Dec. 20, 1960 J. F. BYRNE 2,965,483

XEROGRAPHIC CONTRAST

Filed Sept. 23, 1958

4 Sheets-Sheet 1

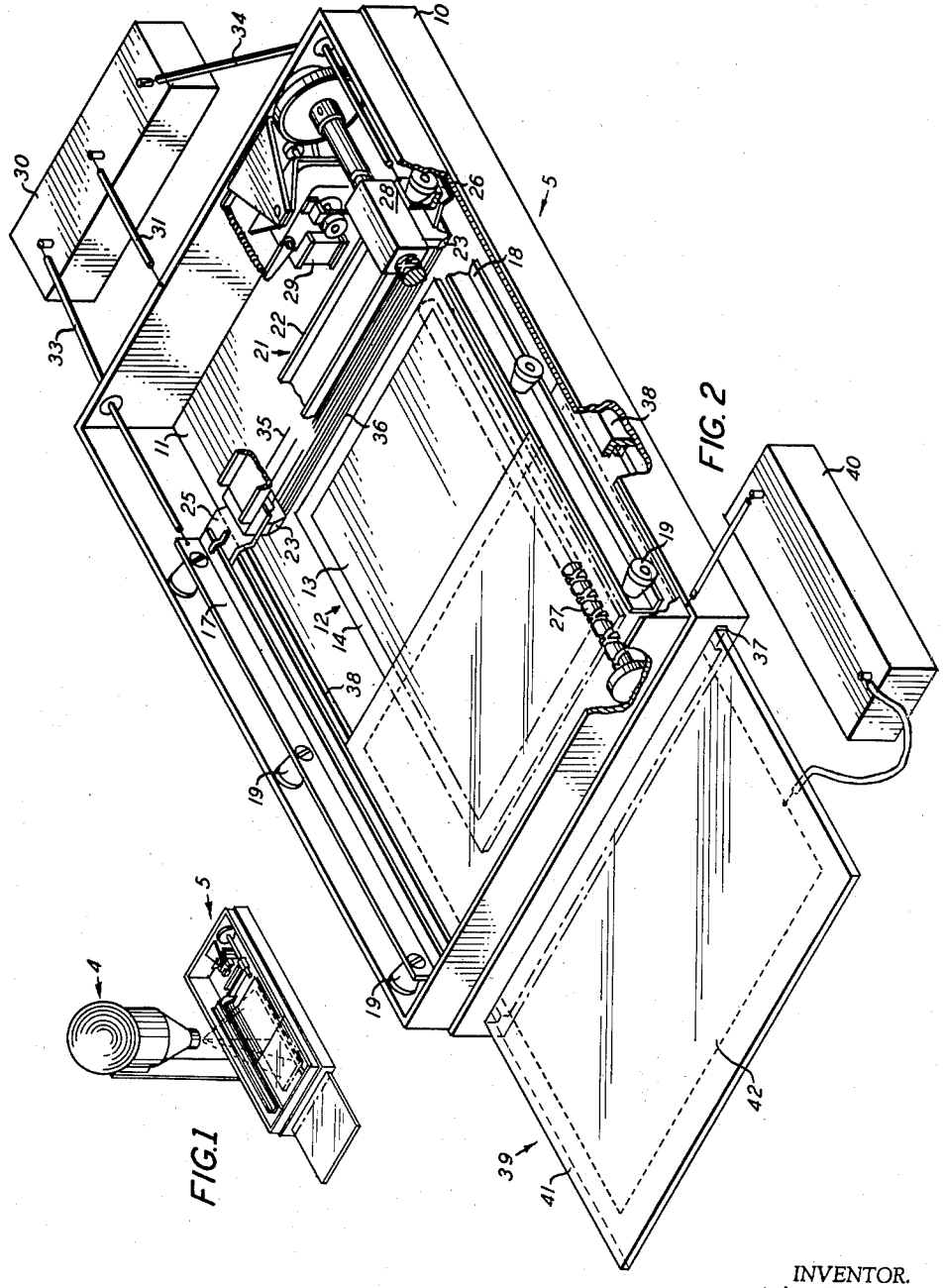


FIG. 2

FIG. 1

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XEROGRAPHIC CONTRAST

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4 Sheets-Sheet 2

