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R. E. HAYFORD ET AL
ELECTROPHOTOGRAPHIC METHOD

2,868,642

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FIG. 1

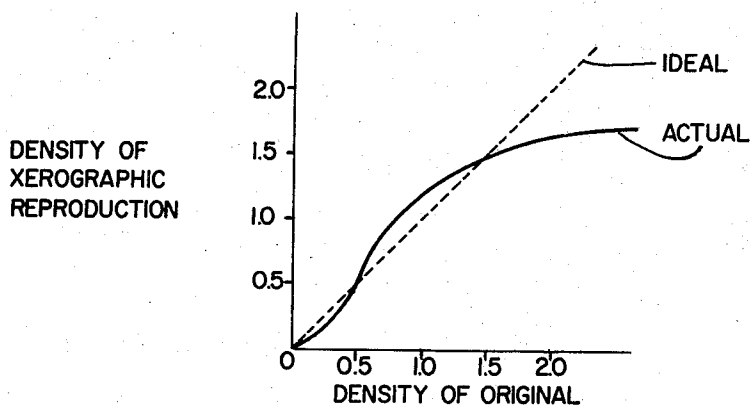
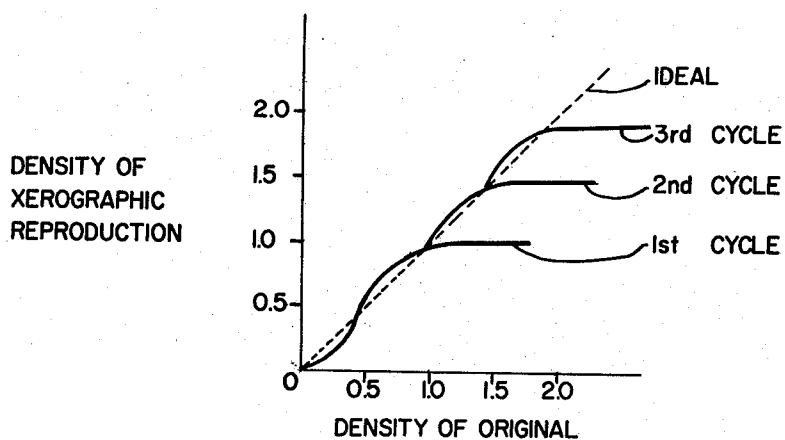


FIG. 2



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ELECTROPHOTOGRAPHIC METHOD

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5 Claims. (Cl. 96—1)

The present invention relates, in general, to the art of electrophotography, and more particularly to methods of enhancing the range of photographic density over which a xerographic reproduction conforms substantially to an original copy.

The electrophotographic process sequentially involves (a) the sensitization of a xerographic plate, (b) the exposure of the sensitized plate to an original image to be reproduced, (c) the development of the exposed plate to produce a powder image, (d) the transfer of a powder image from the plate to a final support, and (e) the fixing of the transferred image to form the final print.

A standard xerographic plate is constituted by a thin layer of selenium on a backing plate of polished brass, the selenium being deposited thereon in a vitreous form. In the dark state, the selenium layer has an extremely high resistivity, but when exposed to light the resistivity is reduced many orders of magnitude, depending on the intensity of the light. By reason of its high electrical resistance in darkness, the selenium layer can be charged electrostatically, which charge is retained for a prolonged period should no light impinge thereon. However, when light strikes the xerographic plate, the resistivity decreases and the charge is lost to the backing plate.

In the basic electrophotographic process the xerographic plate must be sensitized before use by impressing an electrical charge on the selenium surface. This is customarily accomplished by means of a corona discharge device. After sensitization the plate is exposed to a light image in a camera. Where light strikes the plate the selenium is rendered conductive and the electrical charge on its surface leaks through to the metal backing plate in proportion to the intensity of illumination. The retained electrical image then present on the plate is developed by subjecting the plate to a cloud of charged powder particles. These particles are attracted to the electrical image and they deposit on the plate in a quantity depending on the potential of the electric image.

Various methods of generating the powder cloud have been developed, such as by blowing air through a mass of powder and forcing the resultant cloud through a small orifice to break up clusters of powder. These methods are disclosed in greater detail in the co-pending application of Eugene Ricker filed May 7, 1953, and assigned Serial No. 353,520.

