June 10, 1941. S. G. GUERRERO 2,244,992

COLOR RESPONSIVE CORRECTION METHOD FOR POLYCHROMATIC REPRODUCTION

Filed Nov. 8, 1938 2 Sheets-Sheet 1

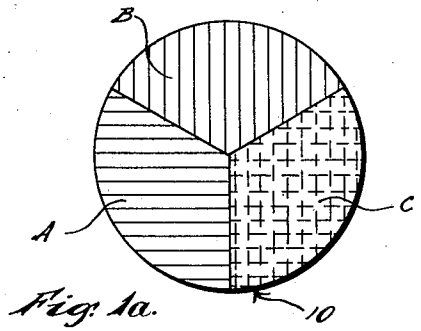


Fig. 1a.

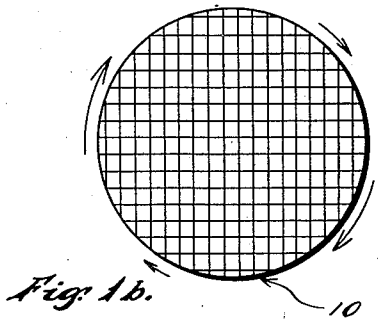


Fig. 1b.

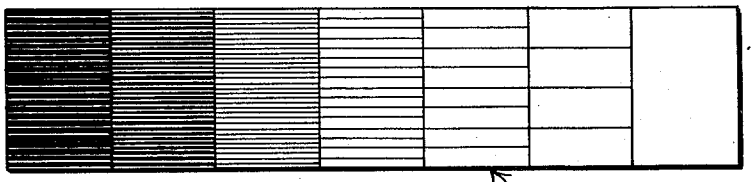


Fig. 2.

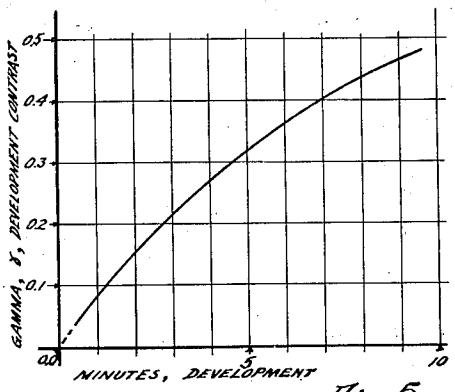


Fig. 5.

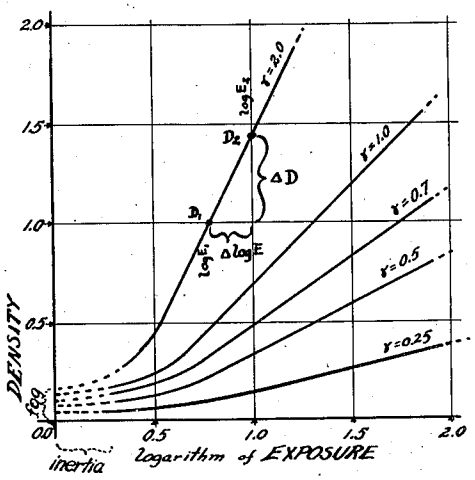


Fig. 4.

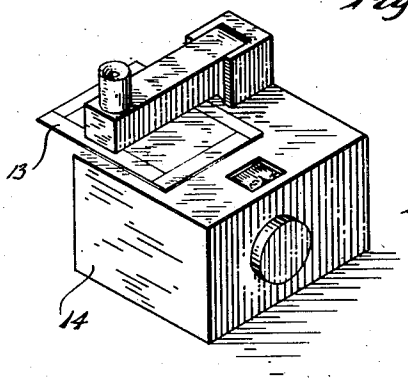


Fig. 6.