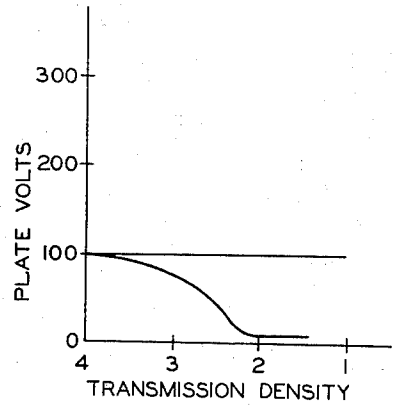


FIG. 3A

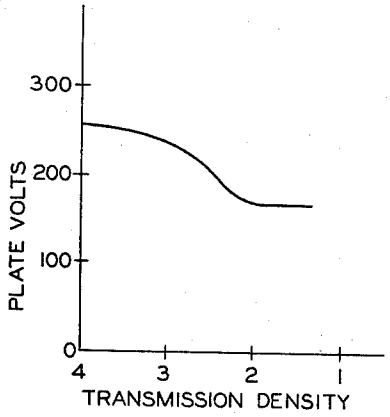


FIG. 3B

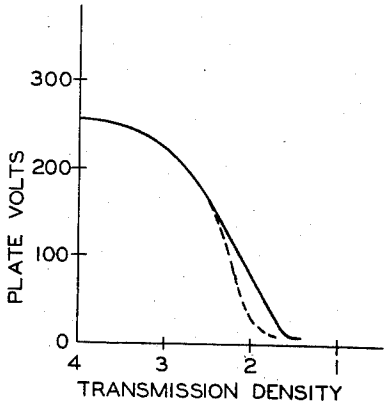


FIG. 3C

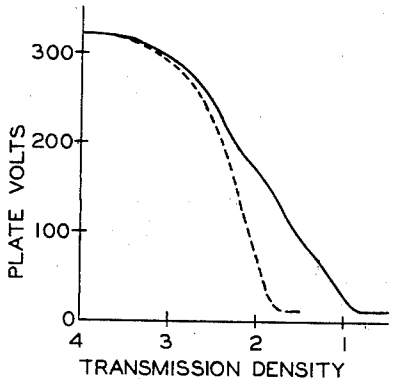


FIG. 5

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Dec. 20, 1960 J. F. BYRNE 2,965,483

