THE ENGLISH DUFAYCOLOR FILM PROCESS*

W. H. CARSON**

Summary.—*The Dufaycolor three-color additive system of color cinematography, employing a geometrical color-screen or réseau imprinted on the film base, is briefly described. As many as a million color elements per square inch are employed, and a correct color balance is achieved by adjusting the area covered by the blue dye in relation to that covered by the two other primary colors. No appreciable changes of equipment are required in applying the system commercially, either in photographing, processing, or projecting, from what is now found in use.*

Many may wonder at the presentation of a paper on a subject as old in color photography as a color-screen process. However, the developments of the past two years have proved the process to be no longer in the theoretical and experimental stages but on a practical and commercial basis, and for that reason a discussion of the new Dufaycolor system seems to be in order.

Any engineering group may rightly be skeptical of the recommendation or adoption of any innovation in the industry that can not conclusively demonstrate its basic soundness in both the theoretical and practical fields. However, past experience has shown that new scientific developments and improvements must be injected into the industry from the bottom up rather than from the top down. The introduction of sound into the motion picture industry came after years of research and the expenditure of millions of dollars in experimentation, which have been little recognized by the layman or the box-office patron. It was only through the tremendous pressure brought to bear by the sound technicians who visualized its future that it was finally grudgingly accepted by the producer and exhibitor and even more reluctantly by the public. Today it is impossible for silent productions to compete with talking pictures.

The whole technic of producing silent motion pictures, including

* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** New York, N. Y.

script writing, directing, acting, photographing, lighting, stage construction, processing, projection, and theater construction, has been revolutionized to serve the new medium of sound. But in return for all that, a broadened scope of dramatic and popular application of sound pictures with respect to their increased entertainment value has been found. Since we are dealing with an industry that depends for its continued prosperity on its dollar-and-cent value and an adequate return to its stock-holders, it must be admitted that the advent of sound motion pictures has enabled the motion picture industry to retain a position in the entertainment field through a most trying period, when almost every other industry in the luxury field has been forced into bankruptcy, if not completely annihilated.

Color in motion picture photography must enjoy the same consideration in planning productions, selecting subjects, actors, make-up, costumes, settings, in directing, lighting, and photographing, that is now being given to sound, if it is to contribute as fully to the progress of the industry; but it can not fail to assume a position of similar importance in the very near future. No claim for originality is made for these statements, and recognition must fairly be given to the pioneer work that has been done by Technicolor under the able direction of Dr. Herbert T. Kalmus along those lines. The progress that has been made up to the present in recognizing a distinct technic in color production lends some encouragement to the conviction that producers are awake to the possibilities of color, and are only waiting to be shown the practical means of application and be assured consistently satisfactory results on duplication before making it a major consideration in future productions.

The first question that arises is whether colored motion pictures having a true color fidelity throughout the full range of the visible spectrum can be produced commercially for a slightly increased cost, which increase might be justified by an increase either in the box-office receipts or in entertainment value, permitting the motion picture to maintain or improve its present outstanding value as *entertainment* so that financially it may continue to compete successfully against other and newer amusements.

No industry that occupies such a paramount position as the motion picture industry occupies in the amusement field can afford to "rest on its oars" during a time when changing conditions in the social order are creating a superabundance of leisure for the average person, who can now indulge more frequently in the pleasures that formerly he was able to enjoy only to a limited extent; or, if these are not sufficient to satisfy his need, seek new and other diversions with which to fill his time. Countless thousands of dollars are being spent to create, on an ever-increasing scale, extravagant and spectacular productions that must in time break down of their own weight. Some new and startling feature must be introduced to rejuvenate the appeal, a feature that would admit of simplifying or abandoning the costly artificial settings and bring into play a new artistic medium, which, while new in motion pictures, is one of the primal appeals to which human beings react—*color*.

After a comprehensive study of all the theoretical processes available and those that have been in a measure successful, the conclusion was reached that two-color and three-color optical and imbibition processes have not, with existing equipment, both taking and projection, given a result on the theatrical screen that will satisfactorily fulfill these various requirements. The ideal method of producing colored motion pictures would seem to be a system by which such colored pictures could be made with the existing cameras and lighting equipment, and supplied to the exhibitor for satisfactory use on his present projection equipment without expensive alterations; and, what is equally as important, to accomplish that result without any radical change in the present laboratory procedure. Thus it would be possible for every producing company to add color as a supplementary feature to its productions without disrupting its organization or making large capital investments. All these requirements are fulfilled by the Dufaycolor process, here described.