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COLOR RESPONSIVE CORRECTION METHOD FOR POLYCHROMATIC REPRODUCTION

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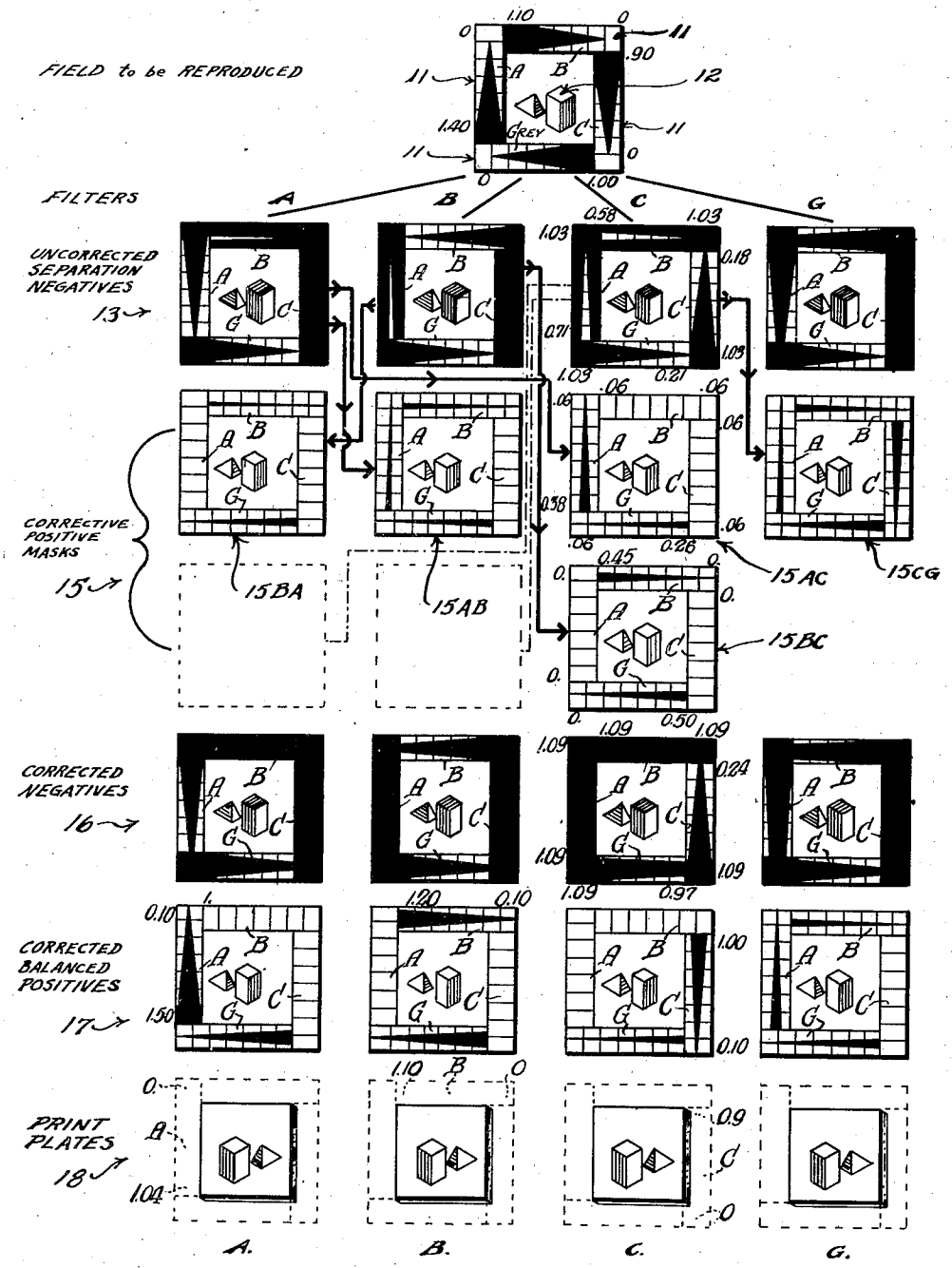


Fig. 3.