XEROGRAPHIC CONTRAST

Filed Sept. 23, 1958

4 Sheets-Sheet 3

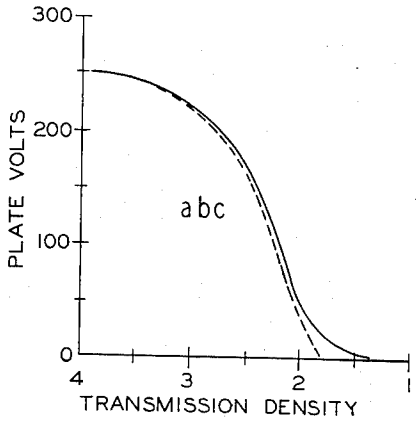


FIG. 4A

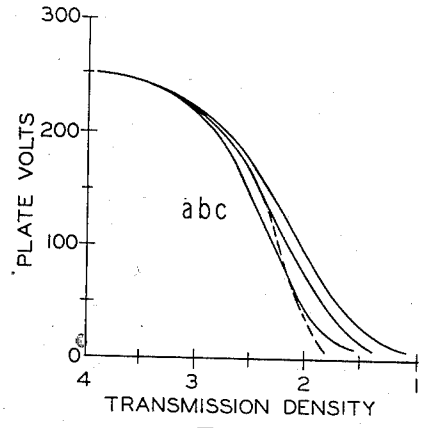


FIG. 4B

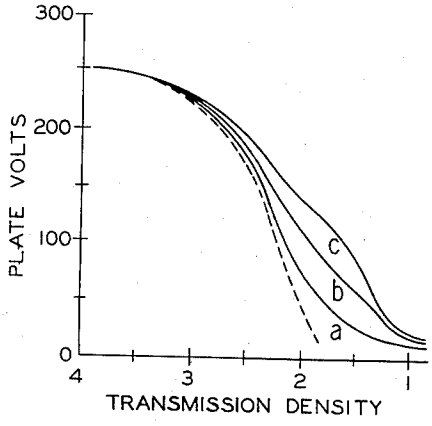


FIG. 4C

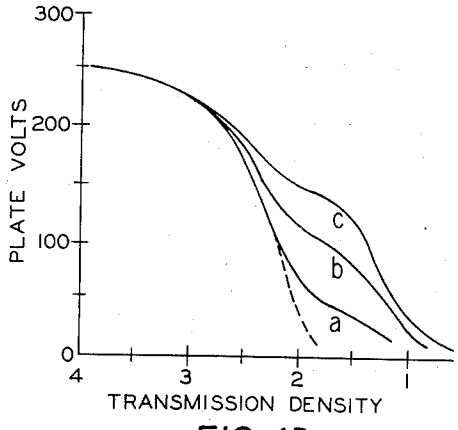


FIG. 4D

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Dec. 20, 1960 J. F. BYRNE 2,965,483

XEROGRAPHIC CONTRAST

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4 Sheets-Sheet 4

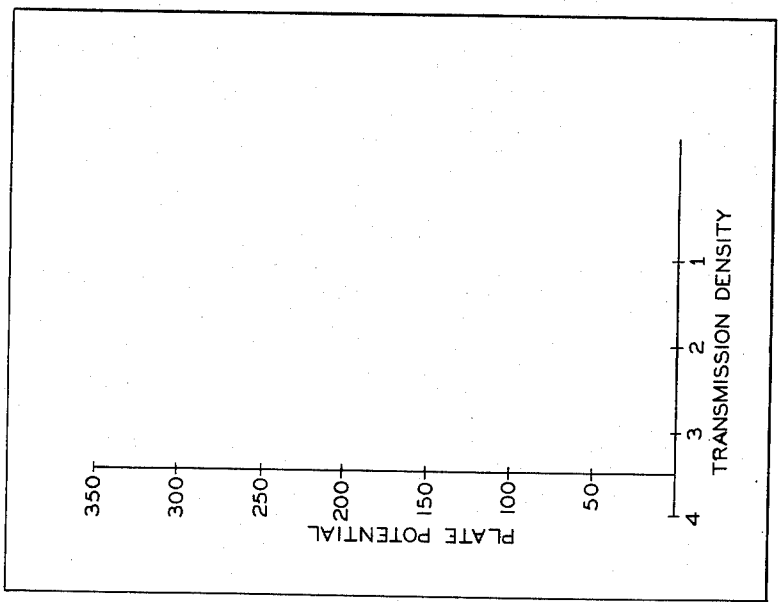


FIG. 7

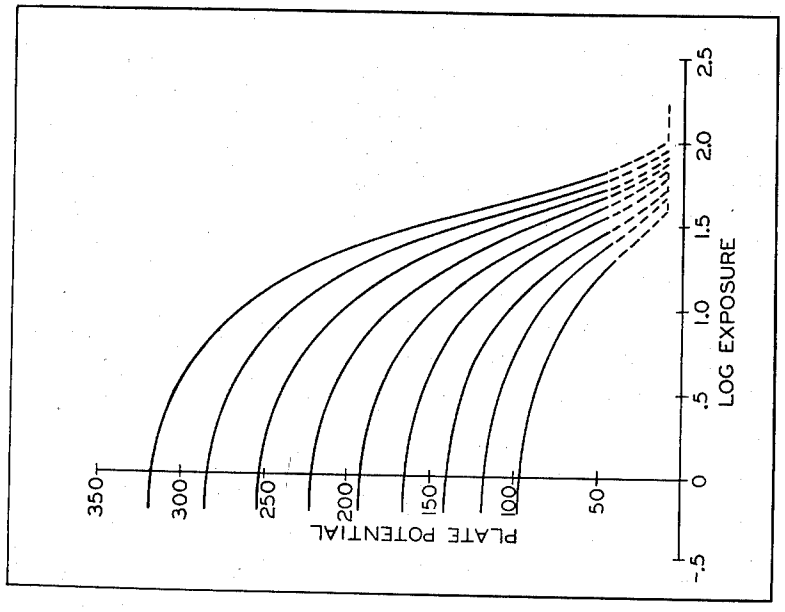


FIG. 6

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United States Patent Office 2,965,483
Patented Dec. 20, 1960

2,965,483

XEROGRAPHIC CONTRAST

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Filed Sept. 23, 1958, Ser. No. 762,875

9 Claims. (Cl. 96—1)

This invention relates to xerography and, more particularly, to contrast control in xerography.

