THE TECHNICOLOR PROCESS OF THREE-COLOR CINEMATOGRAPHY*

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Summary.—*The development of the Technicolor process is reviewed historically with particular reference to the guiding motives and technical objectives. This leads up to a brief description of the three-color camera and the three-color imbibition printing process. Following this is a discussion of the photographic principles involved in color photography particularly as they apply to the Technicolor three-color process.*

In the earliest days of the Technicolor development, we recognized that the ultimate goal of workers in the field of color cinematography must be a process that would add a full scale of color reproduction to the existing black-and-white product without subtracting from any of its desirable qualities, without imposing any complications upon theater projection conditions, and with a minimum of added burden in the cost of photography and in the cost of prints. These considerations seemed clearly to indicate a three-color subtractive printing process capable of ultimate low cost of manufacture.

In those days, most other efforts to develop a subtractive printing process made use of double-coated positive stock, invented about 1912 by Hernandez-Mejia. We found a number of objections to the use of this stock; particularly, to the spatial separation of the two components, to the susceptibility to scratching during processing and projection, but most of all, to the impediment imposed upon an ultimate three-color result.

Surveying the field, we chose to work upon the multi-layer, or monopack process, and the imbibition process. In a monopack process the several components are in successive layers, all coated upon the same side of the film strip. In the imbibition process, the several components consist of images formed in water-soluble dyes

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printed on, or rather into, a gelatin-coated film strip, much as colored ink images are printed upon paper in the process of photolithography. A multi-layer, or monopack, process can theoretically be used as a taking process and as a printing process; whereas imbibition, being a photomechanical process, is limited to use as a printing process and requires to be supplemented by a taking method, preferably one providing distinct separation negatives. As printing processes, both monopack and imbibition yield a final product containing all components upon one side of the film strip and with no limitation as to their number. Some fundamental and far-reaching work upon the monopack process by the late Dr. Troland, who at the time of his death was research director of Technicolor, resulted in the issuance in 1932 of Reissue Patent No. 18,680, containing two hundred and thirty-nine claims, broadly covering this field both for taking and printing. The imbibition process seemed to present a less formidable array of processing problems than did the monopack process, so we pushed its development with even greater effort.

We found it necessary to split the problem into two stages. As the first step in an imbibition process it is necessary to prepare a film bearing images consisting of a raised relief of hardened gelatin. This relief image, or matrix, serves the same purpose as the etched copper or zinc plate of photolithography. First, we had to find out how to make a gelatin relief suitable for use as a printing plate. We decided to content ourselves temporarily with two components and to stop short of actual imbibition by making use of an intermediate process wherein two gelatin reliefs, produced upon thin celluloid, were glued together back to back and dyed in complementary colors. Prints of the Technicolor sequence in *The Ten Commandments*, and of Douglas Fairbanks' all-color picture, *The Black Pirate*, were made in this manner.

Then, after having learned how to make gelatin relief matrices of good quality, we tackled the problem of making adequate transfers from those matrices. We had to learn how to prepare the blank film so as to permit imbibition without diffusion. We had to devise a transfer machine capable of handling film in long lengths and in quantities, and in which blank and matrix could be brought into registered contact and held there for several minutes while the dyes transferred.

Simultaneously with work upon these various subtractive printing processes, we devised a camera that gave two-color separation negative images free not only from fringing and parallax but also from the harmful effects of celluloid shrinkage. In this camera the two images were in symmetrical pairs, one being the mirror image of the other. These were arranged upon a single strip of negative stock with both members of the symmetrical pair positioned accurately with respect to symmetrically adjacent pairs of perforations. The perfect geometrical symmetry of this arrangement is shrinkage-proof during the entire life of the negative. The very compact prism system of this camera permitted the use of relatively short focal length lenses. The aberrations of the glass path were taken into account in the computations for these lenses.

Two-color imbibition prints were brought out commercially in 1928, just about the time that sound swept the industry. We were then immediately faced with the necessity of combining color with sound. The only procedure obvious at that time was tò make the sound-track identical with one or both of the picture components; but this would give a sound-track in dye, which would have varying absorption throughout the range of wavelengths to which photoelectric cells are sensitive. The response from such a track would then, of course, differ for one type of cell from that for another type and especially so in the case of a variable-density track. We avoided this problem by starting, not with a blank film, but with a strip of positive stock upon which the sound-track could be printed and developed in silver while leaving the picture area blank. Imbibition transfer of the picture components into this blank area could then take place. This method is capable of giving a sound-track absolutely identical to that used in the black-and-white art. Better yet, because of the complete separation of the sound-track technic from the picture technic, the necessity of any compromise between sound and picture quality is eliminated and ideal sound-track processing conditions are possible. Many millions of feet of two-color imbibition prints with a silver sound-track were produced by Technicolor in 1929 and subsequent years.