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2,244,992

COLOR RESPONSIVE CORRECTION METHOD FOR POLYCHROMATIC REPRODUCTION

Salvador Garcia Guerrero, Mexico City, Mexico

Application November 8, 1938, Serial No. 239,547

1 Claim. (Cl. 95—2)

My invention relates to natural color reproduction by photographic and photo-mechanical means and is particularly directed to overcoming the inherent deficiencies in color characteristics of the media customarily employed. As will be seen, this is done in an objective rather than subjective manner, not liable to the judgment of the operative, by photographic color responsive color compensation.

The invention eliminates the tedious hand retouching and staining methods which are commonly used. Such methods of correction depend on the color judgment of the workman, and the result is merely his guess-work. For this slow, expensive and inexact procedure, substitute an exact, scientifically controlled and corelated process which permits rapid and accurate work to be done and a greater volume of work accomplished.

The whole reproduction sequence is controlled by exact measurement, the faults inherent in the inks are automatically recorded and proper correction is calculated from measurements responsive to each color fault.

For a definite understanding of the theory underlying my process a brief explanation of the subtractive process of color reproduction is helpful. It has been learned by experiment that human vision depends on the stimulation of three response mechanisms of the nervous system, one being stimulated by reception at the eye of blue-violet light, another by green light, and the third by red-orange light. The color sensation is determined by the relative stimulation of these three responses by the light being observed. For example, if all are equally stimulated, the impression is white; if red is lacking the impression due to equal stimulation by the blue and green is blue-green, which becomes more white as red stimulation is added.

Then to control the color sensation, it is necessary and sufficient to control the relative intensity of each of these three visual, or additive, primaries, commonly called red, A, green, B, and blue, C, which reach the eye.

The scene is therefore analyzed to determine the relative intensity of these primaries by successively photographing through like colored filters. This results in separation negatives; the opacity of that exposed to red light being an inverse record of the intensity and distribution of red light; the "green taken" of green light, the "blue taken" of blue light.

For convenience, positive prints of these negatives are made, thus providing records which indicate the relative degree of absorption necessary to produce the original scene gradation in each color.

To control the red stimulation, the positive of the red record may now be printed or otherwise colored in such way that red light is absorbed in the proper degree and distribution. However, this red absorbent or "minus-red" color must control only red light, not having any effect on blue or green light, for complete control of blue must be responsive to the "blue-light-responsive" positive; and absorption of green be controlled solely by the "green made" positive. Therefore, by the same reasoning, the green light is controlled solely by a "minus green" density in its positive record; and blue light is modulated entirely by "minus blue" pigment in its record.

Now when the effect of these color controllers are synthesized, by superposition or other successive action on white incident light, each controls its own color sensation, not infringing on any other, and the relative distribution of the three primaries is reproduced as it was in the original scene.

The colors "minus red," "minus green," and "minus blue" are called the subtractive primaries or printing primaries and might properly be termed "blue-green," "blue-red," and "red-green," or also cyan, magenta and yellow. However, the customary terms are "blue," "red," and "yellow," and they are conventionally referred to as "A," "B" and "C," which characters also may refer to the taking filters. For convenience the terms A, B, and C will be used to designate the separations; A being taken through a red filter and printed in "blue" ink; B being taken through a green filter and printed in "red" ink, and C being taken through a blue filter and printed in yellow ink.

The faults in practical application of the above theory lie in the fact that the pigments used in printing absorb the colors which they should not absorb and that the taking filters transmit colors which they should not transmit, thus controlling not only the color each is designed to modulate but also affecting the intensity of the other primaries. That is, the A pigment is designed to absorb and control only red light, but it also absorbs blue and green, which it should reflect, or transmit, perfectly. The B pigment should absorb only green light, but it also has considerable density to blue. The C or yellow pigment is most nearly perfect, having very little absorption of red or green light.

My process provides integrated control and

measurement of these faults and provides for their accurate compensation.

Further objects, advantages and features of invention may be apparent in the following description and accompanying drawings, wherein

Figure 1—*a* shows a color disc stationary;

Figure 1—*b* shows a color disc rotating.

Figure 2 is a detail view of a control tint step strip.

Figure 3 shows a color subject to be reproduced, and the successive stages in separation, correction, and printing.

Figure 4 illustrates a method of determining graphically the degree of development required in the mask.