In the basic method of xerography as disclosed in Carlson Patent 2,297,691 a xerographic plate, including a photoconductive insulating layer, is first uniformly charged in darkness to an electrostatic potential of the order of several hundred volts and then exposed to a pattern of light and shadow which has the effect of selectively dissipating electric charge from the illuminated areas of the photoconductive insulator thereby forming an electrostatic latent image. This latent image can be made visible by bringing the surface of the photoconductive insulator into proximity with a mass or suspension of finely divided, electrostatically attractable material which is attracted to the surface of the photoconductive insulator in relation to the amount of charge residing thereon.

The electrostatically attractable material may be viewed on the photoconductive insulator or it may be transferred to another support such as a sheet of paper for more convenient viewing and to permit the reuse of the xerographic plate while retaining the image.

Various forms of image development are known and any of them may be used in connection with the present invention. One such method particularly suitable for use in developing continuous tone images is disclosed in Landrigan 2,725,304.

Where high quality continuous tone reproduction is desired in xerography, vitreous selenium is commonly used as the photoconductive insulator, but other suitable photoconductive insulators are known including, but not limited to, sulfur, anthracene, and dispersions of photoconductive materials such as zinc oxide or other photoconductive pigment in an insulating binder.

For plate potentials greater than about 50 volts, selenium, and photoconductive insulating materials generally, have been found to lose their electrostatic charge or potential upon exposure to light in close accordance to the following relation:

$$\sqrt{V_0}-\sqrt{V}=kE$$

where V_0 is the initial potential and V is the potential remaining after an exposure E, and k is a constant depending upon the particular photoconductive insulating material and the units of measurement. This type of charge-exposure relationship, when coupled with the relationship between the charge on the photoconductive insulator and the developed image density as found in the Landrigan or other development methods, leads to an undesirably high contrast in the developed image. Where a positive-to-positive development method is employed, the overall xerographic process has been found to offer about the same overall contrast in reproduction as a No. 3 or No. 4 photographic paper, which are generally known as hard or contrasty grades. As a consequence, images as reproduced by the above processes tend to have an unpleasant, harsh appearance and the

range of tonal values which can be reproduced has been very small. This contrast problem is not met with to the same degree in the negative-to-positive forms of xerography.

We have now found a way to modify the relation between the potential on the photoconductive insulator and the exposure to provide for a lower contrast reproduction and a greater exposure acceptance range. This is accomplished through the use of an induction electrode maintained at a non-constant voltage during exposure, as will be further explained hereafter.

It is accordingly an object of the present invention to provide a novel method and a novel apparatus to alter and control contrast in xerography.

It is a further object to provide a xerographic reproduction method with reduced contrast.

It is a further object to increase the exposure acceptance range of xerography.

It is still a further object to control the relation between exposure and xerographic plate potential through the use of an induction electrode in a novel manner.

These and other objects will become apparent through the following descriptions and drawings in which:

Fig. 1 represents a simplified schematic perspective view of an apparatus suitable for carrying out the invention;

Fig. 2 represents an enlarged perspective view of part of the apparatus of Fig. 1;

Figs. 3–A, B, C are curves of potential versus subject density at different stages of carrying out the invention.

Figs. 4–A, B, C, D are curves of potential versus subject density for various modifications of the invention;

Fig. 5 is a curve of potential versus subject density for another modification of the invention;

Fig. 6 is a set of potential decay curves useful in predicting the results of the invention; and,

Fig. 7 is a prepared form used in connection with Fig. 6 for graphically computing the results of the invention.

In Fig. 1, 4 is a conventional photographic enlarger adapted to project a light image from a transparency or other original onto a xerographic plate (not shown) located in charging apparatus 5.

