

[54] **METHOD OF CONTROLLING THE
BRIGHTNESS ACCEPTANCE RANGE AND
TONAL CONTRAST OF A XEROGRAPHIC
PLATE**

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317/262 A, 262 AE

References Cited

UNITED STATES PATENTS

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3,355,289 11/1967 Hall et al. 96/1 R X
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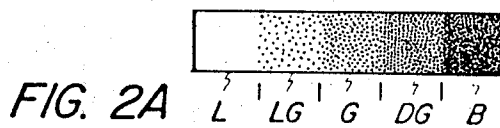
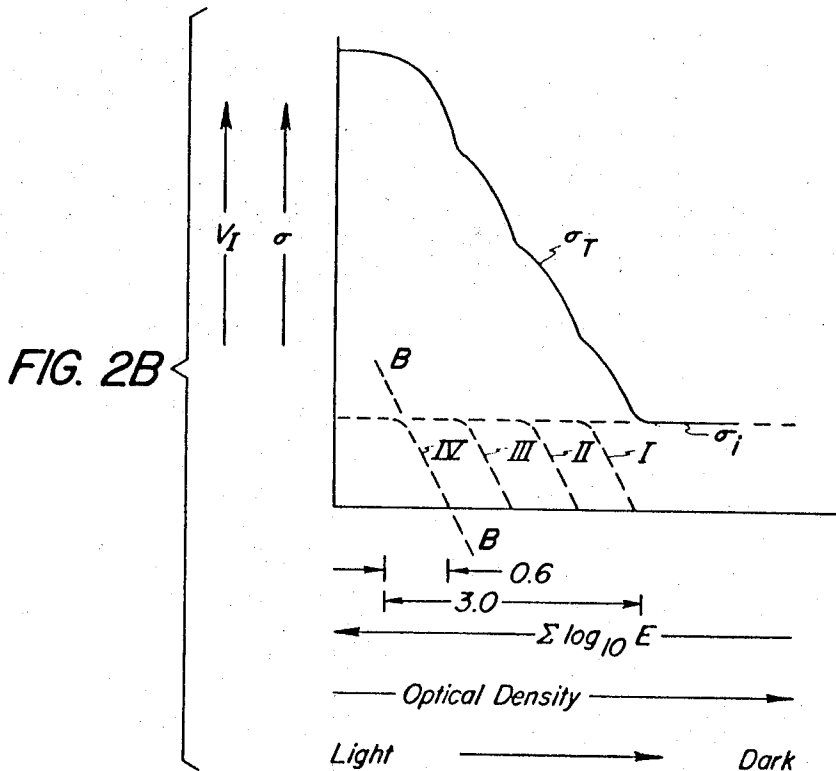
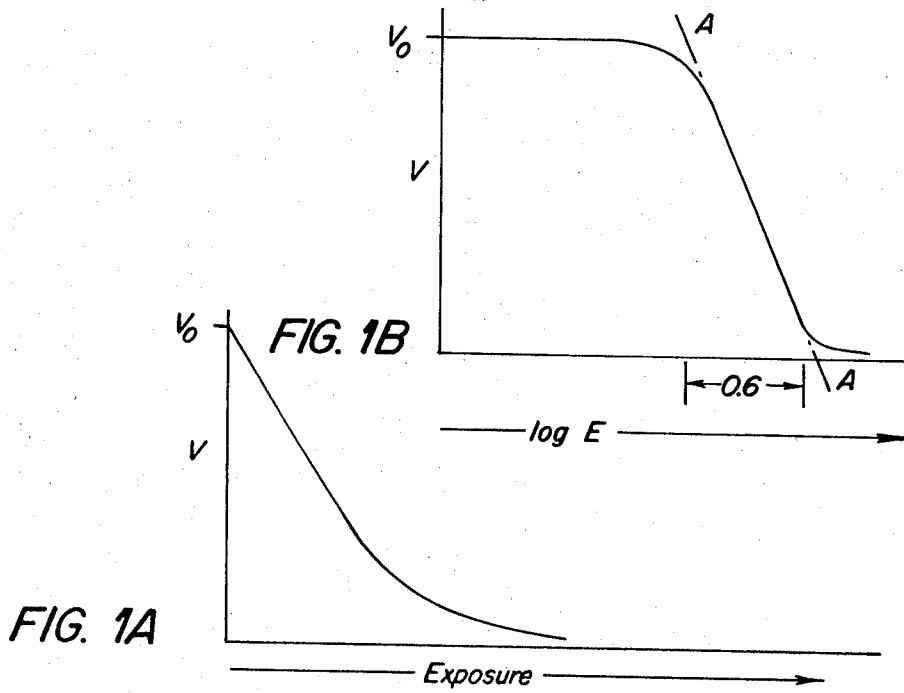
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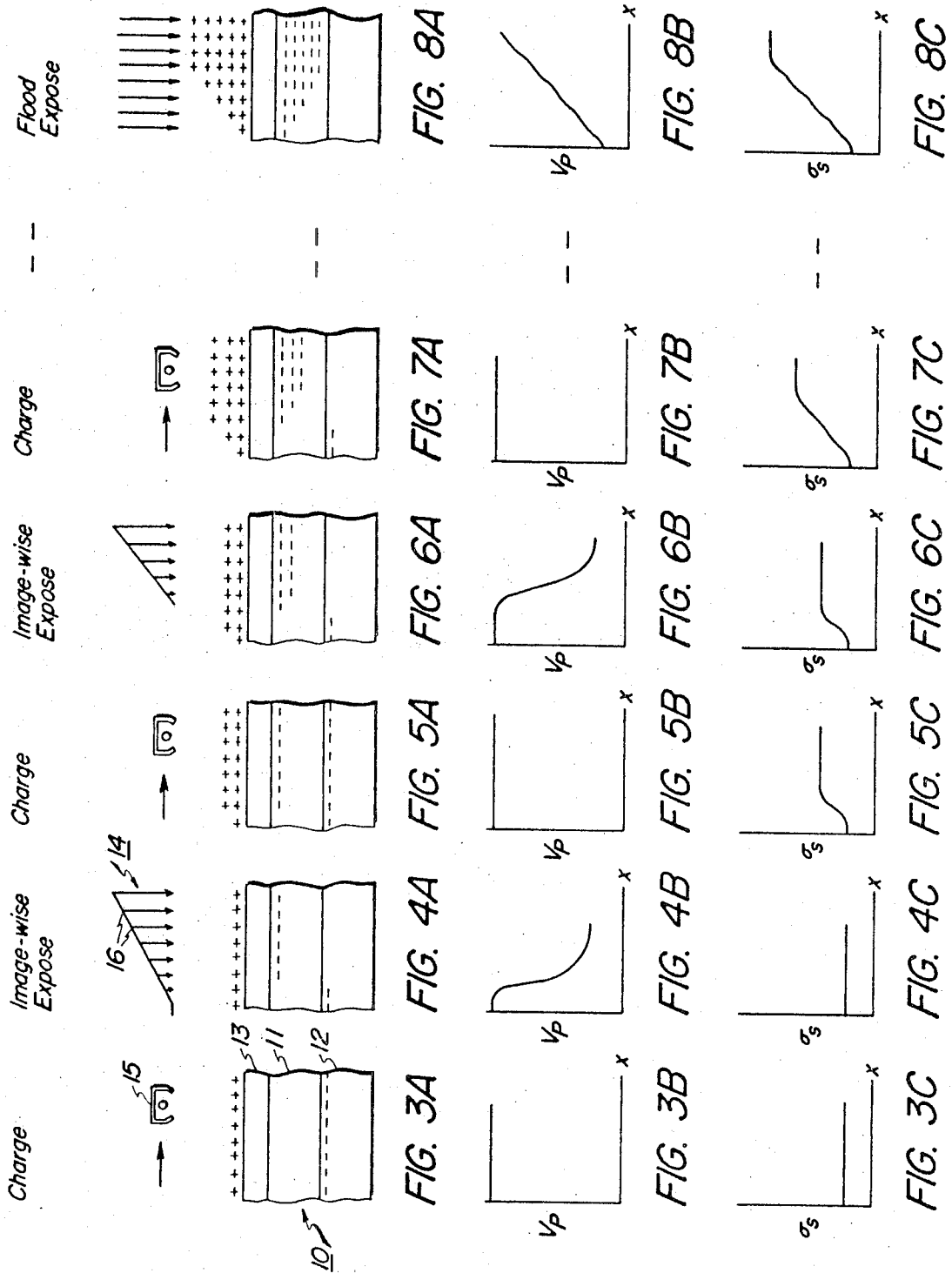
[57] **ABSTRACT**

