United States Patent [19]

Sato et al.

[11] **3,784,397**

[45] **Jan. 8, 1974**

[54] **IMAGING SYSTEM**

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[21] Appl. No.: **110,921**

[30] **Foreign Application Priority Data**

Feb. 4, 1970 Japan.................................. 45-9841

[52] **U.S. Cl.**..... **117/37 LE,** 96/1 LY, 118/DIG. 23, 355/10

[51] **Int. Cl.**...................... **G03g 13/10,** G03g 15/10

[58] **Field of Search**............................... 117/37 LE; 118/DIG. 23, 637; 355/10; 317/3, 7; 96/1 LY, 1 R

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[57] **ABSTRACT**

Method for forming images by providing an electrostatographic imaging member bearing an electrostatic latent image on a recording surface, positioning the recording surface spaced from and facing a development electrode, contacting the recording surface with toner particles whereby at least a portion of the toner particles deposit on the recording surface to form at least a partially imaged recording surface, and maintaining the field strength of the development electrode weak during the initial period of development and then increasing the field strength of the development electrode during the latter period of development to form a substantially uniform developed image substantially free of streak, halo, edge effect, and background deposits.

16 Claims, 23 Drawing Figures

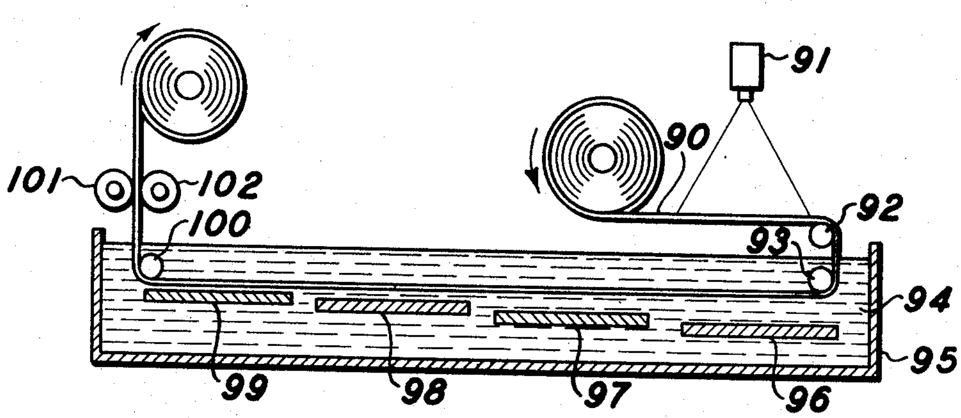


FIG. 1

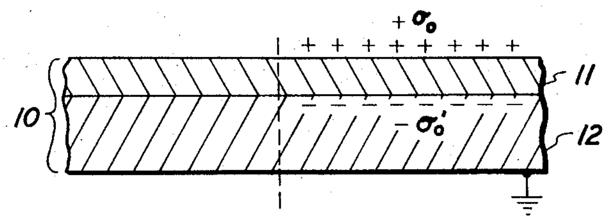


FIG. 2

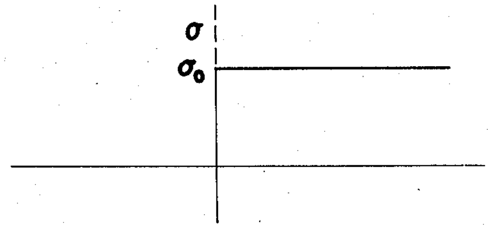


FIG. 3

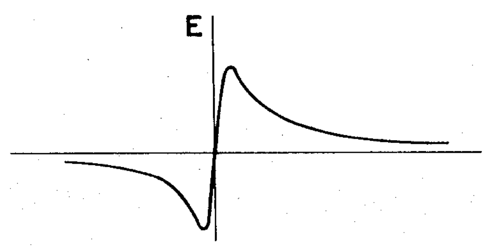


FIG. 4

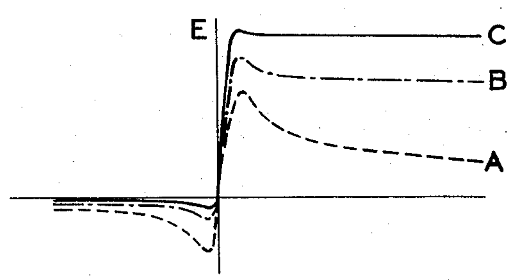
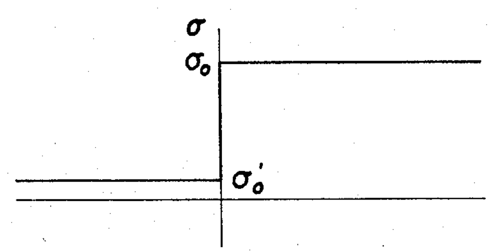


FIG. 5



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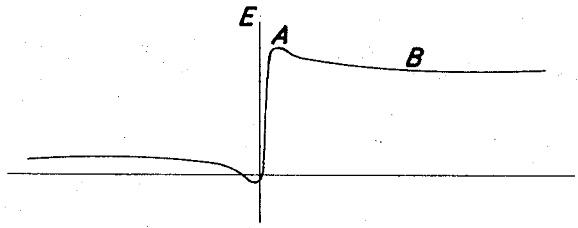
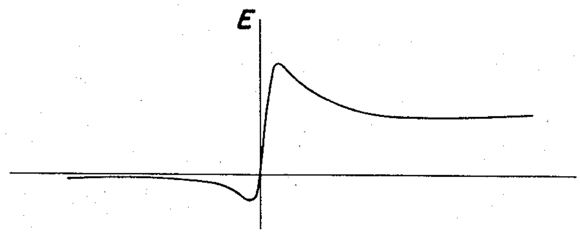


FIG. 6



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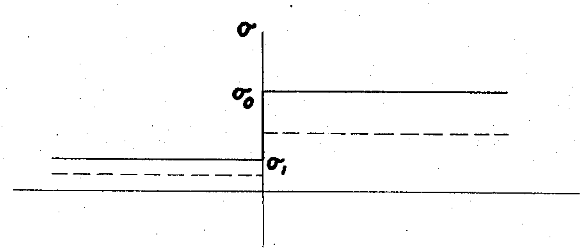


