Sept. 1, 1964 H. E. CLARK ETAL 3,146,688

XEROGRAPHIC MACHINE

Filed May 1, 1961

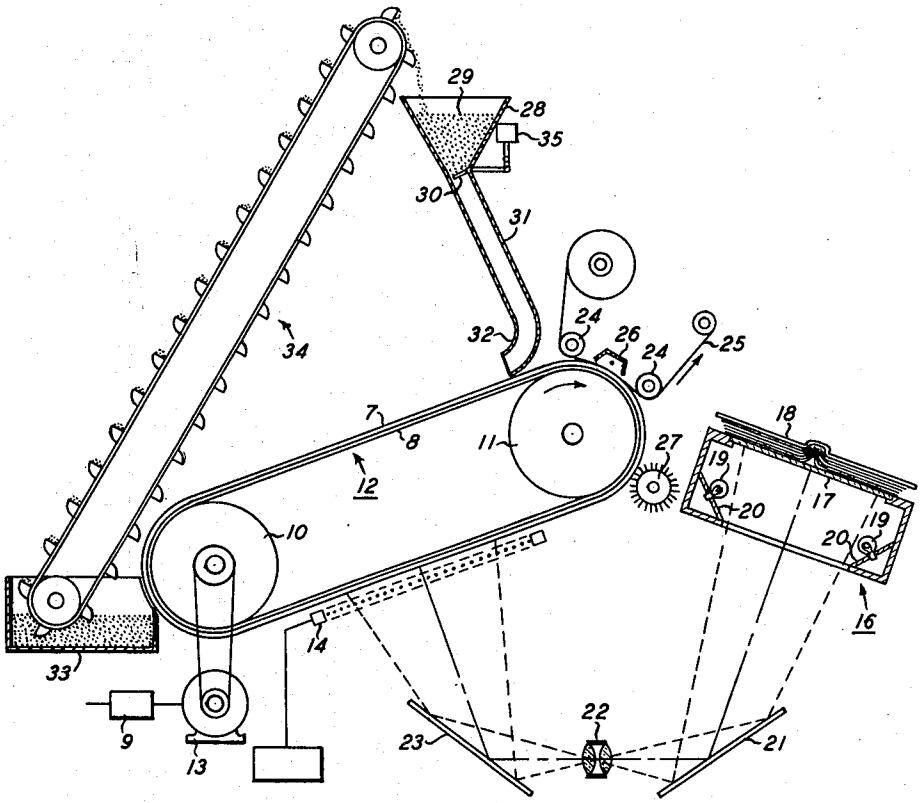


FIG. 1

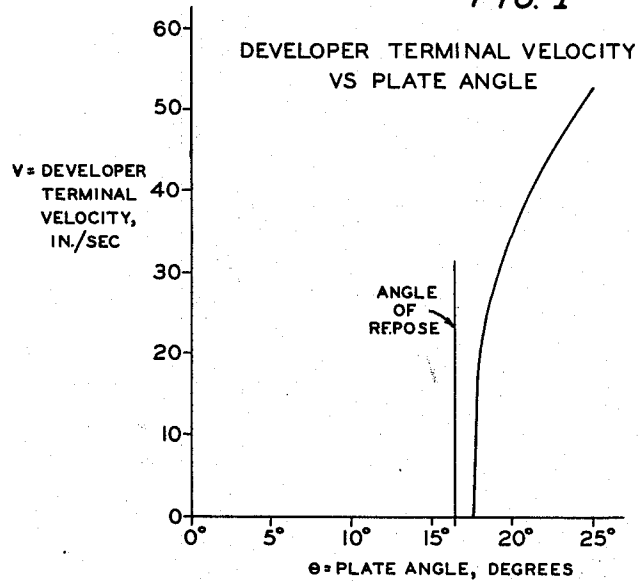


FIG. 2

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XEROGRAPHIC MACHINE

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4 Claims. (Cl. 95—1.7)

This invention relates to xerography, and more particularly, to improved xerographic copying machines and to improved developing methods therefor.

In a common form of xerography, a uniform electrostatic charge is placed on the photoconductive insulating layer of a xerographic plate, an electrostatic latent image is formed on the plate through exposure to an original subject or pattern of light and shadow, the latent image is made visible through the selective attraction of black powder or other materials, and the developed image is then generally transferred to a sheet of paper or other support. Various forms of apparatus are known for carrying out these process steps in a mechanical or automatic fashion.