A method of controlling the brightness acceptance range and tonal contrast of a xerographic plate having an insulating overlayer, which includes the steps of charging and imagewise-exposing the plate, and repeating these steps at least once more, to cumulatively store the latent electrostatic images formed by each of the charging and exposing steps on the plate. The plate is then recharged and flood-exposed, and electrostatically attractable particles and deposited thereon to develop the latent electrostatic image.

9 Claims, 22 Drawing Figures

SHEET 1 OF 2





METHOD OF CONTROLLING THE BRIGHTNESS ACCEPTANCE RANGE AND TONAL CONTRAST OF A XEROGRAPHIC PLATE

This is a continuation-in-part application of a prior copending application Ser. No. 213,022 filed on Dec. 28, 1971, now abandoned.

This invention relates to xerography in general and, in particular, to a method of controlling the brightness acceptance range and extending the tonal contrast of xerographic plates for producing high fidelity copies.

BACKGROUND OF THE INVENTION

Conventionally, in the xerographic process, as disclosed in U.S. Pat. No. 2,297,691 to Carlson, copies of an original are obtained by placing a uniform electrostatic charge upon a photoconductive layer of a xerographic plate in darkness, forming a latent electrostatic image on the surface of the photoconductive layer by exposing the layer imagewise to light or to a source of actinic radiation to discharge selected areas of the layer, developing the latent image into a visible form by depositing an electrostatically attractable developer material or toner onto the charged surface, and transferring and fusing the image on a suitable base such as a copier paper. The aforementioned xerographic process provides high quality copies at relatively low cost and high speed and has been found especially well suited in making line copies.

Further progress made in xerographic art has extended the processes to make gray tone copies. Thus, for example, as disclosed in the U.S. Pat. No. 2,965,483 to J. F. Byrne it is shown that the brightness acceptance range can be extended and the tonal contrast can be controlled for a xerographic plate having a photoconductive insulating layer by charging the plate and then placing a transparent electrode layer above the plate, applying a DC potential to the transparent electrode, imagewise exposing the plate, changing the DC potential of the electrode and exposing the plate in succession. In particular, Byrne shows that the successive exposure is accompanied by changes in the DC potential applied to the electrode without recharging the plate.

While the copies obtained by the aforementioned xerographic methods are satisfactory in many application, they do not produce very high fidelity copies of originals which contain a wide range of gray shades and tonal contrasts. They tend to copy black or shade areas blacker than the original and light shades or light gray areas whiter than the original.

Accordingly, one object of the present invention is to provide an improved xerographic method.

Another object of the present invention is to provide improved methods of extending the tonal contrast and the brightness acceptance range of the xerographic plate for providing high fidelity copies.