Fig. 2 shows the construction of charging apparatus 5 as shown in Fig. 1. Support frame 10 serves to position all components and includes a base plate 11 generally made of conductive material, but which can optionally be made of glass or the like upon which is placed xerographic plate 12 comprising a photoconductive insulating layer 13 and a conductive support 14. In some cases conductive support 14 may be omitted. Conductive rails 17 and 18 are positioned on opposite sides of frame 10 and each rail is secured to frame 10 but insulated therefrom by insulator 19. A charging bar or scorotron 21 is slidably mounted in frame 10 and may be passed over xerographic plate 12 at a slight distance therefrom. It comprises a support channel 22 generally of conductive material, carrying at each end insulating blocks 23 between which are a set of three corona generating wires 35 and a set of screen wires 36. Charging bar 21 is supported in frame 10 by hangers 25 and 26 which slide on rails 17 and 18 respectively. Hanger 25 is connected to corona generating wires 35 and hanger 26 is connected to screen wires 36 whereby the potential of each set of wires may be controlled by applying a potential to the corresponding rail. High voltage power supply 30 is connected to base plate 11 and thus to conductive support 14 through wire 31 and is connected to the two sets of wires in charging bar 21 through wires 33 and 34 connected to rails 17 and 18 respectively. Frame 10 also rotatably supports a reversing lead screw 27 which is adapted to move the charging bar back and forth over xerographic plate 12

by means of the lead screw block 28 which engages the groove in the lead screw and is attached to support channel 22. Electric motor 29, also attached to frame 10, is used to rotate lead screw 27. Conventional control apparatus such as a microswitch (not shown) may be provided to stop motor 29 in charging bar 21 after charging bar 21 passes back and forth over xerographic plate 12 and returns to the starting position as shown. Frame 10 also includes a slot 37 and channels 38 in which may be inserted or removed in close parallel proximity to xerographic plate 12 a transparent conductive induction electrode 39. Suitable materials for transparent conductive electrode 39 include glass or plastic sheets with thin evaporated metal layers or with copper iodide coatings, but the preferred material is a sheet of glass having a transparent conductive tin oxide layer on the face nearest the xerographic plate 12, i.e., the lower face. This type of conductively coated glass is commercially available under the trade names Nesa and Electropane. A high voltage may be applied to conductive electrode 39 by power supply 40.

In a typical application of the present invention, a xerographic plate 12 which may include a thin layer 13 of vitreous photoconductive insulating selenium on a metal base 14 is first charged to a positive potential of several hundred volts by applying from power supply 30, in accordance with standard xerographic practice, a potential of several hundred volts positive to screen wires 36 and a positive potential of about 6000 to 8000 volts to corona generating wires 35 and by energizing motor 29 to move charging bar 21 back and forth over the xerographic plate. Transparent conductive electrode 39, during charging by bar 21, is not in position in channels 38. Transparent conductive electrode 39 is then inserted into channels 38 and a negative potential of the order of several thousand volts is applied to electrode 39 by power supply 40. The voltage applied to transparent electrode 39 should be sufficient to lower the electric field in the selenium layer caused by the positive charge polarity on the surface of the xerographic plate and to lower the potential of the surface with respect to the backing of the plate. The proper potential to apply to electrode 39 is the desired change in plate potential times the ratio of the capacitance per unit area of the selenium layer 13 to the total capacitance per unit area between metal base 14 and the electrode 39. Enlarger 4 is now energized and projects a light image onto plate 12 through transparent induction electrode 39. After the exposure is partially completed, the potential is removed from induction electrode 39 and the exposure completed with electrode 39 at zero potential. The exposure could also be made in two successive parts rather than one as described. After exposure is completed, plate 12 may be removed from charging apparatus 5 and developed by conventional means.

The working of the present invention can be more clearly understood from an examination of the curves of Figures 3–A, B, and C. Each such curve shows the relation between the potential of an area of the xerographic plate and the transmission density of the corresponding area of the original transparency, or the reflection density if an opaque original is used. Units of log exposure could equally well be used for the horizontal or density scale. The horizontal line in Fig. 3–A represents the plate potential after the plate has been charged and after the voltage has been applied to electrode 39 but before exposure. It is uniform in all areas of the plate and in this particular example is 100 volts. The curved line of Fig. 3–A shows the plate potential as a function of density after the first part of the exposure. This curve is of the form predicted by the previously given relation $\sqrt{V_0}-\sqrt{V}=kE$. The lower horizontal or toe portion represents the observed failure of the above relation for very low potentials. Fig. 3–B shows the plate potential versus density after the voltage has been removed from electrode 39. This curve is the same as Fig. 3–A, but displaced upward by the increment of potential caused by removing potential from electrode 39, which increment in this particular case is 156 volts. The solid line of Fig. 3–C represents the potential versus density relation after the second part of the exposure. The broken line, by comparison, is the same relation for a plate which has been given a single exposure only without the use of electrode 39. It will be seen that the solid line representing the plate exposed in two parts with different electrode potentials spans a greater length of the density scale, is more nearly linear, and is less steeply sloped. These characteristics all lead to improved quality in the image developed on such a plate regardless of the development method employed. It can also be seen by comparing Figures 3–A and 3–C that the first part of the exposure was such as to substantially completely discharge areas corresponding to the brightest parts of the image.