Generally commercial apparatus embodying automatic flow from one process step to another includes what has become known as cascade development and automatic commercial equipment typically also includes a cylindrical xerographic plate. Cascade development employs cascade developer comprising generally carrier particles adapted to roll or cascade across the surface to be developed bearing toner particles electrostatically adhering but adapted to deposit through release from the carrier particle to charge patterns on the surface to be developed. The developer is flowed or cascaded across the surface to a point along the circumference of the cylindrical plate whereat the cascading developer flows away from the plate because of inertia and gravitational pull. Inherent in all known commercially available apparatus is non-uniformity in the velocity of the developer as it passes across the cylindrical plate. Velocity non-uniformity results in non-uniform development from point to point during passage across the plate and in addition if the velocity of the developing material becomes too high, a scrubbing or similar action takes place so that deposited developer conforming to the image to be developed is actually removed from the plate rather than deposited in accordance with the basic objective of any developing system.

This invention is concerned with a novel form of xerographic apparatus which is simple, compact and capable of yielding unusually dense and high quality images. This invention is also concerned with a novel developing arrangement for improving xerographic development.

It is accordingly an object of the present invention to provide improved automatic xerographic equipment.

It is a further object to provide improved xerographic development apparatus.

FIG. 2 is a graph relating developer velocity to xerographic cascade development methods.

These and other features and objects of the invention will be apparent from the following description and from the drawings in which:

FIG. 1 represents a partly schematic sectional view of an embodiment of xerographic copying apparatus according to the invention; and

FIG. 2 is a graph relating developer velocity to xerographic plate inclination.

Referring to FIG. 1 of the drawings, the apparatus is seen to include a pair of axially rotatable cylindrical elements 10 and 11 about which is supported a xerographic plate 12 in the form of an endless flexible belt. The upper portion of the belt in this embodiment is inclined at an angle of about 19 degrees from the horizontal. Plate 12 comprises a web of strong, flexible, and preferably electrically conductive material 8 such as a strip of cold rolled aluminum, brass or steel a few thousandths of an inch thick or a metallized plastic web such as aluminized polyethylene terephthalate. Plate 12 in this embodiment is illustrated as coated on its outer surface with a thin layer of a photoconductive insulating material 7. Any of the photoconductive insulating materials known in connection with xerographic plates which are capable of being flexed without destroying their usual plate characteristics may be employed, including but not limited to, a thin layer of vacuum deposited vitreous selenium or a thin layer of zinc oxide in an insulating resin binder. Selenium and many other photoconductive insulating materials coated on a flexible support may be repeatedly bent around a radius of a few inches without cracking or flaking from the support and without losing xerographic effectiveness. It is also possible to substitute for the endless plate 12, as shown, two or more flexible sheet-like xerographic plates which are connected to each other in an end-to-end relationship by coil springs or the like or coated and uncoated areas intermittently along the surface of the conductive material 8. As will be apparent from a further description of the operation of the machine, such other plates will function in the same manner as a truly continuous plate and such structures are intended to be encompassed by the term "endless flexible belt" as used in the specification and claims.

A motor 13, operated by timer 9, is provided to rotate cylindrical element 10 and thereby to move xerographic plate 12 in the direction shown a sufficient distance so that a region of the plate lying between cylindrical elements 10 and 11 along the lower section of the endless loop is transferred to a position between elements 10 and 11 along the upper portion of the loop and vice versa. Positioned adjacent and beneath plate 12 and between cylindrical elements 10 and 11 is a full frame corona charging device 14 which is connected to a high voltage power supply 15. This device generally comprises a grid of fine wires positioned adjacent and parallel to plate 12 and is more fully described in U.S. Patent 2,932,742. By activating high voltage power supply 15, a large area of plate 12 corresponding to charging device 14 is brought to a uniform high potential of the order of several hundred volts as is well known in the xerographic art. Exposure apparatus is provided to project onto plate 12 and through charging device 14 a pattern of light and shadow corresponding to an original subject to be reproduced. Because the functional area of charging device 14 consists only of a set of very fine wires, it is possible to effect exposure through charging device 14 without objectionable shadows or the like being recorded. The image projection apparatus includes a copy box 16 including a glass platen 17 on which may be laid the original copy such as, for example, a book 18. Illumination is provided by two or more lamps 19 which are set into reflector plates 20 of polished aluminum or the like. The combination of lamps 19 and reflector plates 20 provides a highly uniform degree of illumination over the original subject such as book 18. Light scattered from book 18 is reflected by a first mirror 21 through a lens 22 which then focuses an image of book 18 onto xerographic plate 12 through reflection at the surface of a second mirror 23. In accordance with known xerographic principles, the projection of a pattern of light and shadow on the charged surface of xerographic plate 12 causes selective charge dissipation resulting in the formation of an electrostatic latent image.