BRIEF DESCRIPTION OF THE INVENTION

In accordance with the present invention, the brightness acceptance range and tonal contrast of a xerographic plate having a conductive substrate, a photoconductive layer and an insulating overlayer are extended by charging the imagewise exposing the plate and storing the discharge pattern at the interface of the insulating layer and photoconductive layer, and repeating the charging and exposing steps at least once in register with the first charge and exposure steps, thereby

cummulatively adding the charge patterns before the plate is charged and flood-exposed to form a resultant latent electrostatic image thereon. The latent image is then developed with a toner and transferred and fused onto a paper in the conventional manner. In accordance with another feature of the invention, the copying process is speeded up by performing charging and exposing steps simultaneously.

The foregoing and other objects and features of the present invention may be more clearly understood from the following detailed description in conjunction with the accompanying drawings wherein:

FIG. 1A shows the plate potential versus the exposure of xerographic plate in linear scale;

FIG. 1B shows the same shown in FIG. 1A except in semi-logarithmic scale;

FIG. 2A shows a schematically photographic step tablet having shades of gray ranging from black to white;

FIG. 2B shows the plate potential versus the exposure in a semi-logarithmic scale;

FIG. 3 through 8 shows the cross section of a xerographic plate versus its electrostatic potential and the charge density characteristic after successive charge and exposure steps involved in the present method.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

The tonal quality of xerographic copies depends upon various factors such as photosensitivity, spectral response, acceptance potential, dark decay, retentivity and residual potential characteristics of the photoconductive layer of the plate, and the electrostatic plate potential (i.e., the free surface potential relative to the conduct substrate) versus the exposure characteristics of the plate. The last mentioned characteristic gives a measure of the quality of xerographic copies in that it determines the brightness acceptance range and tonal contrast of the xerographic plate. The brightness acceptance range refers to an effective range of electrostatic potential gradients formed on a xerographic plate after the plate is electrostatically charged and imagewise exposed to light or an activating radiation.

It has been found that the electrostatic potential gradients formed by the usual steps of charge and exposure are not proportional to the variations in the tone or shades of the darkness of the original. Thus, for example, the plate voltage versus exposure relationship of the usual photoconductive layer made of vitreous selenium is found to display a substantially square root decay characteristic upon exposure as shown in FIG. 1A where the plate potential versus exposure is shown in linear scale. A useful portion of this characteristic gives measure of the brightness acceptance range and tonal contrast of the plate and this portion is shown in a straight line A—A segment of the plate potential versus exposure as shown in FIG. 1B where the exposure is shown in logarithmic scale.

The photo induced discharge curve of FIG. 1A is often expressed in mathematical terms, $\sqrt{V_0} - \sqrt{V} = KE$ in which V_0 refers to the initial potential at which the xerographic plate is uniformly charged by suitable corona generating means such as a corotron or scorotron in darkness, V to the potential remaining on the plate after the exposure, and E to the exposure and K to a constant which depends upon the characteristics of the photoconductive layer, the brightness acceptance

range (i.e., useful portions of line A—A) is about 0.6, which is not wide enough to copy faithfully various shades of gray found in most original that have density differences that usually range between 1.0 and 3.0.

FIG. 2A shows a photographic step tablet having shades of gray such as light gray GL, gray G, and dark gray DG ranging between light L and black B areas. Qualitatively stated, the xerographic plate 10 (FIG. 3A) is first charged and image-wise exposed to the original (FIG. 2A) at a level high enough to over expose all but the black B areas and store them in the form of negative charges at the photoconductor/insulator interface. The charging and image-wise exposure steps are repeated in succession but at successively lower levels of exposure so that charge images of the dark gray DG, gray G, light gray LG and white or light areas L are formed and stored. The resulting successive charge images cumulatively stored at the photoconductor/insulator interface represent an electrostatic image of the original with brightness acceptance range which is much wider than that obtained by a conventional electrostatic process.