We were now ready to move on to a three-color process. Since we had planned to do so from the beginning, we encountered no fundamental impediment in our printing process. Mechanically, we had merely to combine the imbibition paths in groups of three instead of in pairs.

The proper choice of dyes presented more of a problem. In a two-color process many colors are compromised, so to speak, and there is considerable choice as to the manner and extent of compromise. In a three-color process, the accuracy of reproduction is greatly increased and the freedom of choice is greatly restricted.

An adequate three-color camera was an exceedingly difficult problem. Three-component taking methods that use only a single aperture (monopack, screen-plates, and lenticulated films) have advantage of economy of light and of mechanism, but they all have other disadvantages, particularly as regards separating or differentiating between the various components; and some of them present difficult raw-stock manufacturing problems.

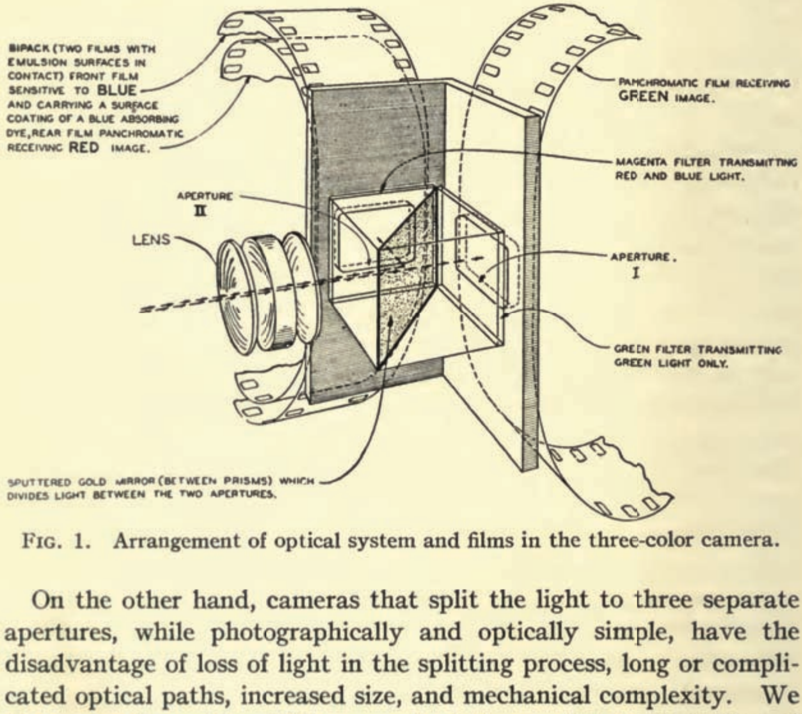

Fig. 1. Arrangement of optical system and films in the three-color camera.

On the other hand, cameras that split the light to three separate apertures, while photographically and optically simple, have the disadvantage of loss of light in the splitting process, long or complicated optical paths, increased size, and mechanical complexity. We chose as a favorable middle-ground solution an intermediate line of attack wherein *three* records are obtained at two *apertures*.

Fig. 1 shows schematically the arrangement of the optical parts and films in this camera. In making use of a bipack at one aperture, we have incorporated means for the practical elimination of halation and also for the elimination of any dependence upon the surface coating of one of the films for the exact determination of our red light filter. Thus, two of the most serious faults of ordinary bipacks have been removed.

To insure that there shall be no differential shrinkage among the three strips of negative, we specify that the celluloid base shall be of the low-shrinkage type, as made by the Eastman Kodak Company. This low-shrinkage celluloid base is of such quality that after processing the negative, including the manufacture of a volume of release prints, the shrinkage is approximately $^1/_8$ of 1 per cent, with differences in shrinkage among the members of a group of about $^1/_8$ of the total shrinkage. This amounts to a small fraction of $^1/_{1000}$ of an inch across the longest dimension of the picture and is therefore entirely negligible.

A group of five lenses ranging in focal length from 35 mm. to 140 mm. have been designed for this camera to our specifications by Messrs. Taylor, Taylor, and Hobson. The chromatic correction of these lenses has been designed to give, in coöperation with our film arrangement, three images of unusually high correction, thus compensating for the loss of definition in the red record of the bipack. The most notable feature of these lenses, however, is the inclusion in the 35-mm. design of what might be called the inverse telephoto principle, whereby the back focal length is considerably longer than the equivalent focal length.