Figure 5 illustrates a way of determining the time required for development of the mask at standardized conditions.

Figure 6 shows a measuring instrument applied to a separation negative.

In my color reproduction process the filters used should approximate as nearly as possible the theoretical standard and the pigments are chosen as nearly as possible to be each the complementary of its taking filter as this permits brighter tints to be attained in correct hues. However, it is necessary to adjust and balance the inks so that they have the proper relative reflective characteristics, and so that these are properly tied in to the entire sequence of reproduction.

This is accomplished by the use of a color disc 10, which comprises three equal, 120°, sectors as shown in Figure 1—*a*. Using printing plates of the same qualities and which are made under reproducible conditions, one sector is printed in A ink, blue green; one in B ink, magenta; and the third in C ink, yellow. On being whirled the color sensations merge into one and should appear a neutral grey, as in Figure 1—*b*. If any color predominates it is necessary to reduce its printing intensity by dilution with tint base or varnish, reprint that sector and retest until adjusted properly.

Color control step strips 11 are now prepared in each color and in black, and will serve to coordinate all subsequent steps of the process.

Each step strip may comprise a suitable number of steps, preferably seven as shown in Figure 2, approximately equally spaced in density, and ranging up from pure white of the paper or support to the full intense saturation of the standardized ink, as balanced on the test disc. The grey scale is printed to equal that gradation of grey which would result from the mixture of tne primary color scales, and will be degraded from pure white to deep black.

The preferred method of preparing the color tint strips is by printing each from a standard plate but successively diluting the ink with tint base or varnish, which may be according to the following schedule.

Step	Parts of adjusted ink	Parts of tint base
	Percent	*Percent*
1	100	0.0
2	83	17
3	66.4	33.6
4	49.8	50.2
5	33.2	66.8
6	16.6	83.4
7 purest white paper	0.0	0.0

A subject which is to be reproduced is arranged as shown in Figure 3 with a control step strip 11 on each side of the field 12, so that they will be reproduced on the edges of the negatives and may be readily trimmed from the final corrected positives or printing plates.

Separation negatives 13, of equal contrast, at about gamma equal to one, are made in the usual way, thru A, B, and C filters; and a "grey printer" negative is exposed thru yellow filters of different absorption bands, or thru infrad-red filters, or by successive balanced interposition of the tricolor filters, or from a combination diapositive from the A, B and C separation negatives.

The gradation of the respective step strips and their various reproductions are graphically shown in Figure 3 by the use of the convention that the solid density, of the darkened wedge, lying in a step is evenly distributed over the area of that step. A further convention followed is that faults are represented by central white wedges, while purposeful densities are represented by central black wedges.

It may be seen however, that the negative 13A exposed through a red filter and to be printed blue-green is evenly exposed in its yellow scale C because the yellow pigment absorbed no red light and consequently each step of the yellow scale reflects as much red as the white paper, resulting in even and complete darkening of the negative. The high uniform density of this strip insures that no blue-green ink will be printed in the yellow strip area of the reproduction. The grey scale G of course, is graded up in density as is also the blue green scale A, this indicating that blue green ink will be deposited on these areas of the reproduction as it should be. However, the "red" scale B, which should be of uniform and high density so that no blue green A pigment would be deposited in this area, does show gradation—having less opacity in the portions corresponding to the greater density of the original scale 11B. This is due to the fault of the B pigment in absorbing red light, resulting in less exposure of the negative from the darker areas of the B scale. This gradation would cause blue-green ink to be printed which is obviously non-essential to the reproduction of a pure magenta, B scale.

Similarly in the green taken negative 13B, the yellow C scale is evenly opaque and the grey and the magenta B scale show gradation, but a fault is apparent in the blue scale A which also shows gradation and would permit magenta ink to be printed in a scale which needs only blue-green, A, ink for its perfect reproduction.