For ordinary transparency purposes little importance seems to be attached to the pattern of the screen so long as the three primary additive color elements are present in the proper balance and proportion. Dufaycolor, Lumière, Agfa, Finlay, or other transparencies that are really representative of these systems will all produce apparently perfect color rendition with suitable transmitted light if viewed at a distance of about eighteen inches by the average eye or projected from standard lantern-slide size to the usual small-screen size.

Where non-geometrical color-screens are used it necessarily happens that masses of the red, blue, or green units occur in the form of blotches or larger areas, and it is obvious that for achieving perfect effects on greater magnification better results can be attained when the three primary color elements are regularly broken up into the smallest possible units and uniformly distributed. For that reason the geometric matrix or réseau, as it is termed, seems to have a decided advantage. It is believed that the Dufay system is the first screen process in which projection from standard 35-mm. film to theatrical screen size has been seriously attempted. The application of a réseau of this kind to a film base by mechanical means, on a regular and comparatively inexpensive commercial basis, further seems to enhance its value as an acceptable medium for use in the professional motion picture field.

The idea of applying a series of colored lines or squares to the film base, originally suggested by Vidal in 1895, was used by Dufay in the further development of the process under discussion, wherein a contiguous series of red and green squares (or any two of the primary colors) were placed alternately between lines of blue (or the third primary color). Theoretically it would not seem to be of great importance as to what order was used in the application of the three primary colors. In practice it was found that on account of the high visual contrast of the blue line, the screen so constructed was much more visible when magnified to the extent necessary in motion picture work than a different arrangement. At present the screen is produced with blue and red squares and a green line, which has the effect of reducing the visibility of the screen on projection.

It is obvious that the smaller the area of each individual unit, the more perfect will be the blending of the color units by the eye, even upon excessive enlargement, and the less the effect on image definition. It was formerly believed that fifteen lines to the millimeter was the limit of practical mechanical production, but within the last year a screen having nineteen lines to the millimeter (*i. e.*, one thousand lines and spaces to the inch) has been very satisfactorily produced, and recent improvements point to a still further reduction of the line width. Even with the present line width it has been found that the réseau is not visible beyond the first six rows of the seats in the average theater. This provides the present screen with approximately a million color elements to the square inch, and further diminution will have a progressively startling effect in definition and luminosity.

The statement that such a screen or réseau can be produced mechanically, consistently, in large quantities, on a commercial basis, and at a reasonable cost, will bear some scrutiny; so the first question that arises is, has it been done? The answer is that it is now being done by a reputable and well-known English manufacturer on 21-

inch acetate motion picture base in 1000-foot lengths at the rate of 90,000 35-mm. ciné feet per week. Increased production is contemplated immediately, and the reception of the film by the English producers has been very enthusiastic.

The next question is, how is it done? A film base of suitable thickness (acetate base has been used exclusively because eventually legal restrictions will require it, but similar results are possible on nitrate) is first coated with a thin layer of collodion containing a dye, let us say blue, adjusted to the spectral hue of the blue primary. After drying, the film is then passed through a highly specialized type of rotary printing machine consisting of a steel roller milled one thousand lines to the inch (really five hundred lines, with an equal number of spaces between). The machine embodies an elaborate