However, it is not the purpose of this paper to go into further detail as to the design and construction of the camera, but to move on to a discussion of the methods of operating the camera. First, however, a brief outline of the complete process as we now work it is perhaps desirable.

The Technicolor three-color camera photographs the three primary aspects of a scene (red, green, and blue) upon three separate film strips, simultaneously, at normal speed, without fringe or parallax, in balance, and in proper register with each other. These separate strips are developed to negatives of equal contrast and must always be considered and handled as a group.

From these color-separation negatives, we print by projection through the celluloid upon a specially prepared stock, which is then developed and processed in such a manner as to produce positive relief images in hardened gelatin. These three hardened gelatin reliefs are then used as printing matrices which absorb dye. This dye is then transferred by imbibition printing to another film strip which, when it has received all three transfers, becomes the final completed print ready for projection. To carry on the process of imbibition, it is necessary merely to press the matrix film into close contact with a properly prepared blank film and hold it there for several minutes. Matrices, of course, can be used over and over again.

The colors of dyes used in the transfer process must be the subtractive primaries, namely, minus-red (or cyan), minus-green (or magenta), and minus-blue (or yellow). The relation of the taking colors to the printing colors is made clear in Fig. 2.

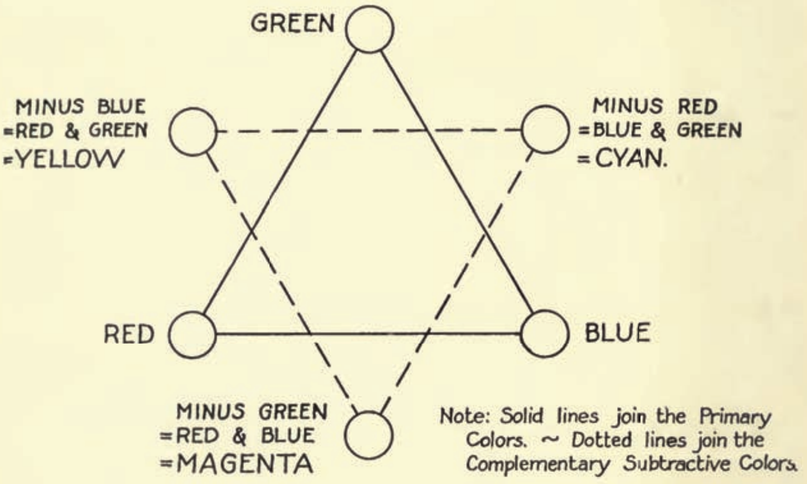

FIG. 2. Diagram showing the relation of the taking colors to the printing colors.

(To show the manner in which the final print is built up, a short demonstration reel was projected. First was shown the sound-track and the yellow dye component, next the cyan component, then the magenta component, and finally the complete image.)

The process just described is designed to reproduce whatever is placed in front of the camera, not only as to color but also as to light and shade. But even the best of reproduction procedures, even that of oil painting upon canvas, is rather severely limited as regards reproducing light and shade. The contrast from whitest white to blackest black in a painting is perhaps 1 to 32. Upon projection from transparencies, as in motion picture work, the range may be slightly greater, about 1 to 64, but in no case is the great range of sensitivity of the eye adequately reproduced. The art of painting and the art of photography then, have this in common: that they seek to suggest a great range of visual contrasts by a skillful use of the more limited contrasts available in the method of reproduction.

In color photography, all very full exposures tend to bleach out to white, and all low exposures tend to drop into black. A highlight upon a face in black-and-white photography can, in the final print, be merely the bare celluloid, and the result will be still entirely satisfactory; but if, in a color print, such a condition exist, the delicate flesh tint will, in that area, be bleached out to white, and the face will look blotchy. All areas of the face should, therefore, be reproduced in such a manner as to yield a good flesh tint. Very light make-ups, and oily make-ups having considerable shine, are apt to be troublesome. In any case, it is necessary to control the light and lighting contrasts accurately and to avoid "hot spots."