Figures 4–A, B, C, and D are all similar to that of Fig. 3–C, but illustrate the variety of different curves that can be obtained by suitable adjustment of the system parameters using a two part exposure with different electrode potentials for each part. The solid line of Fig. 4–A represents a series of the indistinguishable curves sharing the common characteristic that log E_1 minus log E_2 equals 0.6; i.e., the logarithm of the second part of the exposure exceeded that of the first by 0.6, or, the second part of the exposure was 4 times the first. The three curves, *a, b, c,* are ones for which the plate potential at the start of exposure and the plate potential increment added by removing the electrode potential were 196 and 60; 144 and 112; and 100 and 156, respectively. The broken curve again represents a plate given a single exposure without the use of a variable potential electrode 39 and in this case is scarcely distinguishable from the solid line. The solid lines of Fig. 4–B represent a family of curves for which log E_1 minus log E_2 equals +0.6; i.e., the second part of the exposure is one-fourth the first. Similarly, Fig. 4–C represents a family of curves for which log E_1 minus log E_2 equals 0.9 and Fig. 4–D represents a family of curves for which log E_1 minus log E_2 equals 1.2. In each case the plate potential at the start of exposure and the plate potential increment added by removing the potential from electrode 39 were for curves *a, b,* and *c,* were 196 and 60, 144 and 112, and 100 and 156, respectively. In each case the broken curve represents a plate given a single exposure without the use of a variable electrode potential. It can be seen from the above figures that the response of a xerographic plate to illumination can be varied over very wide limits. It can also be seen that the variable potential and induction electrode method only becomes effective when the second part of the exposure is less than the first.

Fig. 5 illustrates the additional improvement obtainable by using a three part exposure with different electrode potentials for each part. The solid line represents the potential versus density relationship obtained with a three-part exposure while the broken line again represents the relation for a single exposure without the use of the induction electrode. It can be seen that the light acceptance range is increased by nearly one logarithmic unit, or ten times, over the corresponding single exposure curve.

Decay curves of the type shown in Figures 4 and 5 may be computed in advance by a graphical method involving the use of prepared forms as shown in Figures 6 and 7. Figure 6 represents a sheet of paper on which is drawn a family of light decay curves; i.e., curves relating the potential of a particular xerographic plate to total light exposure for a number of different initial potentials. The horizontal axis is calibrated in units of log exposure while the vertical axis is linear in plate potential. Any convenient unit of exposure may be used for preparing the horizontal axis scale; such as foot candle seconds or the like. Fig. 7 represents a sheet of tracing paper or

the like on which is drawn only a vertical axis identical with that of Fig. 3 and a horizontal axis calibrated in units of log density spaced apart the same distance as the log units of Fig. 6 and corresponding to the transmission or reflection density, as the case may be, of various areas of a subject to which the xerographic plate is to be exposed. The vertical axis of Fig. 7 is located at a point along the horizontal axis which corresponds to the vertical axis or zero log exposure point of Fig. 6 for the conditions to be used during the first part of the exposure of the xerographic plate. It will be understood that the exposure at a given point of the xerographic plate is related to the density of the corresponding portion of the subject by a number of constant, calculable factors including the intensity of illumination at the subject, exposure time, and the characteristics of the optical system, if any, between the subject and the xerographic plate. Thus, an area of the original having a density corresponding to the vertical axis of Fig. 7 will, when used in the particular apparatus for which Fig. 7 was drawn, give an exposure of zero logarithm units; that is, one unit of exposure itself since the antilogarithm of zero is one.