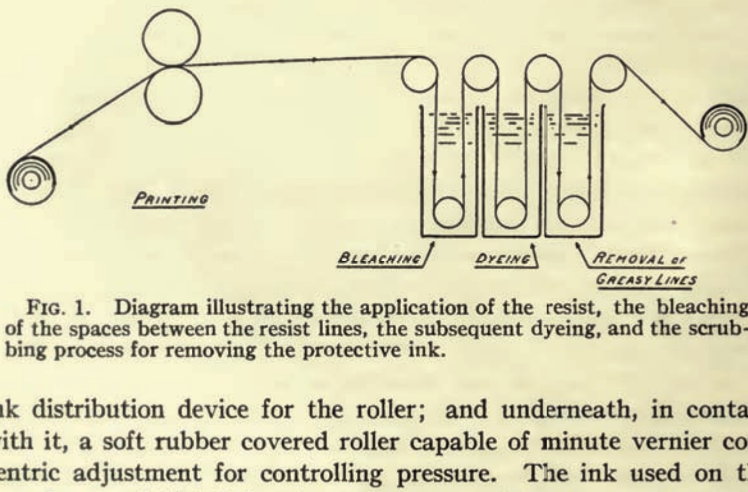

FIG. 1. Diagram illustrating the application of the resist, the bleaching of the spaces between the resist lines, the subsequent dyeing, and the scrubbing process for removing the protective ink.

ink distribution device for the roller; and underneath, in contact with it, a soft rubber covered roller capable of minute vernier concentric adjustment for controlling pressure. The ink used on the press is a special kind, forming a moisture resistant line printed upon the basic color. The idea of using a greasy resist was first suggested by du Hauron and Bercegol in 1907. And here again reference should be made to the remarkable far-sightedness of Louis Dufay in the application of the basic principle of the geometric screen and the use of resistant medium for applying the primary colors to the film base by mechanical means.

In the development of any new idea, there must be some individual or group that has enough faith in its ultimate value to be willing to finance it through the sterile years when salaries must be paid and valuable council and encouragement given in the face of apparently meager progress. It has been fortunate that this process has been sponsored by Spicers, Ltd., of London. This firm, manufacturers of all kinds of fine paper products, is an old English family organization, whose commercial solidity has enabled them to keep their wheels turning through the past lean years, and who have provided the financial backing and the technical guidance of such men of their organization as A. Dykes Spicer and S. R. Wycherley to bring this process to its present degree of perfection. However, the credit for the practical application of the resist on a commercial scale must be given to Charles Bonamico, a French engineer with Spicer-Dufay. His engineering skill in perfecting a means of milling a steel roller for applying the lines, and the subsequent control of application of the ink, marks one of the outstanding factors in the success of the process.

Although the ink used in applying the resist is much thinner than would ordinarily be used for typographic purposes, under suitable conditions it assumes a partially dry state, providing lines having substantially sharp parallel edges and free from blur or creep, and when subsequently passed through a properly selected bleaching bath, produces perfectly clear white lines between the ink-protected lines.

In the same machine, which has been especially designed for the process, the film is then passed into a bath containing dye of such concentration that will give the primary red on the intermediate bleached white lines. Allowing time and space for suitable washing to remove the excess red dye, the film then passes into a solution and a mechanical scrubbing action removes the protective ink. A simple diagram illustrating the method is shown in Fig. 1. If at this stage the film be examined with a microscope, we shall find that it is covered with a fine grid of alternating blue and red lines, having the same width and with perfectly contiguous but not overlapping edges, and each line representing a perfect primary filter in the two colors named (Fig. 2).

After drying, the film is again passed through a similar rotary printing machine, but this time the lines on the printing rollers are at an angle of about forty-five degrees to the original lines (theoretically the best angle is not forty-five degrees: this has a very important bearing on other features of the process). The width of the lines applied in this operation is not the same as that of the lines applied in first, but is so controlled that the imprinted area alongside two contiguous squares, so formed, is equal to the area of each of the squares. The film is then bleached in a manner similar to that formerly described, the bleached line is dyed the third primary color (green), and the resisting ink is then removed in the same manner as described before (refer to Fig. 1). The film is then dried and wound up. This arrangement produces a perfectly balanced neutral grey screen when viewed or projected. When examined microscopically, a réseau such as illustrated in Fig. 3 is seen.

The next question refers to the emulsion to be applied to this réseau. While there are, of course, many applications for color film and the emulsion characteristics are correspondingly numerous, for

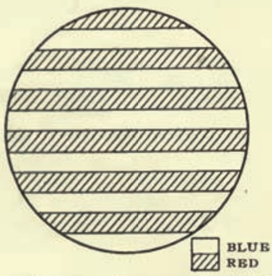

FIG. 2. Appearance of the film under the microscope, after the process illustrated in Fig. 1.