The art of the color cinematographer is intermediate between that of the painter and that of the stage artist. The painter has to work with pigments having a limited range of contrast but has great freedom of choice as to composition. The stage artist works with light, and so does not encounter the pigment limitation; but he must select his costumes, backgrounds, *etc.*, to be harmonious in a great variety of arrangements, most of which are more or less out of his control. In color cinematography the difficulties of both are combined; there is the pigment limitation combined with the comparative lack of control of composition. To illustrate this difference let us take, for example, a scene wherein a figure clad in white is to be illuminated by red light, as from a fire which is not visible to the audience. The stage artist, in arranging such an effect, must have a suitable background for the figure when it is viewed from a great many different angles. In arranging his lights, however, he can call for more and more intense beams of red light until he has achieved the desired effect. If a painter is endeavoring to get the same effect in a painting, he can select a favorable pictorial composition, but to depict the red illumination he can use only the brightest red pigment in his palette. If he is dissatisfied with his first effort, he can not heap on more and more of his red pigment. Obviously nothing is to be gained in that manner. He can only improve his result by suppression of, or contrast with, the background. Now in color cinematography, the brightest red that is available is the full value of red pigmentation in the film, and this is obtained by full value of the magenta and yellow dyes without any cyan dye. These conditions result from full exposure of the red negative with no exposure in the green and blue negatives. If the color cinematographer is not satisfied with this full pigmentation and endeavors to get a more intense red by piling on more red light in front of the camera, he merely over-exposes the red negative and begins to get some exposure in the green and blue negatives. The corresponding areas in the print tend to bleach out to white. The significance of the pigment limitation can be summed up in a very few words: if the desired effect can be shown in a painting, it can be photographed, and if it can not be painted, it probably can not be photographed. While no such brief statement is ever strictly true, this one contains such a large percentage of truth that it is worthy of being set up as a guiding principle.

In color photography, it is necessary to operate at rather high levels of illumination. If one is not careful, this may lead to a condition like this: given only relatively weak light-sources, one finds it necessary to use a great many of these sources, in order to attain an adequate level. The widespread distribution of these units then tends to kill all shadows and eliminate modeling on faces. If, then, the attempt is made to provide modeling by superimposing a localized shaft of light, as from a spot-light, the face is burned up, blotchy, and generally unrecognizable. The way out of this dilemma is to recognize that modeling should properly be produced by shadows, and to use fewer and brighter sources or to mass the sources of illumination so that shadows have a chance to exist. In other words, it is just as important for the cameraman to determine directions from which light shall *not* come as it is to determine directions from which light *shall* come.

While color contrasts will occasionally produce a pleasing result when flatly lighted, that is not the way to get sharp photography, nor in general, the most pleasing photography. The Technicolor process is capable of reproducing a full scale of contrasts and those effects of light and shade (*chiaroscuro*), and those directional effects so striking in black-and-white are even more effective in color. These considerations apply not only to the lighting of figures and faces but also to the design and lighting of sets. In the design and painting of sets, the art director should have in mind the cameraman's problem of achieving the necessary light levels with a minimum number of sources of illumination. Under these conditions, it is always much easier to keep parts of a set in low key by keeping light away from them, than it is to paint them dark and then be forced to illuminate them strongly.

This need for fewer and brighter sources is one of the reasons why we choose carbon arcs in preference to incandescent tungsten lamps. Another reason is the fact that only in the white-flame carbon arc and in sunlight do we find the correct balance of blue and red components for the photographic emulsions with which we have to work. If tungsten lamps were to be used, it would be necessary to throw away the excess red light by the use of blue glass bulbs or over-all filters. An additional reason for the use of arcs is that at the high levels of illumination which we require, the heat rays emitted by incandescent lamps are a serious problem. Arcs radiate more light and very much less heat. If incandescent units were properly filtered to correct the color of the light and to absorb heat rays they would undoubtedly be useful on special occasions.

Special arc units have been developed by the National Carbon Company and Mole-Richardson, Inc., for use in connection with the Technicolor three-component process. They have been designed to solve some of the earlier difficulties with arcs, especially noise and flicker. The older types of arc also gave off some smoke which appeared as carbon dust in the air, but it is possible to incorporate absorptive means in the vents to absorb this smoke. The only drawback to the use of arcs is the necessity for "time out" for retrimming, but this can usually be made to coincide with other "time out" activities, particularly if the head electrician works closely with the director.

There is no danger of Kleig eyes when using arcs, provided only that a sheet of ordinary glass is between each arc and the eyes of the people. This is a simple enough requirement and entirely eliminates any danger.

The required level of illumination is not very different from that which was in use by many black-and-white cameramen before the introduction of supersensitive film. We have devised methods of measurement of illumination levels for the guidance of the cameraman.

Exterior photography divides itself into four classifications:

(*A*) Sunlight shots wherein the scenery is of maximum importance. These occur abundantly in travelogues and scenics and quite frequently in dramatic photography, especially in establishing long shots.

(*B*) Sunlight shots wherein faces are of greatest importance.
(*C*) Imitation sunlight exteriors built upon a dark stage and artificially illuminated.
(*D*) Night exteriors.