The blue taken, yellow printer negative 13C has the expected gradation in the grey and in the yellow C scale, but exhibits faults in both the red, B, scale and the blue, A, scale due to undesired absorption of the blue light by the blue-green, 11A, and magenta, 11B, step scales which should reflect blue light uniformly. This would result in yellow, C, ink being printed in all of the scales, while it should be printed only on the yellow and grey scales as reproduced. The grey printer 13C exhibits some gradation in all scales, which would result in degradation of these colors unnecessarily if uncompensated.

It may be noted that the above faults which I propose to correct depend upon the density of the original scale; consequently the means of correction should depend upon the density of the original scale. It will be seen for example that the faulty transparency of the C negative due to presence of blue green A ink in the subject may be corrected or neutralized by adding

a density corresponding in some degree to the amount of blue green A ink in the subject.

By my procedure the measure of the density of the original scale is found in that separation negative properly showing its gradation. That is, the gradation of the A scale is shown in the A separation negative, of the B scale in the B negative, and of the C scale in the C negative.

To correct the C negative, for example, so that yellow dye will not be deposited in the blue-green, A, scale, a positive transparency **15AC** is made from the A negative of such contrast that the transparency of the A scale of the C negative is exactly corrected by the added density of the corrective positive, which will have the requisite characteristic since it is responsive to the color density of the original step scale.

The required degree of contrast is determined thru quantitative measurement of the density values of the various control scales, as is shown in the following tabulation of actual test values. A densitometer **14**, as shown in Figure 5, being applied to a negative **13**, is customarily-employed for this purpose.

Sensitometric schedule

Actual test data in process of correction of negatives for polychromatic reproduction. Figures tabulated are the densities at respective ends of the control step strips, and corresponding steps in the respective negatives and superposed masks.

	"Blue" scale A	"Red" scale B	Yellow scale C	Grey scale G
Density of original scales	140- 0	110- 0	90- 0	100- 0
Uncorrected "blue" printer, 13A	16-150	138-150	150-150	19-150
Corrective mask from "red," 15BA	0- 0	12- 0	0- 0	28- 0
Total superposed densities	16-150	150-150	150 -150	47-150
Density difference, or range of corrected negative, 16A	134	0	0	103
Uncorrected "red" printer, 13B	88-154	32-154	148-154	12-154
Mask from "blue," 15AB	76- 10	24- 10	16- 10	44- 10
Total superposed densities	164-164	56-164	164-164	56-164
Density difference of corrected negative, 16B	0	108	0	108
Uncorrected yellow printer, 13C	71-103	58-103	18-103	21-103
Mask from "blue," 15AC	38- 6	6- 6	6- 6	26- 6
Mask from "red," 15BC	0- 0	45- 0	0- 0	50- 0
Total superposed density	109-109	109-109	24-109	97-109
Density difference, of corrected negative, 16C	0	0	85	12
Uncorrected grey printer, 13G	76-173	118-173	173-173	21-173
Mask from yellow, 15CG	24- 8	38- 8	68- 8	62- 8
Total superposed densities	100-181	156-181	241-181	83-181
Density difference of corrected negative, 16G	81	25	"-60"	98

Actual calculation of the required development contrast or "gamma," γ, of the positive corrective masks, **15**, is based on the laws of photosensitive materials, formulated and applied practically to photography by Hurter and Driffeld. It is found that the opacity, i. e. the ratio of incident to transmitted light, of the photographic deposit increases exponentially with the exposure, the factor of increase depending upon the degree of development,

$0=E^{\gamma}$ or more simply and usably,

$\log 0=\gamma \log E$ over a considerable range of exposure, exposure being a product function of light intensity and the duration of its action. For convenience, "log 0" is termed Density, "D", and now for two different exposures on the same emulsion: and same degree of development, γ:

$D_1=\gamma \log E_1$ and $D_2=\gamma \log E_2$

Subtracting,

$D_1-D_2=\gamma(\log E_1-\log E_2)$

and

$$\gamma=\frac{D_1-D_2}{\log E_1-\log E_2}=\frac{\text{Density difference}}{\log \text{exposure difference}}=\gamma$$