In normal operation the high voltage power supply 15 is first energized for a short time to uniformly charge plate 12 and lamps 19 are then energized for a short

time to form an electrostatic latent image on plate 12. Following exposure, motor 13 is then briefly energized to move plate 12 through about ½ of a complete rotation so that the area bearing the electrostatic latent image is now along the upper portion of the endless loop formed by plate 12 rather than along the lower portion. Image development is effected while the latent image bearing portion of the plate is in the upper position by a development apparatus which will be described hereinafter. While development is being carried out a second latent image may be formed at the lower portion of plate 12. When plate 12 is next advanced, the developed image area passes a transfer and a cleaning station before returning to the charging and exposure position where it is ready for further reuse. The transfer station comprises a pair of rollers 24 which urge a web 25 of paper or the like against plate 12 and a corona charging device 26 positioned between rollers 24 and adapted to apply an electrostatic charge to the back of paper 25 thereby transferring a developed powder image from plate 12 to paper 25. A cleaning station may comprise an axially rotatable fur brush positioned in lightly touching contact with plate 12 and adapted to be driven by a motor or the like, not shown. Brush 27 removes any residual developer powder from plate 12 and thereby permits the plate to be indefinitely cycled between the charge-expose position and the developing position.

It is a feature of the apparatus as thus far described that it utilizes the so-called full frame method of image exposure rather than an exposure system adapted to continuous motion of the plate. Since each of the original subject, the optical system and the xerographic plate are stationary during exposure, there is no possibility of image resolution being degraded by vibration or lack of synchronism as may occur in a moving system. Additionally, the full frame method of image exposure permits the employment of much simpler apparatus than does a moving system. At the same time, however, it is possible, in accordance with the present invention, to retain the simplicity and rapidity of image development associated with rotary xerographic machines which employ moving exposure. Further, development according to the present invention is more efficient and yields denser images than previous methods employed either with flat or cylindrical xerographic plates.

The development system includes a supply hopper 28 which is positioned above xerographic plate 12 and which contains a supply of xerographic developer 29 which may comprise any of the well known types of cascade developer material. As is well known, developer 29 generally comprises a mixture of very finely divided pigmented particles known as toner, generally having a diameter in the range of a few microns, mixed with much larger particles known as carrier. Toner and carrier have triboelectric properties such that they electrify each other and such that the toner particles are adherent upon the carrier particles or beads. Xerographic developer materials of this type enjoy wide commercial use and are available from Haloid Xerox Inc., Rochester, New York. Supply hopper 28 includes a gate 30 which controls the flow of developer into a chute 31 which terminates in a curved section 32. The effect of chute 31 and curved section 32 is to direct developer 29 approximately tangentially against xerographic plate 12 in a downward direction and at a velocity determined principally by the height of chute 31 and to a lesser extent by the inclination of chute 31 and the radius of curved section 32. Chute 31 may either be inclined somewhat in the direction shown or vertical, or inclined in a direction opposite from that shown. The illustrated configuration, however, is believed to yield the most compact machine arrangement. The developer discharged by curved section 32 flows downwardly over the surface of plate 12 and is caught in collection hopper 33 after flowing over the end of plate 12.

The developing apparatus as heretofore described may be used for manual operation but is adapted to automatic operation through utilization of conveyor 34 driven by a motor not shown, to return developer from hopper 33 to hopper 28 together with solenoid 35 or the like to operate gate 30 and thereby control the flow of developer over plate 12.

As developer 29 flows over plate 12, the toner, in accordance with known principles of xerography, is selectively detached from the carrier particles and attached to the xerographic plate by the electrostatic latent image thereon, thus forming a visible developed image on the plate. Additionally, the developer flowing over plate 12 is accelerated or retarded toward the terminal velocity corresponding to the particular inclination of the plate. The terminal velocity is that velocity which would ultimately be reached by the developer if the xerographic plate were of indefinite length. It is, of course, also that velocity at which the developer in flowing over the plate will neither speed up nor slow down. The terminal velocity is influenced by a great many factors in addition to the angle of the plate and including such things as atmospheric conditions, the nature of the surface being developed, the nature of the developer material, the strength of the electrostatic charge pattern on the plate, and the like. In practical situations, however, it has been found that these factors play a relatively minor role as compared with the plate angle.