To determine a decay curve according to the present invention, the translucent form of Fig. 7 is placed over that of Fig. 6 so that both vertical axes coincide and the horizontal axis of Fig. 7 is lowered beneath that of Fig. 6 so that the horizontal axis of Fig. 6 crosses the vertical axis of Fig. 7 at a voltage or potential corresponding to that which is to be added to the xerographic plate by the change or removal of the electrode potential. The light decay curve of Fig. 6 which has the same image potential as that of the xerographic plate at the start of exposure is then copied onto Fig. 7 by running a pencil over the curve, which is visible through the tracing paper of Fig. 7. The pencil line drawn on Fig. 7 now represents, when read in terms of its own vertical axis, a curve of xerographic plate potential versus subject density as would be measured after the electrode potential has been changed or removed, but before the second part of the exposure has commenced. The translucent sheet of Fig. 7 can then be moved upward so that the horizontal exposure axes of both sheets coincide and the vertical axis of Fig. 7 is displaced to the right of that of Fig. 6 by an amount, as measured on the horizontal scale of Fig. 6, corresponding to the logarithm of the ratio of the magnitude of the second part of the exposure to that of the first part of the exposure. Thus, if the first and second parts of the exposure are equal, the two vertical axes should coincide. If the second part of the exposure is ten times the first, then the vertical axis of Fig. 7 will be displaced one unit to the right along the scale of Fig. 6. If the second part of the exposure is one-tenth that of the first, then the vertical scale of Fig. 7 will be displaced one unit to the left and similarly for other exposure ratios. After the translucent sheet of Fig. 7 has been properly positioned with respect to Fig. 6, a point is selected on the pencil tracing of Fig. 7 having a potential equal to the initial potential of one of the curves of Fig. 6. Such a point can be graphically located by drawing a line horizontally from a point over the beginning of one of the curves of Fig. 6 until it intersects the pencilled curve previously drawn on the sheet of Fig. 7. When such a point on the pencilled curve has been located, a second line is drawn vertically downward until it crosses that same decay curve of Fig. 6 which has the given initial potential and an "X" is drawn at this point. The above procedure can be repeated for a considerable number of the initial potential values of Fig. 6 and a smooth curve can then be drawn through the "X" marks on the translucent sheet of Fig. 7 to give a curve representing the xerographic plate potential versus the subject density after the second part of the exposure. An analysis of the above procedure will show that the final potential corresponding to any given subject density has, in effect, been determined by taking the plate potential after the change or removal of

the electrode potentials, referring this to the light decay curve having this particular potential as its initial value, and following this particular light decay curve for a distance corresponding to the additional illumination given in the second part of the exposure. By the above methods curves can readily be determined corresponding to any desired combination of plate charging, electrode potentials and ratio of exposure parts.

The graphical method described above may also be extended to the computation of curves resulting from the use of three or even more separate exposure parts. The simplest way to compute the potential versus density curve for a third part of the exposure is to take a second piece of tracing paper having scales as shown in Fig. 7, place it over the sheet of tracing paper having the curve computed for the first two parts, align the two vertical scales, displace the overlying sheet downward by an amount corresponding to the potential increment to be added by the second change in electrode potential, and tracing the underlying curve onto the overlying sheet of tracing paper. The curve on this overlying or second sheet of paper now represents the potential versus density relationship after the second change of the electrode potential. This second sheet of tracing paper according to Fig. 7 is then placed over Fig. 6, the horizontal scales of both sheets are aligned and the tracing paper sheet is moved to the right or left so that its vertical scale is displaced from that of Fig. 6 by a distance corresponding to the ratio of the third part of the exposure to the first. The method of graphical construction described in the preceding paragraph can then be used to compute the potential versus density curve resulting from the third part of the exposure. The process of the present paragraph can be repeated if it is necessary to compute the results of exposures with more than three separate parts.

In general, between each part of the exposure the potential of electrode **39** will be further lowered and the last part of the exposure will be made with the electrode at zero potential (with respect to the metal base **14**). In some cases, however, the last part of the exposure may be made with some other potential on the electrode in which case there will be a further uniform increment of potential added or subtracted from the plate when it is removed from charging apparatus **5**. It is generally desirable to make a single continuous exposure of the plate and to vary the electrode potential stepwise during this exposure, but it is also possible to make a series of separate exposures, varying the electrode potential between exposures. This modification may be desirable where a flash tube or the like is used as a light source. In this case also the individual exposure parts might be varied by adjusting the lens aperture of enlarger **4** rather than by varying the exposure time. Similarly, it is also possible to make a single continuous exposure while continuously varying the potential on electrode **39**. This is the equivalent of using a very large number of very small separate exposure parts according to the procedure described above. In a further modification of the invention the initial charging of the plate as by the charging bar **21** in apparatus **5** may be omitted. In this case, the first part of the exposure is made with a first potential on electrode **39** and the second or subsequent parts are made with greater potentials on the electrode. The results obtained by this modification are generally similar to those obtained by the first described embodiment except that there results a pattern of potential on the plate after the removal of electrode **39** in which the more highly illuminated areas have the greater potential.