In group *A* there are pronounced differences between color photography and black-and-white photography because color photography can reproduce those pleasing color contrasts of sky, water, blue haze, foilage, beach, *etc.*, which are almost entirely lost in black-and-white. Furthermore, there is always a strong directional effect to the sunlight with very pronounced shadows. A front cross-light is best in color, whereas a side- or back-cross would generally be preferred in black-and-white.

In class *B* it must be realized that few faces will stand the harsh lighting of the direct sun as in a front cross-lighted setting. So gauzes, diffusers, reflectors, and sometimes "booster" light, must be called into use. Conditions are then most favorable if the sunlight comes from behind the figure. This is true in color or in black-and-white. The skillful cameraman takes advantage of the changing directions of sunlight throughout the day to schedule his shots and angles for best results. Coöperation between director and cameraman in such cases is even more important than in the case of interiors.

It is, of course, perfectly obvious that if artificial light is to be mixed with daylight, as in the case of "booster" light, the color of the "booster" light must approximate sunlight. Here again the use of carbon arcs in preference to incandescent lights is clearly indicated. One might wonder if the change in sunlight quality from morning to late afternoon might not show upon the screen in abrupt changes in color of successive scenes. We have found it generally possible to correct for such differences in the printing. Such correction, however, is not possible where one encounters simultaneously very yellow light from the sun with blue shadows illuminated from a clear sky. Such an effect will, of course, carry through to the screen, and a very beautiful effect it is.

The set-ups of group *C* are very troublesome if the illusion of reality is of importance. This illusion almost always is important in a motion picture so that the artificialities of the usual stage lighting are scarcely acceptable at all. Shadows can perhaps still be painted upon buildings, walls, and backgrounds but of course not upon people. Nor can the shade of a tree be so imitated. What is really needed is a light-source of greater power than any now available. Pending the development of such a source, the sun promises to return to its former importance. In other words, sizeable sunlighted exteriors to be photographed in color had best be real. The difficulties of imitating grass, shrubs, *etc.*, also argue in the same direction.

In the case of night exteriors (class *D*), color has one great advantage over black-and-white in that it is possible to contrast moonlight and lamplight, for example, by the use of blue and amber filters.

Technicolor adds practically no complications to sound recording other than a somewhat noisy camera and the necessity of eliminating "whistle" from the arcs. If the camera is adequately blimped, the problem of camera noise is solved forthwith. The whistle caused by high-frequency ripples in the electric current coming from the commutators of direct-current generators can be practically removed by the combination of an alternating-current filter at the generator and additional choke-coils at the individual arc units.

When we come to the trick department, however, color has its special problems. Fades, lap-dissolves, wipe-offs, *etc.*, can all be made by duping all three negatives and taking pains to preserve the register, exposure, and contrast balance. Those methods of composite photography that depend upon color differences can not be used in Technicolor. The projection background process is, of course, ideal for trick shots in color. However, there is the problem of adequate illumination of the projection screen. So far, projected backgrounds have been used in Technicolor only in relatively small areas, such as through the rear window of a taxi or limousine. Eventually, we hope to be able to work out means for handling projection backgrounds in very much larger sizes, but at present we are rather restricted.

There is a general appreciation of the fact that "color is coming." When sound swept the industry several years ago, it meant the introduction of a new and different technic, and of men of new and different training. The sound engineer was the "big shot." The cameraman was locked in a padded cell with his camera, and the art director was told how he could and could not construct his sets to meet the new acoustic considerations. Conditions will be much more enjoyable for everyone concerned when color sweeps the industry. The sound men will not be affected in any way at all, but the cameraman and the art director will be given new tools to work with, whereby the value and importance of what they can contribute to a picture will be greatly increased. For these reasons it is to be expected that the technicians generally will be enthusiastic and coöperative with the rising tide of color.

It is the policy of the Technicolor Company to organize and maintain a nucleus camera department and color art department for the purpose of accumulating experience and disseminating information and advice as to the skillful and effective use of Technicolor. Beyond this nucleus the policy is to invite coöperation from the studio organizations and especially from those cameramen and art directors who desire to continue to lead in their respective fields. These men will generally be surprised, first, at the extent to which their conscious sense of color has become atrophied through lack of use while working in black-and-white; second, at the speed with which they can regain it; and, third, at the utter inadequacy of black-and-white photography in comparison with good color photography.

When our color was of inferior quality, we used to hear the expression "color interferes with the drama." Since the introduction of the three-component process, the expression has been rapidly fading out of use. Good color assists good drama. Dr. Herbert T. Kalmus, President of Technicolor, has supported a liberal policy of research and development work since the organization of the company. This policy is continuing, and the work involves nearly all departments. We propose to continue to improve our product until the last doubter is swept off his feet.