It should be appreciated that although only a single embodiment of an automatic apparatus incorporating and showing the principles and a structure of constant velocity development in accordance with the principles of this invention is included herein, there is no intention to be limited to the particular showing but instead FIG. 1 is for illustrative purposes only and it is intended to encompass broadly methods and apparatus including the principles of constant velocity development as illustrated and as will be readily apparent to those skilled in this art.

In accordance with this invention it has been found that for optimum development, developer should flow at a constant velocity across the surface being developed. This type of flow produces a dense image which is uniform throughout. Further, as will appear more fully in the discussion which follows, the preferred velocity appears to be that minimum rate of speed at which blocking (as will be discussed) does not occur. To more fully appreciate how speed relates to angle of inclination of the surface being developed, FIG. 2 is discussed below.

FIG. 2 is a graph showing the relationship between terminal velocity and angle for an electrostatic image bearing selenium xerographic plate and a conventional xerographic cascade developer comprising 1.1% Type 10 Toner and 98.9% standard black carrier, available from Haloid Xerox Inc., Rochester, New York. Terminal or other developer velocities may be readily measured by adding a few light-colored particles to the developer and then making a time exposure photograph of the flowing developer when illuminated by a flashing stroboscopic light. Each light-colored particle will photograph as a series of distinguishable dots and the spacing of these dots is a measure of developer flow velocity. Other methods of velocity measurement may also be used.

As shown in FIG. 2 the angle of repose for an uncharged selenium xerographic plate with the above indicated developer materials is approximately 16.5°. In other words, if a layer of developer is placed on top of a horizontal uncharged (non-image bearing) plate which is then slowly tipped, the developer will not start to flow until the plate reaches an inclination of about 16.5°. At angles somewhat less than the angle of repose, developer will flow over the xerographic plate if it is applied to the plate with an initial velocity. However, at these angles, developer flow tends to be unstable and terminal velocity is not an accurately reproducible function of inclination.

It can also be seen from the curve in FIG. 2 that for a xerographic plate bearing an electrostatic latent image the terminal velocity versus plate inclination curve starts at about 18°, which is a somewhat greater angle than the angle of repose for an uncharged plate. Developer will flow at angles between 16.5° and 18° but the flow is locally unstable and carrier beads will stick to the xerographic plate in certain image areas. As the plate angle is increased past 18° it can be seen that the terminal velocity increases very rapidly, indicating that the developer will rapidly accelerate at high plate angles unless it meets or is fed to the plate at a correspondingly high velocity. The terminal velocity versus plate inclination curve for an uncharged plate is substantially the same as that shown for an image bearing plate, except at angles close to the angle of repose where stable flow without bead sticking may be exhibited by the uncharged but not the charged plate.

Table I is illustrative of the variations in angle of repose which are associated with various developer compositions and plate surfaces. The plate surfaces are plain aluminum, plain aluminum with a 20 micron selenium coating, grained aluminum as used in lithography, and grained aluminum with a 20 micron selenium coating. Obviously, the uncoated aluminum materials are not xerographic plates at all, and only the selenium coated plain aluminum corresponds to a normal xerographic plate. The developer compositions are represented by six different types of carrier materials, each taken both without any toner and with 2% standard toner. Obviously again, the data on untoned carriers are purely for comparative purposes, since these materials are not per se xerographic developers. All listed materials are products of Haloid Xerox Inc., Rochester, New York. The first four carriers comprise glass beads with various surface coatings, whereas the last two comprise graded sand with different coatings. It can be seen that the angle of repose with a normal selenium xerographic plate, standard carrier, and 2% toner concentration is 14.5° rather than 16.5° as found in connection with FIG. 2 for a more conventional 1.1% toner concentration. Thus it can be seen from Table I that the angle of repose depends on the xerographic materials employed, but only to a relatively slight degree.

TABLE I

Angles of Repose for Several Carriers on Various Surfaces

Carrier	Angle of Repose (Degrees)							
	Untoned Beads				2% Toner on Beads			
	Al	Al+	Gr Al	Gr Al+	Al	Al+	Gr Al	Gr Al+
Standard	20	22	22	20	16.5	14.5	14.3	14.8
FK-2	27.5	28	26.5	26.5	20	18.5	19	18
GC-2 on #7 glass beads	19	20	18	17.5	13.5	12.5	12.8	12.3
GC-2 on #5 glass beads	16	17.5	16.5	17	14.5	11.5	14	11
FC-2 on 20-40 mesh sand	24	23.5	23.5	24	18.5	18.5	19	17.5
C-2 on 20-30 mesh sand	24	26	24	24.5	18	21.5	19.8	10.5

Legend: +=with 20 selenium coating. Al=Aluminum sheet. Gr Al =Grained aluminum sheet.