Referring to FIG. 2B, the abscissa represents an optical density or shades of gray with the increasing level of darkness from left to right. The abscissa also represents cumulative levels of exposure expressed in a logarithmic scale from right to left. The vertical axis represents a charge density of the negative charges at the photoconductor/insulator interface. The vertical axis can be seen as a potential (i.e., the potential at the surface of the insulating layer with respect to the grounded substrate) of the plate in that the potential is directly related to the charge density after the flood exposure step. The charge density versus exposure for each of the different levels of the exposure are shown by the dotted curves I, II, III and IV. A straight dotted line B-B represents a charge density at the interface after the initial charging step and exposure steps. The sloping portions of the charge density versus the exposure curves contain useful intelligence in that the shades of gray can be directly related to this portion of charge density. When flood exposed, the range of charge density in turn provides potential pattern on the plate that is subsequently utilized in developing the latent image xerographically in a well known manner.

According to the present invention, the foregoing phenomena are advantageously utilized to extend the brightness acceptance range of the xerographic plate. By reducing the exposure in the successive charge/exposure cycle, information on different range of shades of gray are obtained in the form of varying charge density as shown by the curves I, II, III, and IV, respectively. Thus, as explained already, the charge images of the black B, dark gray DG, gray G, light gray LG, and light L areas of the original (FIG. 2A) are obtained by charging the plate and image-wise exposing it at a high level of intensity and repeating the charging and exposure steps while reducing the exposure in increments by a suitable amount. As shown in FIG. 2B, the foregoing steps bring about an accumulation of charges at the photoconductor/insulator interface. As shown graphically, the solid line curve represents a sum of the charge pattern generated by the successive and exposure steps.

In the foregoing, while the charge level is shown to be maintained at a constant level, this need not be so limited. As well known in xerography, the charge may

be maintained at a constant level by using a scorotron as the corona device. But, in the alternative, a corotron may be used as the corona device which produces and deposits charges on the xerographic plate in a conventional manner.

Now, the present invention method described in general above will be described in detail in terms of the effects that each of the charging and exposure steps has on the potential at the plate surface with respect to the conductive substrate and the charge density at the surface of the insulating layer.

FIGS. 3A through 8A show a cross sectional view of a xerographic plate 10 which may comprise a photoconductive layer 11 supported on a conductive substrate 12 and an insulating layer 13 over the photoconductive layer 11. The conductive substrate 12 may be made of aluminum or any other conductive material that will deleteriously react with the photoconductive layer. The insulating layer 13 may be a polyvinyl resin having a thickness of between 10 – 12 microns overlying a selenium photoconductive layer 11 which may have a thickness of approximately 5 microns. For a more detailed description of the characteristics of a xerographic plate having an overcoat or layer of the insulating layer, the reader may refer to U.S. Pat No. 3,234,019 to R. H. Hall.

According to the present method, a uniform layer of charges, for example positive ions, are deposited on the insulating layer 13 of the xerographic plate 10 from a corona discharge device 15. Note that the insulating layer 13 may be of the type deformable by electrostatic forces. The positive charges deposited on the free surface of insulating layer 13 create equal and opposite negative charges at the interface of photoconductive layer 11 and conductive substrate 12. This creates a uniform plate potential V and charge density on the plate as shown in FIGS. 3B and 3C.

Next, as shown in FIG. 4A, the uniformly charged plate 10 is exposed image-wise. The amount of exposure is high enough so that the electrostatic image of black and dark gray areas are obtained and stored at the photoconductor insulator interface. In terms of phenomenon involved, it is believed that upon exposure the light or photons generates electron-hole pairs in the plate in proportion to the amount of light striking the photoconductor layer 11 which are immediately separated by the applied electric field. The negative charges of the pairs migrate to the insulator/photoconductor interface and stored there while the positive charges + migrate to the conductive substrate and are neutralized by the negative charges (–) existing there. This migration results in a reduction in the electrostatic potential V_p across the exposed portion of the plate 10 as shown in FIG. 4B. The potential at the unexposed portion remains at the same level as before the exposure.