To produce a final print of the picture the powder image is transferred and fixed to a white plastic sheet which is coated with an adhesive. The powder image adheres to the adhesive and is thus removed from the selenium surface. Finally, the transferred image is covered with a transparent adhesive tape.

The light-fidelity or naturalness of the reproduction thus formed is a function of the brightness range of the picture, this range extending from white through progressively darker shades of grey to black. Where the photographic density of the reproduction corresponds closely to that of the original copy throughout the brightness range, the resultant picture will exhibit a high order of

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light-fidelity. However, experience has shown that with the continuous tone xerographic process as heretofore carried out, the density range is limited in scope and the picture contrast is relatively poor. Consequently, if the light areas on the picture are truly light, then the dark areas are only a moderately dark grey. On the other hand, if the dark areas are decidedly dark, then the light areas are not particularly bright.

Accordingly, it is the principal object of the present invention to provide an improved xerographic process resulting in an increased brightness range, that is to say, an increased range of photographic density over which the xerographic reproduction closely corresponds with the original.

More particularly, it is the object of the present invention to provide an improved xerographic process wherein the ultimate reproduction is effected by repetitive cycles of charging, exposure and development to produce an increased brightness range.

For a better understanding of the invention, reference is made to the following detailed description thereof to be read in connection with the accompanying drawing wherein:

Fig. 1 shows the density curve of a xerographic reproduction with respect to the density of the original, which curve is typical of the conventional electrophotographic method.

Fig. 2 shows the density curve of a xerographic reproduction with respect to the original density, which curve characterizes a cyclic xerographic process in accordance with the present invention.

Visually, photographic density is closely allied with the darkness of the picture deposit. Photographic density is measured by determining the light transmission or reflection properties of the picture deposit. More specifically, the density figure is the log of the ratio between the light incident to the deposit and the light reflected therefrom. The exposure is plotted on a logarithmic scale, for the range covered (frequently as high as 10,000 to 1 in intensity) is too great to plot conveniently in any other manner, and also because the logarithm scale more nearly approaches the scale of brightness involved in vision. Thus a density of 1.0 means that only 10% of the light is reflected, while a density of 2.0 means that only 1% is reflected.

Normal photographs can be reproduced with excellent fidelity with the density range going from zero to as high as about 1.8. This upper density level is well above the limit attained with the electrophotographic technique as heretofore practiced without sacrifice of the lower densities. The technique in accordance with the invention makes possible an increase of the brightness range over the range from substantially zero to this level and higher.

Referring now to Fig. 1, there is shown a typical density curve of a xerographic reproduction of the prior art type with respect to the original density. In the figure the photographic density values of the original appear along the abscissa and the values of the reproduction appear along the ordinate, the same scale of units being used on both axes. If the response curve is a straight line with a slope of 1 (at 45°), a proper exposure produces an exact reproduction of any brightness scale.

Thus, the ideal situation is represented in Fig. 1 by the dotted line at the 45° angle, the line being perfectly straight from 0 to 2.0 in the density range. However, for the conventional xerographic reproduction, the actual curve, as represented in Fig. 1 by the solid line, flattens out quite sharply at a density value of about 1.5 and also falls somewhat at the density values below 0.5.

In accordance with the present invention, with a view

to enhancing the brightness range the xerographic process is carried out in the following cyclical manner. In the first cycle, the xerographic plate is sensitized by an electrostatic charge and exposed to the light image emanating from a positive photographic transparency in the usual way. The sensitized plate is then developed by the powder cloud technique for a period lasting about one-half the normal time required for complete development. Normal exposure and development periods are established empirically with the specific electrophotographic equipment employed. Thus, the plate at this stage in the process is underdeveloped.

In the second cycle, the xerographic plate bearing the under-developed image is recharged, then placed in the camera in keyed position in register and re-exposed. The re-exposure operation makes use of an exposure exceeding the normal time limits, preferably about eight times the normal exposure. It will be noted that in the re-exposure, in the dark image areas the light must pass through both the dark portions of the photographic transparency and the heavy image areas of the xerographic developer. Thus the light is masked both by the dark portions of the transparency and the heavy image areas of the developer. Next, the image is again developed, this time to completion. The remaining steps of transfer and fixing are along conventional lines.