Developer flow velocity has been found to be a very important factor in influencing the quality and efficiency of cascade development. At high flow velocity it has been found that the developer material actually scrubs deposited toner off the plate surface. In prior forms of xerographic apparatus the developer has been applied to a xerographic plate in such a manner that it rapidly accelerated thereafter. Thus, the development initially effected by the developer material while traveling slowly has been largely counteracted by the undeveloping or erasing effect of the developer as it speeds up. As the developer flow velocity is decreased, however, it is found that development efficiency increases and much denser images are obtained. It has also been found that there is a minimum developer flow velocity which must be maintained. When this speed is not maintained, occasionally carrier beads as well as toner particles are attached to the xerographic plate by the forces associated with the electrostatic image thereon. Sticking beads are very undesirable because they cause deletions as well as damage to the xerographic plate during image transfer. Sticking beads per se can be avoided by such expedients as forming the beads of magnetic material and removing them with a magnet, but this does not overcome the problem of deletions or small undeveloped areas caused by the sticking beads. The minimum acceptable developer velocity is influenced by a number of factors such as the carrier particle size and triboelectric properties, the strength of the electrostatic latent image on the surface being developed, and the ratio of carrier to toner, since this affects the electrostatic charge on the carrier particles. In general, however, it has been found that the sticking is associated with plate inclinations which are less than or close to the angle of repose and with the developer velocities associated therewith, whereas bead sticking is generally absent at plate inclinations a few degrees greater than the angle of repose and with developer velocities corresponding to the terminal velocities associated with such inclinations. In examining FIG. 2 in this connection it is apparent that the optimum angle for conventional xerographic materials is in the general area of 19° which corresponds to a terminal velocity for a developer of about 28 inches per second. This angle is just sufficiently greater than the absolute minimum angle of about 18° to provide an adequate margin of safety against bead sticking. It has been observed that a relatively high and uniform image density is obtained with constant velocity development at plate angles between 18° and 20°, whereas, there is a noticeable fall off in image density at a 25° inclination. It will be appreciated that prior xerographic development methods have typically involved plate angles in the order of 45°.

In accordance with the present invention, the apparatus of FIG. 1 is capable of being adjusted and is adjusted to provide a developer flow velocity over the entire area of plate 12 subject to development substantially equal to the optimum velocity. This adjustment is essentially made in two steps. The first step is to choose the proper inclination for the upper surface of plate 12 as determined, for example, from FIG. 2. Adjustment mechanism is not shown in the figure because ordinarily the plate angle need not be changed and is therefore initially designed into the apparatus. The second step is to adjust the velocity at which the developer is applied to the plate to substantially coincide with the terminal velocity for the particular plate angles and materials employed. Where the initial velocity is equal to the terminal velocity, the developer will continue to flow across the surface of the plate at an unchanging velocity which has also been chosen as the optimum velocity and which will provide uniform, dense and higher quality images than have heretofore been produced. To a first approximation the initial developer velocity is equal to that which would be reached by the developer in falling through a vertical distance equal to the height of chute 31 and curved section 32. This free-flow velocity is given by the relation $V=8\sqrt{h}$ where V is the velocity in feet per second and h is the chute height in feet. The actual velocity is somewhat less than this theoretical velocity because of frictional effects in chute 31 and along curved section 32. Again, chute 31 is not shown as being adjustable because its configuration is generally set when the apparatus is designed and need not be changed thereafter. When making initial adjust-

ments of chute 31 and curved section 32, it is desirable to make stroboscopic photographs of the flowing developer by the procedure described above. If the photograph shows the developer to be accelerated as it passes across the plate, the initial velocity is too high and chute 31 should be shortened somewhat. Conversely, if the photograph shows the developer to be decelerated, the initial velocity should be decreased by lengthening chute 31. Obviously other measuring techniques may be used.

While the invention has been described in connection with specific embodiments for illustrative purposes, it will be understood that various modifications may be made without departing from the spirit of the invention or the scope of the appended claims. In particular, it is noted that the improved method of xerographic development disclosed herein may be practiced with other forms of xerographic apparatus illustratively including but not limited to, apparatus of the type illustrated embodying moving exposure systems, incorporating rigid, flat xerographic plates, and the like in either other automatic equipment or in manual equipment.