As noted in FIG. 4B, the voltage versus the potential v_p is not completely reduced to zero. This is so because the charge still remaining at the interface between the photoconductor insulator interface maintains the potential, though reduced due to the recombination of positive and negative charges. If there were no insulation layer and if the exposure (i.e., intensity and duration of light) is high enough the exposed part will have zero potential as is the case with a conventional xerographic process with a xerographic plate having no insulating layer over the photoconductor. It is believed here that the positive charges on the surface of the

plate is prevented from combining with the negative charges migrated toward the interface between insulating layer and photoconductive layer because of the insulating layer. Thus, the potential V_p does not go to zero at the exposed part. So the net effect is as if the negative charge ($-$) migrates from the substrate to the photoconductor/insulator interface upon exposure, as schematically shown in FIG. 4B.

In the foregoing manner, an electrostatic pattern representing darker areas or shades of gray areas of the original is formed on the plate.

As shown in FIG. 4C, the charge density σ_s at the plate surface remains at the same level for the exposed portion and unexposed portion as before the exposure because the charge on the surface does not migrate through the insulating layer 13.

Next, the plate 10 is again charged positive by the corona device 15 to deposit more positive charges on the insulating layer 13 as shown in FIG. 5A. Once again, the negative charges are at the photoconductor/substrate interface. When plate 10 is again exposed, the light generates again electronhole pairs which are immediately separated by the applied electric field. The negative charges of the pairs migrate to the insulator/photoconductor interface while the positive charges from the pairs migrate to the conductive substrate and are neutralized by the negative charges existing there.

Now, more specifically, referring to FIG. 5B, the charging step causes the plate potential V_p to become uniform again as determined by the uniform potential level of the coronal device. FIG. 5B shows that the potential V_p goes back to the same level as it was before as shown in FIG. 4B. This would be the case, if the corona generating device 15 is of the scorotron type which charges a dielectric surface to a given potential and will not deposit any additional charges once the charged surface reaches the given potential. It will be noted, however, that while, in this example, the potential V_p (FIG. 5B) is shown at the same level, as in FIG. 3B, it need not be so limited. As it is well known, by using a corona generating device of different design (e.g., AC based corotron or scorotron with varying DC biases, the potential V_p can be changed to different values. The additional positive charges induce more negative charges at the photoconductor substrate interface. This causes the charge density σ_s on the plate corresponding to the exposed portion 14 to increase as shown in FIG. 5C.

The plate is again imagewise exposed (FIG. 6A) in register with the first exposure shown in FIG. 4A to obtain gray information. The exposure causes the charges to migrate from the conductive substrate to the interface between the photoconductor layer and insulating overlayer and be stored there. This causes the plate potential V_p to form a pattern as shown in FIG. 6B. The surface charge density σ_s remains unaffected as shown in FIG. 6C. It is to be noted that the second imagewise exposure (FIG. 6A) is less than the first imagewise exposure (FIG. 4A). This is to record the areas that are less dense or lighter than the darker areas recorded by the previous exposure (FIG. 4A). The plate is recharged by the corona generating device to a uniform potential (FIG. 7B) and this causes the surface density σ_s to increase as shown in FIG. 7C. Note that the charge density increases cumulatively, i.e., the charges formed in this charging step is added onto the charges deposited on the plate in earlier steps.

In a similar manner, charges formed from the successive charge and imagewise exposure are cumulatively stored at the interface surface. It is noted here that each set of the charge and imagewise exposure steps is controlled so that the charges formed and stored at the insulator surface represents a particular level of tonal information of the original and this is repeated with decreasing amounts of exposure, to obtain charge patterns representing lighter shades of gray at the photoconductor/insulator interface. These steps are so controlled that the net distribution and density of the charges correspond to a wide range of shades of gray found in the original. The charges so formed are cumulatively stored at the surface. After the last imagewise exposure and charge step, the plate is flood exposed as shown in FIG. 8A. The flood exposure makes the electrons in the conductive substrate 12 migrate to the insulator/photoconductor interface. Flood exposure involves the step of exposing the plate to a light source until the electric field in the photoconductor is relaxed (i.e., the electric field is reduced essentially to zero). While flood exposure is preferred way of realxing the electric field, other generally known methods may also be used. For example, the plate may be heated to relax the field or enough time be allowed to have dark decay to reduce the field to zero. Depending upon the characteristics of the photoconductor, this may take anywhere from a fraction of a second to a number of days.