In a preferred procedure, three cycles are used, in which case in the second cycle image development is also carried out to less than completion, for example, about one-half of full development. This is followed by a third operational cycle consisting of charging, re-exposure in register, again for about eight times the normal exposure, and thereafter a complete development. The ultimate result is a xerographic reproduction in which there is substantially close correspondence between the density of the original and the density of the xerographic reproduction throughout the density range of nearly zero to about 1.8. This upper limit can be further increased by a cycle of four or five exposures and has in practice been made as high as 2.2.

Referring now to Fig. 2, the results attained by the repetitive cycles of exposure and development is made evident. Here in the lower portion of the original curve, the long exposure effects a substantially complete discharge, so that the development in the second cycle does not deposit additional developer in the high-light areas on the picture. Toward the upper ranges, however, the combination of the light-absorbing action of the photographic positive transparency and the light-absorbing action of the previously developed xerographic powder image leaves a substantial charge on the plate, whereby the second development cycle causes additional deposition or density more or less as indicated by the upper curve.

The point of intersection between the upper and lower curve and the flatness of the upper curve will be controlled principally by the duration of the second exposure. What occurs in the second exposure is that the high-light portions, and progressively the next portions are discharged. In consequence, the greater the exposure, the more this point of intersection moves out on this curve and the flatter the upper curve becomes. Ideally this point of intersection should be brought roughly to the shoulder of the first curve. Once the system is set up to achieve the extended brightness range, it becomes uniformly adaptable to all varieties of images. It is not necessary to vary the procedure with each image of different characteristics.

The basic xerographic development apparatus and the method of development to be used in conjunction with the present technique may follow the teachings in the above-identified co-pending patent application, although it is not limited thereto. In actual practice, a development electrode spaced at $\frac{1}{60}$ inch and biased at about 6 volts was used, with charcoal as the developer material.

Normal exposure and development was first established empirically to attain good results with the specific equipment used. It was found in this instance that normal development time was four seconds.

Accordingly, in the first cycle a normal exposure was made followed by a development of two seconds, i. e. about $\frac{1}{2}$ of the normal period, so that the good results in density fell off very close to 1.0, and generally at about 1.1. In the second cycle, the exposure was for approximately eight times the normal period and the development (two seconds) again about one-half the normal time. This caused the second density results to level off at about 1.4 or 1.5. The third cycle repeated the conditions of the second cycle, with the result that this time the final density leveled off at about 1.8, which, as pointed out earlier, is far superior to the results heretofore obtained.

While appropriate changes in exposure and development can be made to attain high final density values with the first two cycles, this might involve greater distortion of the image. Specifically, it would call for a slightly higher cut-off point in the first development and shorter exposure in the second cycle. This, however, as will be apparent from the curve in Figure 1, would give rise to distortion in the middle ranges.

While there has been disclosed what at present are considered to be preferred methods in accordance with the invention, it will be obvious that many changes may be made therein without departing from the essential spirit of the invention. The repetitive cyclical method as disclosed herein is not limited to specific development or exposure periods or specific xerographic equipment, nor is the number of repetitive cycles limited to the specific examples set forth herein. It is intended, therefore, in the appended claims to cover all such changes and modifications as fall within the true scope of the invention.

What is claimed is:

1. The process of producing an electrophotographic reproduction of a pattern of light and shadow to be recorded comprising the steps of applying a uniform electrostatic charge to a photoconductive insulating surface overlying a conductive backing, exposing said surface to a pattern of light and shadow to be reproduced, whereby there is produced on said surface a pattern of electrostatic charges corresponding to the pattern of light and shadow to be reproduced, repeating cyclically at least once the steps of contacting said surface bearing the electrostatic latent image with finely-divided electrostatically-charged powder particles whereby said particles begin to deposit on said surface in accordance with said electrostatic image, removing said particles from contact with said surface while deposition is still substantially incomplete leaving on said surface a lightly visible powder image corresponding to said electrostatic image, applying a uniform electrostatic charge to said surface, exposing said surface to the original pattern of light and shadow, the exposure being made in register with said powder image and for a length of time substantially greater than that necessary for the brightest portion of the original scene to reduce the electrostatic potential of the corresponding portions of said surface to their lowest value, and then at the end of the last cycle contacting said surface again with finely-divided electrostatically-charged powder particles until deposition of said particles is substantially complete, transferring said final powder image from said surface to an image support and fixing said powder image to said support material.