Now in printing, the "log exposure difference" is equivalent to the available density difference of the negative being printed, so that to obtain a desired density difference or range in a positive from printing an available density difference in a negative the development contrast required will be:

$$\gamma=\frac{\text{Density difference required in positive}}{\text{Density difference available in negative}}$$

The result may also be obtained graphically after the manner of Figure 3, wherein the density difference available is laid off on the horizontal scale in such manner that the included portion of a characteristic curve covers the desired density difference on the vertical scale, and the mask is developed to the gamma of the selected curve. This graphical method would permit the toe or the shoulder of the curve to be used if desired for special control effects, but for rigorous application of my process the straight line portion of the characteristic should be used.

For practical attainment of this calculated value it is advisable to standardize development conditions and prepare a chart similar to Figure 4, which shows the gamma obtained at a given duration of development. Having found the required gamma, the time of development necessary is found from this graph.

As an example of the calculations and corrections applied to correct any deficiency the correction of the C or yellow printer is explained in detail. First observing the A scale of the negative **13C**, it is noted that a density difference of 32 must be corrected by an inverse or positive density difference of 32. This must be responsive to the presence of blue green in the original, which is measured by the gradation of the A scale in the negative **13A**. Here the density difference is 134 which must be so printed that a positive of density difference 32 results.

$$\gamma=\frac{32}{134}=0.24$$

and such time of development, three and one half minutes as shown by the chart, for this contrast is given a properly exposed print from the negative **13A**. This positive **15AC** is superposed accurately on the negative **13C**.

Now proceeding to correct the faulty B scale of the negative it is seen that a density difference of 45 must be compensated. The B scale of the B negative which shall control this correction in accord with the presence of magenta, is seen to have an available density difference of 122.

$$\gamma=\frac{45}{122}=0.37$$

The positive **15BC** is developed to this contrast, six minutes according to Figure 4, and is fastened accurately in superposition upon negative **13C** and the previous corrective mask **15AC**, to form in combination the corrected separation negative **16C**. A thin base film is used to advan-

tage for these corrective masks, as it permits more precise registry.

On referring to the density measurement tabulation it will be seen that on addition of the superposed densities at respective ends of the B scale the combination density is equal at each extreme, no gradation remains, and no yellow, C, ink will be placed on the magenta, B, scale. Similarly it is evident that there is no gradation in the A scale and this blue green scale will not be degraded by deposition of C, yellow ink. At the same time the yellow scale has a gradation of 85 which is quite close to the 90 required in the reproduction. This slight adjustment is effected by sensitometric control in the preparation of the positive 17 or print plate 18 to be described.

This corrective action by the compensating positive densities is qualitatively shown quite graphically in Figure 3. The white wedge faults in the negative are precisely filled by the black wedge corrective densities in the respective corrective masks when superposed in registry; and gradation is reduced in the grey strip portion G.

It is notable that a density difference of only 12 remains for gradation of yellow ink on the grey scale G while a density difference of about 100 is noted in the others. This may be understood on realizing that the blue-green A, and magenta B, inks, due to their faults, are absorbing blue light—which is properly the duty of yellow, C, ink. Therefore, some of its work being done, less yellow C, ink need be deposited, and this correction has been precisely effected, responsive to the presence of these inks.

By similar corrective procedure the A and B negatives have been corrected so that gradation is present only where ink should be deposited.

The uncorrected grey printer negative 13G, whatever the method employed to obtain it, is subject to correction by superposition of a positive mask 15CG printed from the uncorrected yellow printer negative 13C. This results in brightening those portions of the reproduction where yellow is to be printed and to a lesser degree where magenta and blue-green are to be printed, these latter effects being due to use of the uncorrected C negative in printing the mask.

Use of my method of control, however, makes the use of the grey printer far less essential than hitherto. Previous use of a "black printer" has served two functions—to define delicate details which might be indistinct thru non registry of the three color plates and secondly, to cover up and hide the faults which I eliminate by color responsive correction. These faults become increasingly obvious with greater depth of the superposed inks, that is, in the dark portions; printers "correct" the faulty hue by a heavy overcoating of black. My use of the grey printer is directed only to the former purpose, and preparation and masking of my grey printer is designed to permit this delineation of detail without unnecessary degradation of the brighter colors. Use of a mask printed from the uncorrected C negative permits its "faults" in the A and B scales to be effectively utilized to this end.

