:

(1) The real image of the filter as projected behind the lens elements must lie in the optical plane of the emulsion; the thickness of the film base and the focal length of the lens elements depend on each other. The focal length of the lenses, in turn, depends on the refractive index of the base and on the curvature of the lenses; hence the embossing of the screen must be done in a very particular way.

(2) The real filter images behind the screen should cover the aperture of the lens element in the same way as the filter covers the aperture of the camera lens. No light should be allowed to pass between the filter images, as the white light thus passing would weaken the color. The size of the real filter image behind the screen is determined by the following simple optical relation: If, according to Fig. 1, D is the apparent width of the filter, as viewed from the film, and F is the apparent distance of the filter, then F/D will be the aperture at which the filter appears when viewed from the film. If we call F' the focal length of the screen lenses, d the width of the real filter image, and n the refractive index of the film base, the following equation will result:

$$\frac{F'}{d} = \frac{nF}{D}$$

If the ratio F/D is given by the focal length of the lens and the arrangement of the filter, then the maximum focal length of the lens elements is limited, as the width of the filter image can not be greater than the width of the cylindrical lens elements; or, by using a tricolor filter, the adjoining images on the outer filter strip would overlap, and red and blue colors would appear more or less purple.

(3) The narrower the individual screen lenses, the less the striped screen of the image will be visible on projection; on the other hand, the resolving power increases, and enables even the smallest images to be resolved into their details. Naturally, the grains of the emulsion should be small compared with the width of the stripes of the filter image. In the Agfacolor process, in which the width of the lenticular elements is 0.028 mm., the images of the individual color stripes have a maximum width of 0.009 mm., or twenty times that of the wavelength of green light. With respect to resolving power, the lenticular screen is superior to the mosaic color screen. Owing

to the geometrical coördination of the object, lens, screen, and image, details even smaller than the width of the lenses are reproduced in their correct position as regards color. With images smaller than one-third the width of the screen, mixed color details can not be resolved into their individual color elements.

(4) The quality of the pictures depends largely on the photographic qualities of the emulsion; particularly, on its color sensitivity. The latter, in turn, determines the choice of the filter colors with respect to their spectral transmission. The judgment and decision on this matter and the choice of the filter combination must be based merely on the principles of subjective psychology and on the average taste.

Theoretically, the lenticular films can be printed, but not by the ordinary contact method—numerous possibilities of doing this have been described and patented. It is important to preserve the original coördination between the density and the lens elements. The geometrical coördination between the silver grain, the lens elements, and the projection lens must be identical in both the copy and the original.

From the above it is seen that the characteristics of the lenticular film depend on the fact that the film itself bears the optical system that makes reproduction in colors possible. The quality of the projected picture depends a great deal on the degree of perfection of the screen. Consequently, processing, storing, and projecting require special attention. Grease spots, for instance, frequently encountered in motion picture theater practice, will change the optical properties of the screen or are likely to cause the entire screen picture to disappear.

As a support for an optical system, the entire area of the film must lie in proper relation to the lens and filter in both exposure and projection. Kinks or similar mechanical defects cause color distortions in projection. In addition to this, an exact adjustment of the camera or projection lens with regard to the film is very necessary. If, for instance, the projector aperture is not vertical to the optical axis of the lens, or if the film does not lie flat in the projector aperture, untrue colors will appear at the edges—so-called color dominants. Excessive drying of the film, which always causes some loss of solvents, also causes some displacement of the lens elements and is likely to disturb the projection. It is, therefore, advisable alway to store the film in air-tight cans.

With regard to transmission of light by the lenticular optical system, since the tri-color analysis is made with only one lens (for instance, a red surface would, when exposed and projected, use only one-third of the aperture; and, since the colors of the filters are not pure spectral colors, but contain some gray), there is greater loss of light in this process than in ordinary black-and-white photography. However, in motion picture photography, using lenses of short focal length and greater depth of focus, larger apertures can be used. The maximum usable width of the aperture is limited by the effective area of the lens in which there is no vignetting. If the filter were larger, parts of the lens mounting, or their virtual images, would obscure portions of the filter. This partial loss of one color would cause color dominants to appear at the edges of the picture when projected. For the same reason, it is impossible to use an iris diaphragm in order to reduce the amount of light. It is necessary to use neutral density filters (Eastman) or detachable slit diaphragms (Agfa). For exposure, lenses with relative apertures less than $f/2.0$ are hardly to be considered. The loss of light caused by the optical system can, to a certain degree, be compensated for by increasing the photographic sensitivity of the film. As the situation is at present, lenticular film can be used for outdoor exposures even under an overcast sky, and, under favorable lighting conditions, indoors.

Satisfactory projection can be obtained only with powerful projectors. Because of the loss of light, mentioned before, and for psychological reasons, it is necessary to have maximum brightness for color projection.

Before lenticular film can be introduced into motion picture theaters, some technical (not fundamental) difficulties must be overcome. First, it must be possible to make prints; second, the screen brightness must be sufficient. The requirements regarding illumination in the studio can be satisfied by increasing the sensitivity of the photographic emulsion. It is, however, difficult to solve the problem of obtaining satisfactory illumination on the large screens used in motion picture theaters.

REFERENCES

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