2. The method of producing a xerographic reproduction of a pattern of light and shadow to be recorded comprising electrically charging a photoconductive insulating surface overlying an electrically conductive backing, exposing said surface to a pattern of light and shadow to be reproduced whereby there is produced on

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said surface a pattern of electrostatic charges corresponding to the pattern of light and shadow to be reproduced, contacting said surface with a supply of finely-divided electrostatically-charged powder particles whereby said particles begin to deposit on said surface in accordance with said electrostatic image, removing said supply from contact with said surface while deposition is still substantially incomplete leaving on said surface a lightly-visible powder image corresponding to said electrostatic image, applying a uniform electrostatic charge to said surface, exposing said surface to the original scene corresponding to said powder image, the exposure being made in register with said powder image and for a length of time substantially greater than that necessary for the brightest portions of the original scene to reduce the electrostatic potential of the corresponding portions of said surface to their lowest value, and then contacting said surface again with a supply of finely-divided electrostatically-charged powder particles until deposition of said particles is substantially complete.

3. The method of producing a xerographic reproduction of a pattern of light and shadow to be recorded comprising electrically charging a photoconductive insulating surface overlying an electrically conductive backing, exposing said surface to a pattern of light and shadow to be reproduced whereby there is produced on said surface a pattern of electrostatic charges corresponding to the pattern of light and shadow to be reproduced, contacting said surface with a supply of finely-divided electrostatically-charged powder particles whereby said particles begin to deposit on said surface in accordance with said electrostatic image, removing said supply from contact with said surface while deposition is only about half complete leaving on said surface a lightly-visible powder image corresponding to said electrostatic image, applying a uniform electrostatic charge to said surface, exposing said surface to the original scene corresponding to said powder image, the exposure being made in register with said powder image and for a length of time about eight times greater than that necessary for the brightest portions of the original scene to reduce the electrostatic potential of the corresponding portions of said surface to their lowest value, then contacting said surface again with a supply of finely-divided electrostatically-charged powder particles until deposition of said particles is substantially complete.

4. The method of producing a xerographic reproduction of a pattern of light and shadow to be recorded comprising electrically charging a photoconductive insulating surface overlying an electrically conductive backing, exposing said surface to a pattern of light and shadow to be reproduced whereby there is produced on said surface a pattern of electrostatic charges corresponding to the pattern of light and shadow to be reproduced, repeating cyclically at least once the steps of contacting said surface

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with a supply of finely-divided electrostatically-charged powder particles whereby said particles begin to deposit on said surface in accordance with said electrostatic image, removing said supply from contact with said surface while deposition is still substantially incomplete leaving on said surface a lightly-visible powder image corresponding to said electrostatic image, applying a uniform electrostatic charge to said surface, exposing said surface to the original scene corresponding to said powder image, the exposure being made in register with said powder image and for a length of time substantially greater than that necessary for the brightest portions of the original scene to reduce the electrostatic potential of the corresponding portions of said surface to their lowest value, and then at the end of the last cycle contacting said surface again with a supply of finely divided electrostatically-charged powder particles until deposition of said particles is substantially complete.

5. The method of producing a xerographic reproduction of a pattern of light and shadow to be recorded comprising electrically charging a photoconductive insulating surface overlying an electrically conductive backing, exposing said surface to a pattern of light and shadow to be reproduced whereby there is produced on said surface a pattern of electrostatic charges corresponding to the pattern of light and shadow to be reproduced, contacting said surface with a powder cloud of finely-divided electrostatically-charged powder particles whereby said particles begin to deposit on said surface in accordance with said electrostatic image, removing said powder cloud from contact with said surface while deposition is still substantially incomplete leaving on said surface a lightly-visible powder image corresponding to said electrostatic image, applying a uniform electrostatic charge to said surface, exposing said surface to the original scene corresponding to said powder image, the exposure being made in register with said powder image and for a length of time substantially greater than that necessary for the brightest portions of the original scene to reduce the electrostatic potential of the corresponding portions of said surface to their lowest value, and then contacting said surface again with a powder cloud of finely-divided electrostatically-charged powder particles until deposition of said particles is substantially complete.

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