In carrying out this invention with the electrode separated from the plate by an air gap one may occasionally, depending on the electric field across the gap, experience air breakdown in the gap. Such a breakdown may be avoided by making use of the insulating properties of high pressure gas, of special gases like sulphur hexachloride, or a vacuum. Thus, and for example, the plate and the electrode could be placed in a gas tight en-

closure containing high pressure air or an insulating gas during the exposure and induction step, if desired.

As is apparent, a specific embodiment has been described in connection with the present invention, and it is to be realized that there is no intention to be limited thereto; instead, alternatives and equivalents are intended to be included within the scope of this invention. For example, the xerographic plate has been described as being exposed by projecting an image from an enlarger. Obviously, charging apparatus **5** or its equivalent could be put into a camera in such a way that the plate could be exposed to an original scene. Likewise, exposure has been described as taking place through a transparent conductive electrode **39**. However, metal base **14** may be eliminated or replaced by a transparent member in which case exposure may be effected through the back of the xerographic plate and electrode **39** may be opaque. Similarly, while electrode **39** has heretofore been described as separated from the photoconductive insulating layer by a uniform space, it is apparent that the electrode could also be spaced apart from the photoconductive insulating layer by a thin film of insulating material contacting both the electrode and the photoconductive insulating layer. If a suitable conductive coating is applied to the insulating film, then the film can obviously itself serve as electrode **39**. Likewise, the disclosure has been in terms of a selenium photoconductive insulating layer and positive charging of that layer. Vitreous selenium is widely used as the photoconductive insulating material of layer **13** and selenium generally operates best with a positive charge. However, numerous other photoconductive insulating materials are known including other vitreous materials as well as dispersions of photoconductive materials in insulating binders. Certain of these other materials operate best with a negative charge which may be applied to the plate through the use of negative potentials on wires **35** and **36**. Where the xerographic plate is negatively charged, a positive potential will normally be applied to electrode **39**. Similarly, other variations as will readily occur to those skilled in the art are also intended to be included herein, and it is intended to cover the invention broadly within the spirit and scope of the appended claims.

What is claimed is:

1. In a xerographic method of improving the tonal contrast in a reproduction of an undeveloped electrostatic charge pattern to reproduce a positive reproduction from a positive original, the improvement comprising prior to development and while exposing a xerographic plate to a single pattern of light and shadow

applying a first field of a given polarity through said plate and then applying with exposure to the same pattern in register a second field of said given polarity having a greater intensity than said first field through said plate so as to control the contrast to the desired degree.

2. The method of claim 1 in which the field is increased step-wise and exposure is continuous from start to finish.

3. The method of claim 1 in which the exposure is made in separated parts and in which the field is maintained constant during each part and increased between each part.

4. The method of claim 1 including the application of a third field of said given polarity with exposure to the same pattern in register, said third field having a greater intensity than said second field through said plate.

5. The method of claim 1 in which said xerographic plate includes a layer of vitreous selenium and in which the charge pattern formed on the plate surface comprises positive polarity electrostatic charges.

6. The method of claim 1 in which said first field is applied through the application of a potential to an induction electrode positioned and disposed uniformly closely adjacent a xerographic plate and to which a potential is applied in respect to the xerographic plate.

7. The method of claim 1 in which said first field is applied by first depositing a uniform electrostatic charge on the surface of the xerographic plate and then applying a potential to an induction electrode positioned and disposed uniformly closely adjacent the xerographic plate and to which a potential is applied in respect to the xerographic plate.

8. The method of claim 7 in which the second field is applied by placing the induction electrode potential at about zero volts relative to said plate.

9. The method of claim 1 in which the second field and exposure during the application of said second field is applied to the xerographic plate for a time period less than the time period during which said first field and exposure during the application of said first field is applied to the plate.

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