It will be apparent by analogy that a fault in the C scale of the A negative could be corrected by a proper mask printed from the C negative, and that a fault in the C scale of the B negative could be corrected by another mask from the C negative. These corrections would adhere more closely to theory if the masks were made from corrected negatives and so were responsive to the densities of the other inks to be present in the reproduction. However, these further refinements and corrections are both economically impractical and artistically unnecessary; for with available inks of good quality there is practically no gradation in the C scale of A or B negatives. There remains the possibility that because of their phenomenal permanency one would wish to use pigments of poor color quality. In this case these faults could be compensated in all the tint step scales. However, the brightest white would be darkened to a grey and light tints of any color would be somewhat degraded—in fact, this is the only reason for choosing the most pure inks available for use in my process.

Having now obtained properly corrected separation negatives there remains only to print from them in a standardized manner to obtain proper printing of the original scene.

The printing plates are so prepared from each separation negative that the color tint step scale to be printed by each will be reproduced in its original contrast and density. To achieve density balance in the positives a test exposure is made from any corrected separation negative, the exposure for the others being calculated logarithmically from their known density values. To obtain the required density range in the several color tint step strips, gamma and time of development are calculated as described for the masks. For example, if an exposure of 11 seconds were found suitable for the yellow negative having a maximum density of 109 in the C scale, the exposures for the red printer B negative having a density of 164 in the B scale and for the blue printer A negative having a maximum density of 150 and the grey printer, density maximum 180 would be 40 seconds, 29 seconds and 59 seconds respectively, and development be such as to give the desired density difference. From these balanced positives 17, mechanical print surfaces 18 of qualities equivalent to those used in preparation of the original color disc and color tint step strips are prepared.

It will be understood that having correctly reproduced the separate tint strips and grey, any color or combination of colors in the original will be correctly synthesized in the reproduction.

While I have described my process as applied to three color subtractive reproduction it is evidently applicable to multi-color separation fault correction however complex by use of additional masks made according to my method, and I do not limit my claim to the specific embodiment herein set forth.

I claim:

In a process of color reproduction, preparation of a master stepped density strip, measuring density difference between end steps thereof, preparing therefrom printing plates by identical and standardized methods, inking up and printing from said plates upon a support medium such as will be used in the final reproduction, forming a tint step strip in each of the ink pigments to be used as components constituting control strips, placing said control strips at the edges of the field to be reproduced, photographing said field and control strips successively with sensitivity complementary to each of the several component ink pigments, resulting in initial separation records, measuring the density difference in the control strips between corresponding end steps as reproduced in the several records, preparing a corrective mask for

any initial separation record should any reproduced strip therein have a density-difference, except that which is complementary to the sensitivity used in making the initial separation record, said mask being photographically printed from and being of opposite sense of tonal gradation to, that initial separation record made with sensitivity complementary to the original pigment strip which has a density difference requiring masking in the initial separation record to be masked, said mask being developed to a contrast equal to the ratio: density difference in said strip in the initial separation record to be masked / density difference in corresponding strip in the negative from which mask is printed, securing said mask in registry with the initial separation record for which designed, to form corrected initial separation records, photographically printing corrected secondary separation records therefrom, being developed to a contrast, equal to the ratio: density difference in original master stepped density strip / density difference in corrected initial separation record reproduction of step strip complementary to the sensitivity used in making the initial separation record, preparing printing plates from these corrected secondary records by the identical standardized methods used in preparing the plates for the original tint step control strips, adjusting exposures so that the end steps of the reproduced tint strips are of value equal to that of their original printing plates, inking up each plate in that original ink whose pigment is complementary to the sensitivity used in making the initial separation record, and printing said plates successively in superposition upon a support medium such as was used in printing the control strips.

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