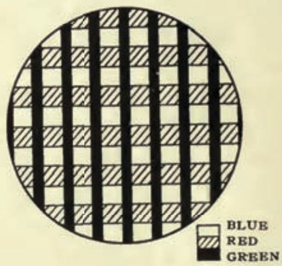

FIG. 3. Appearance of the réseau under the microscope, after application of the third color. (In recent screens the green lines are at an angle of approx. 45 degrees to the blue and red.)

the present only those that apply to cinematography will be considered.

It is interesting to note that in the very early stages of color development the theorists visualized an emulsion that was truly panchromatic and had a high speed and very fine grains. As no such emulsion existed at that time they approached the emulsion makers much as Macbeth sought the witches of Endor and suggested some diabolical brews that too often resulted in nothing more than toil and trouble, and never achieved results on a practical basis. For that reason it may be said that the development of color photography has had to mark time until the art of emulsion making could catch up with its theoretical requirements, and it is believed that that time has now arrived.

It would be of interest to review some of the problems of the photographic chemists. The art of emulsion making formerly depended upon controlling the balance of silver halide and gelatin characteristics, together with delicate manipulation of heating, digestion, washing, ripening, *etc.*, with more or less crude equipment. Today those factors have been so well correlated as to establish a science; and emulsion making equipment has become practically standardized, with automatic engineering controls that assure an accuracy permitting duplication of results within remarkably narrow limits.

Considering also the great strides that have been made within the past few years by all the large photographic manufacturers, both in this country and abroad, in controlling the size of grain of super-speed emulsions without increasing the fog or impairing the keeping quality; and further, in developing new sensitizers by means of which emulsions can be made selective to any portion of the spectrum, visible, infra-visible, and supra-visible, it can be understood that problems in the reproduction of color, that seemed insurmountable a few years ago, have now been resolved by the progress that has been made in the black-and-white field of the art. The application of these advances to color photography now realizes satisfactory results where before the same efforts met only with failure.

So now, for the requirements of this process, emulsions may be selected practically according to specification, provided the basic characteristics of the process are known. These factors are all well known, and are the same as those now operating in black-and-white technic: they may be briefly mentioned as speed, color-sensitivity, grain size, gradation, and gamma. With slight modification it may be said that a good panchromatic emulsion, rich in silver as compared with its gelatin content, with a color-sensitivity that will produce, as nearly as possible, the same density with all three of the primary colors, with a fine grain, and high speed will serve admirably for the process. Such an emulsion is now being used.

There are several important characteristics that had to be considered in selecting the emulsion that might be well discussed at greater length. First, the effect of wavelength on the gradation and gamma: Experience has shown that the effect of wavelength on gamma is negligible, provided it is measured at gamma infinity; but that, of course, must be considered in relation to exposure, development, and intermediate gradation. For that reason an emulsion has been selected that has a long straight line in its characteristic curve together with a short toe. So much progress has been made within the past few months that it is impossible to show by graphs the curves of the emulsion now being used, but it may be said that the range of latitude in the present emulsion is far greater than it was thought possible to produce a year ago. In any screen process it is imperative that the emulsion, no matter how thinly it may be coated, be capable of giving intense blacks, so that any colored area on the réseau may be effectually blocked out, allowing no dilution of the true color by the transmission of a foreign color that is not truly an additive component of the colors in the object being photographed.

Second is the question of the spectral value of the filters. Various statements have been made as to the proportion of the incident light that passes through the many types of matrices used in the various processes, and have ranged from ten to twenty-five per cent. In the

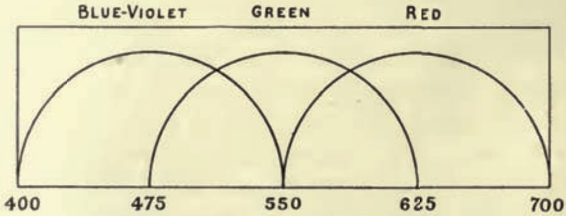

FIG. 4. Diagram showing the approximate overlapping of the spectral transmission of the color filters used in the Dufaycolor process.