The foregoing steps result in the formation of a latent electrostatic image in the form of a potential and charge pattern at the surface of the plate as shown in FIGS. 8B and 8C. The latent image so formed can be developed by the electrostatic toner particles and transferred and fused onto a paper in a conventional xerographic process.

The extension of the brightness acceptance range and the tonal contrast of the plate provided by the repeated charges and exposures described above may be explained in another way as follows:

The plate potential of the photoconductive layer decreases as the exposure increases as shown in FIG. 1A. The electrostatic plate potential versus the exposure usually includes a relatively linear portion A—A (FIG. 1B) which is useful in xerographic processes and which ranges normally about 0.6 in log units in the case of a selenium photoconductor. This range is effectively extended from the normal range of about 0.6 to 2.0 and higher by subjecting the xerographic plate to the repeated steps as described above in detail.

Various modifications may be made to the method described above within the scope of the present invention. Thus, the above described process may be speeded up by reducing the time needed to sensitize and form a latent image on a xerographic plate 10. This can be done by performing the first charging and exposure steps and the second charging and exposure steps simultaneously, using apparatus such as that disclosed in U.S. Pat. No. 3,307, 034 to Bean. As described therein, the optimum charging and exposure results are achieved when the distance between the corona wires is substantially equal to the distance between the wires and the xerographic plate. The following describes specific examples of the present invention.

EXAMPLE I

A xerographic flat plate which comprised 50 microns of selenium coated on a 0.050 inch aluminum substrate

was cleaned by washing with a soap solution followed by a rinse with distilled water. The selenium surface of the plate was then coated with a 6.25 micron layer of vinyl chloride vinyl acetate resin available from Union Carbide, New York, N.Y., using a solvent coating technique. This entailed an application of a 10-12 percent by weight solution of the resin in a 3-pentanone and cyclo-hexanone mixture to the selenium surface and drying the latter in a forced air oven at 50°C for a period of 1 hour.

The plate was charged positively in an xerographic processor such as the one described in the U.S. Pat. No. 2,965,483 to +1,000 volts (V_p). The plate is then exposed through a neutral density wedge representing an original having a density range of 3.0, available from Eastman Kodak Research Laboratories, Rochester, N.Y.

For the light source, an Omega Enlarger Series D with a 75 watt lamp was used. The wedge was used to represent a range of shade or gray tone. An exposure of one second was made with an $f/8$ lens. This exposure completely discharged the selenium photoconductive layer in areas in which have a projected image density less than 2.4 and recorded densities ranging from 2.4 to 3.0.

The plate was recharged to +1,000 volts (V_p) and exposed again with a lens at $f/16$ in registration with the first exposure for one second. This exposure completely discharged the selenium layer in those of the areas where the projected image density was less than 1.8 and recorded information in the density wedge having densities between 1.8 and 2.4. In image areas in the plate having a projected density of greater than 2.4 the internal field in the selenium was substantially unchanged.

This process was repeated three more times with the exposure decreased by a factor of four for each repetition until the entire density wedge was reproduced. After the fifth exposure, the plate was charged to a +1,000 volts (V_p) again and flood exposed using a uniform exposure of 5 foot candle seconds which relaxed the electric field in the selenium layer in all areas. The relaxation of the electric field in the selenium allowed all the surface-image charges (i.e., electrons) to appear at the photoconductor/insulator interface. Since all the charges and their images charges are across the insulating layer, the charge density pattern is also a potential (voltage) pattern, representing a density range of 0.0 to 3.0.