What is claimed is:

1. A xerographic copying machine comprising,
at least two axially rotatable paraxial spaced cylindrical elements,
the axes of said elements being horizontal,
an endles flexible xerographic plate supported over said cylindrical elements,
said plate being supported in the configuration of straight line segments joined by part circular arcs,
an upper segment forming an oblique angle with the horizontal and a lower segment,
charging means to charge the outer surface of the lower segment of the xerographic plate while said plate remains stationary,
transparent means to support an original subject to be reproduced face downward,
means to illuminate said subject while supported,
a projection lens,
first mirror means positioned and adapted to direct the light from said subject through said projection lens,
second mirror means positioned and adapted to direct the light from said projection lens through said charging means into focus on the lower surface of said plate while still stationary,
means to advance the exposed portion of the xerographic plate to the upper segment position only,
means to flow cascade electrostatic image developer material over the outer portion of the upper segment of said plate,
and means to transfer from the xerographic plate to a support material the developed image produced by flowing said developer material.

2. A xerographic copying machine comprising,
at least two axially rotatable paraxial spaced cylindrical elements,
the axes of said elements being horizontal,
an endless flexible xerographic plate supported over said cylindrical elements,
said plate being supported in the configuration of straight line segments joined by part circular arcs,
an upper segment forming an oblique angle with the horizontal and a lower segment,
charging means to charge the outer surface of the lower segment of the xerographic plate while said plate remains stationary,
transparent means to support an original subject to be reproduced face downward,
means to illuminate said subject while supported,
a projection lens,
first mirror means positioned and adapted to direct the light from said subject through said projection lens,
second mirror means positioned and adapted to direct the light from said projection lens through said charging means into focus on the lower surface of said plate while still stationary,
means to advance the exposed portion of the xerographic plate to the upper segment position only,
means to flow cascade electrostatic image developer material over the outer portion of the upper segment of said plate,
and means to transfer from the xerographic plate to a support material the developed image produced by flowing said developer material.

3. A xerographic copying machine comprising,
two axially rotatable paraxial spaced cylindrical elements,
the axes of said elements being horizontal,
an endless flexible xerographic plate supported over said cylindrical elements,
said plate being supported in the configuration of two straight line segments joined by part circular arcs,
the upper segment forming an oblique angle with the horizontal,
charging means to charge the outer surface of the lower segment of the xerographic plate while said plate remains stationary,
transparent means to support an original subject to be reproduced face downward,
means to illuminate said subject while supported,
a projection lens,
first mirror means positioned and adapted to direct the light from said subject through said projection lens,
second mirror means positioned and adapted to direct the light from said projection lens through said charging means into focus on the lower surface of said plate while still stationary,
means to advance the exposed portion of the xerographic plate to the upper segment position only,
means to flow cascade electrostatic image developer material over the outer portion of the upper segment of said plate,
and means to transfer from the xerographic plate to a support material the developed image produced by flowing said developer material.

4. A xerographic copying machine comprising,
two axially rotatable paraxial spaced cylindrical elements,
the axes of said elements being horizontal,
an endless flexible xerographic plate supported over said cylindrical elements,
said plate being supported in the configuration of two straight line segments joined by part circular arcs,
the upper segment forming an oblique angle with the horizontal,
charging means to charge the outer surface of the lower segment of the xerographic plate while said plate remains stationary,
transparent means to support an original subject to be reproduced face downward,
means to illuminate said subject while supported,
a projection lens,
first mirror means positioned and adapted to direct the light from said subject through said projection lens,
second mirror means positioned and adapted to direct the light from said projection lens through said charging means into focus on the lower surface of said plate while still stationary,
means to advance the exposed portion of the xerographic plate to the upper segment position only,
means to flow cascade electrostatic image developer material over the outer portion of the upper segment of said plate,

means to transfer from the xerographic plate to a support material the developed image produced by flowing said developer material,

and means to clean residual developer material from the xerographic plate after image transfer therefrom and before reuse thereof.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,146,688 September 1, 1964

Harold E. Clark et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, lines 58 and 59, for "FIG. 2 is a graph relating developer velocity to xerographic cascade development methods." read -- It is still a further object to provide improved xerographic cascade development methods. --; column 5, TABLE I, ninth column, line 6 thereof, for "10.5" read -- 20.5 --.

Signed and sealed this 13th day of April 1965.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

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