Dufaycolor process the filter colors selected do not transmit in short narrow bands, but rather overlap from one to another much in the manner shown in Fig. 4. Whether that is theoretically the proper way to produce true color in a three-color additive process is of no particular concern if a result having a satisfactory color fidelity for the average eye is achieved. At the same time, such a procedure results in marked advantage as to the proportion of light transmitted to the emulsion on the taking film, and increases the luminosity of the resultant picture on the screen with ordinary projection light. (It has been noticed in this connection that a lower screen luminosity seems to be acceptable in color pictures than would be regarded as satisfactory in black-and-white.) The use of filters having such overlapping transmission characteristics may raise a question concerning the dilution of color on reproduction, but that will be covered later. The filters used also provide a remarkable increase in the latitude of exposure and development as compared with matrices in which filters having narrow transmission bands are used.

Much advancement has been made in England in the past two years in perfecting dyes capable of very much greater light transmission than was formerly attained, without sacrificing their spectral fidelity. These new dyes have been adopted by Dufaycolor. A method has been found to isolate them from the emulsion so that no desensitizing action takes place, and excellent adhesion between the matrix and the emulsion, which has heretofore often been unsatisfactory and extremely difficult to attain, has been accomplished. The two factors of increased speed of modern panchromatic emulsions and better dyes for the filters have made possible a film having a speed hitherto unattainable in screen processes.

Any color process that does not provide for duplication in unlimited quantities, of consistent fidelity, and on a commercial scale is, of course, not worthy of consideration. It is believed that methods have been found and patented by which to accomplish such results to such a high degree of satisfaction that it is almost impossible to distinguish between originals made in the camera for projection and copies made from the original master positive. Up to last year it was believed that the same type of emulsion would serve both for taking and for making subsequent copies or dupes. At present, however, it is believed that the master positive, which might be called the original (and made in the camera), should have a heavy coating of emulsion as compared with the stock used for copies. When it is reversed it seems quite flat and the colors feeble, but when duplicates are made from it by the latest methods on a suitable printing stock, the colors come up to full strength. The maximum density is about 1.2, and a very wide range of gradation is maintained.

It has not been found possible to produce an emulsion adapted to all light conditions, natural (daylight) and artificial (arc and incandescent), without using a compensating filter of some sort. Because of the fact that a large proportion of professional motion picture photography is done under artificial light it seems best for the moment to adapt the film to artificial lighting, and to compensate for other conditions by using the proper filters. While very fast emulsions have been developed for the system, no claim is made that the speed is comparable with that of black-and-white, since there must be a marked reduction in the transmission in any color process. However, a speed has been attained that makes it possible to fulfill the requirements of motion picture studios with the existing lenses and lighting equipment.

Now regarding laboratory treatment: Many studios are at present working on the "master positive" basis, on which a positive is made by reversal from the edited first print after the cutting and timing have been done in order to gain the advantage of reduced graininess and uniformity of density. Although no reference has been previously made, it is understood, of course, that the original film under this process is reversed to produce a positive result (it is possible to develop the film as a negative and make positive prints therefrom). The procedure in reversal is standard. Developers of various kinds have been tested, the best results having been achieved with *M-Q* ammonia of rather high concentration at 65°F. After the bleaching and the second exposure, the second development occurs in an ordinary metol-hydroquinone developer, and it is recommended that the second development be carried on under full illumination. It may be well to mention that by reversal the usual advantage of eliminating the larger grains of the emulsion is gained, leaving the smaller grains to form the reversed image. It should be noted also that the entire procedure can be accomplished on existing motion picture developing machines with only very slight, if any, modification, and is therefore adaptable without expensive changes in equipment or personnel by any producing company that operates its own laboratory.

No mention has as yet been made regarding the possibility of recording sound on the film; but that, of course, has been given full consideration. Several methods have been devised and patented for removing the screen or réseau, before the film is coated with emulsion, from the space along the edge of the film to be occupied by the sound track. In practice it has been found that such a procedure is not necessary, as the number of lines in the screen that is used is so great that any effect it may produce on the various types of sound recording equipment now in use will not produce a reaction within the audible range. Recording can be done by either the variable width or the variable density method if the intensity of the recording light source is increased enough to offset the reduction of light transmission by the réseau. Similar remarks apply to the reproduction of sound during projection.