EXAMPLE II

A layer of 30% $CdSSe_x$ (Cadmium sulfo-selenide) in a polycarbonate resin available from General Electric, Schenectady, N.Y. as Lexan was coated to a thickness of 100 microns on 0.006 inches brass substrate. A one mil Mylar sheet was Bonded to the surface of the $CdSSe_x$ binder plate using heat pressure (250°C at 420 psi). The plate was processed in a charging step involving a negative charge of (-1,000 volts) on the free surface of the plate.

EXAMPLE III

The plate of Example II was processed with the recharge potential increased by a factor 1.2 for each repetition, which gives each exposure the same voltage contrast. The factor 1.2 is obtained by dividing the total

electrical thickness of the plate by the electrical thickness of the photoconductor.

EXAMPLE IV

For this example, a xerographic plate comprised of an 80 microns thick selenium layer deposited on a 1/16 inch aluminum substrate was used. The plate had an approximately 10 microns thick insulating layer of VYNS (a vinyl chloride vinyl acetate copolymer). The plate was charged positively to a potential of about 500 volts and exposed to a positive transparency with the exposure set at a level to record the shadow areas (high density information areas). The charge and exposure steps were repeated until the entire scene was recorded, as in Example I, except the final charging step. In the final charging step, the free surface potential of the plate was reduced to zero using an AC coronal discharge device or other suitable discharge source such as plutonium radiation source or scorotron discharge device. The final charging step removed the electric field across the insulating layer in the shadow areas (regions of the plate where no charge migration took place). This process resulted in the formation of a negative electrostatic charge pattern of the positive transparency.

EXAMPLE V

The structure in Example IV was subjected to the same process described above, except for the final charging step for which a negative charge was used instead of the AC charges. The negative charge was of such a magnitude that it reduced the field across the insulating layer the highlighted areas, that is, the areas having the greatest exposure, to zero. This process resulted in the formation of a positive electrostatic charge pattern of the positive transparency.

While the foregoing has described a method of controlling the brightness acceptance range and tonal contrast in terms of xerographic processes, it will be apparent to those skilled in the art that the present invention can be readily used with little or no modification in the fields of electrophotography in general. Thus, the invention is not limited to xerography or the examples described above. Various other modifications and changes of the present invention will be apparent to those skilled in the art, and as such come within the spirit and the scope of the appended claims.

What is claimed is:

1. The method of controlling the tonal contrast and extending the brightness acceptance range of an electrostatographic plate having a conductive substrate, a photoconductive layer and an electrically insulating layer overlaying said photoconductive layer comprising the steps of:

applying uniformly a first electrostatic charge in a first polarity to said plate.
imagewise exposing said plate a first time to store a charge pattern representing a portion of the tonal information of an original,
applying a second electrostatic charge in said first polarity to said plate,
imagewise exposing said plate in registration with said first exposure at a lower amount a second time than that of the first time store an additional portion of tonal information in the plate,

applying a third electrostatic charge to said plate, and flood-exposing said plate to light to form a latent electrostatic image in said plate.

2. The method according to claim 1, including repeating the steps of charging and exposing said plate with decreasing amount of exposure a number of times so that additional portions of tonal information are successively stored in said plate for increasing the fidelity of the latent electrostatic image.

3. The method according to claim 2, including the step of developing said image with electrostatically attractable particles.

4. The method according to claim 3, including the step of transferring the developed image to a copy sheet, and fixing the transferred image to the copy sheet.

5. The method according to claim 2, each pair of the charging and exposure steps are performed simulta-

neously.

6. The method according to claim 2, the exposure steps take place in succession while the electrostatic plate is being charged continuously at one level.

7. The method according to claim 1, wherein the charge potentials of successive charging steps are adjusted so that a substantially linear potential versus log exposure relationship is obtained.

8. The method according to claim 7, wherein the polarity and magnitude of the final charge step is adjusted to reduce the free surface potential of the xerographic plate to substantially zero.

9. The method according to claim 8, wherein the polarity of the final charge step is set opposite to that of the previous charging steps.

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