The emulsion, which has been described as ideal for color reproduction, is of the same type that would be selected by the sound engineer as the best for true sound reproduction. Sound has been recorded on all the standard systems, including the Movietone News camera, wherein a sound record was taken, through the réseau, on the same film as that used for the picture. Originals and copies have given excellent sound reproduction and, although several English sound experts have expressed the belief that the réseau would interfere with some of the higher frequencies of the audible range, as yet no such interference has been detected in practice.

It has long been thought that it was impossible to reproduce from a screen transparency having a geometrical design due to the difficulty of exactly registering the colored areas in the original with the similar colored areas in the copy. The problem of avoiding moiré effects in reproducing through a geometrical screen has also been adjudged insurmountable but several simple and very ingenious methods have been developed to circumvent both those problems.

Most of the research in the development of this process, theoretical and scientific, has been done by T. Thorne Baker, a member of our Society. Many of the statements in this paper are based upon data that he has supplied.

Many technical points have been brought out in this paper that have not been fully covered; but as the purpose of this presentation is simply to describe the general process, it is hoped that further opportunity will be given later for their more detailed discussion.

DISCUSSION

MR. MITCHELL: What is the relative speed, compared to black-and-white?

MR. CARSON: Developments are occurring so rapidly that I hesitate to answer. I will say, however, that the film that I am showing here is approximately one-fourth as fast as black-and-white. We made some that were only one-third as fast. The fastest emulsion receives through the screen about one-third the light incident on the film.

MR. PALMER: Is the picture you are to show a reversal print or a print from the original?

MR. CARSON: Both. The first is an original or master positive, as made in the camera. The second will be a print made from some of the same scenes as a duplicate, made in England. It was developed under rather unfavorable conditions—by rack and tank, and not by machine; and the evidences of the rack marks are present in the print.

MR. POPOVICI: What kind of light was used for photographing? Arc or incandescent?

MR. CARSON: Arc and incandescent, I understand. I did not see the exposures made, as they were made in England.

DR. GOLDSMITH: Approximately how many lines are there across the screen?

MR. CARSON: Nineteen lines to the millimeter, or approximately one million elements to the square inch. With 25 lines to the millimeter, which is the screen that will be produced next, there will be approximately a million and a half to the square inch. The luminosity and the definition will both increase. The light we are using here is the standard light for black-and-white pictures. Even though there is stray light on the screen, which would not occur under good conditions, the picture is sufficiently bright. That is a fact that I mentioned in the paper—that a lower screen brilliancy seems to be acceptable with color than with black-and-white.

MR. BATSEL: Are the prints made by contact or by projection?

MR. CARSON: Projection. We are not ready to discuss the method of printing right now, for patent reasons; but I will say that it was the combined work of the Ilford group, under the direction of Dr. Renwick, who was formerly with the Dupont Company. The film was made by the Ilford, Limited.

MR. SACHTLEBEN: What difficulties, if any, are experienced in obtaining proper registration of the colors when making a print? How do you manage to have the greens green and the blues blue and not something else?

MR. CARSON: A means has been devised of interposing a prism type of lens between the two films on the projection printer, which divides into four each of the color areas in the original screen as it prints, so that any color area is bound to fall on one similar to it.

MR. CRABTREE: Was the original developed by machine or by rack-and-tank?

MR. CARSON: By rack, also.

MR. KELLOGG: One would expect, with the extent of the overlap of the spectral regions, that the printing process you just described would cost something in saturation.

MR. CARSON: Theoretically, each time you step down, a certain dilution occurs due to the overlaps. Here, again, means were found of eliminating the overlap in the printing operation. While there is some dilution, there is not very much. With proper laboratory treatment and machine control, duplicates can be produced that are entirely satisfactory for commercial use.

MR. SACHTLEBEN: Mr. Carson stated that the quality of the print was superior to that of the original. I believe that has been quite well borne out in this demonstration.

MR. CARSON: We don't consider it so. You misunderstood me.

MR. SACHTLEBEN: I found the second reel that was shown more pleasing than the first.

MR. CARSON: The fact of whether it is more pleasing to the eye or not is something that is more or less a matter of personal taste. What I meant to say was the spectral fidelity of the original is greater than the spectral fidelity of the duplicates. I do not believe that the duplicates are exactly as good as the original. If you saw the two run side by side, you could distinguish the difference. If you saw one run in one place and one in another, they would appear so nearly alike that you would find it difficult to say which was which.