FIG. 8

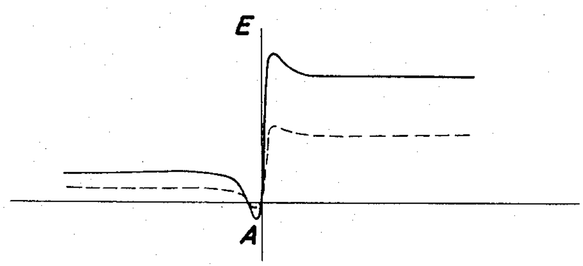


FIG. 9

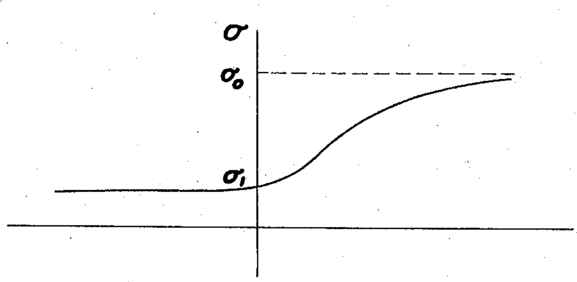


FIG. 10

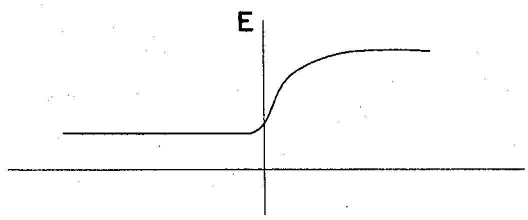


FIG. 11

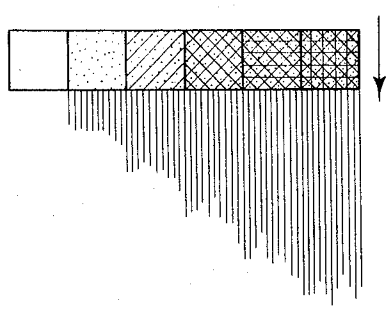


FIG. 12

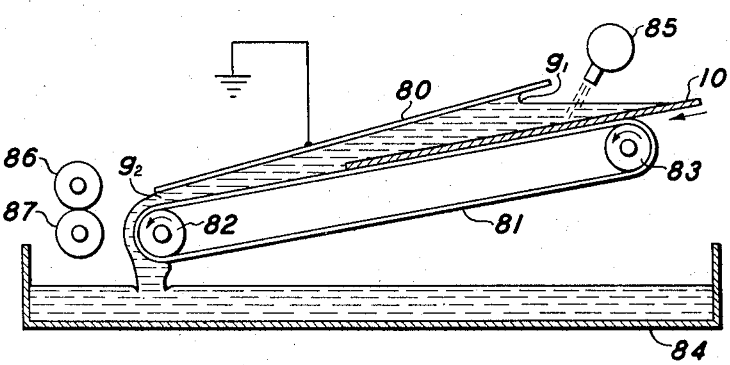


FIG. 13

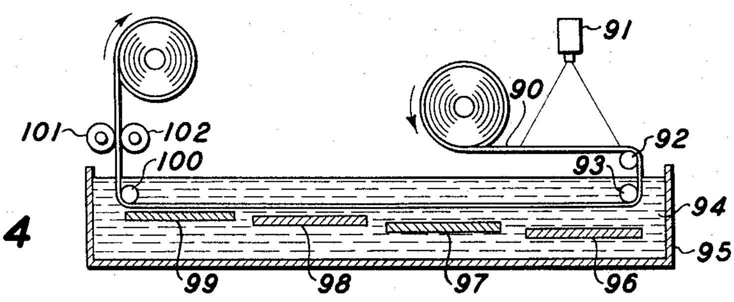


FIG. 14

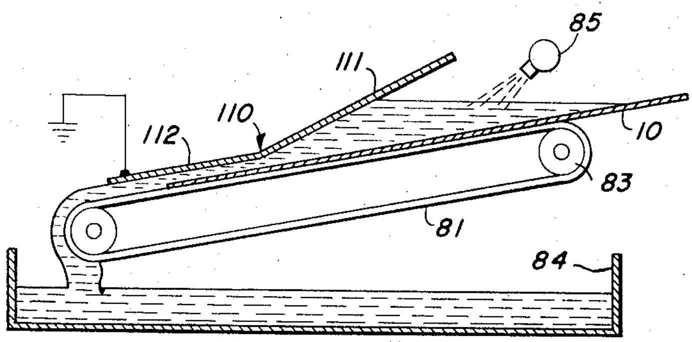


FIG. 15

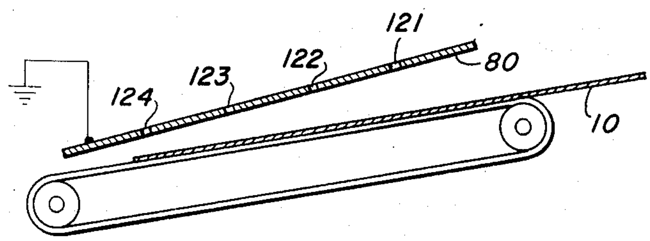


FIG. 16

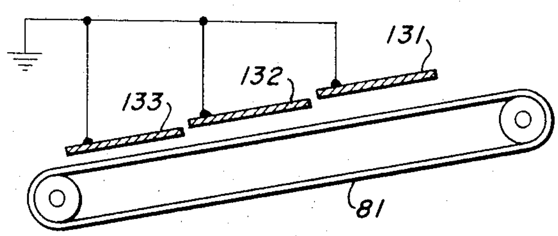


FIG. 17

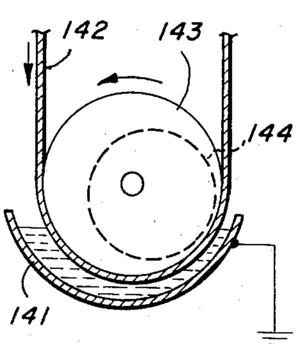


FIG. 18

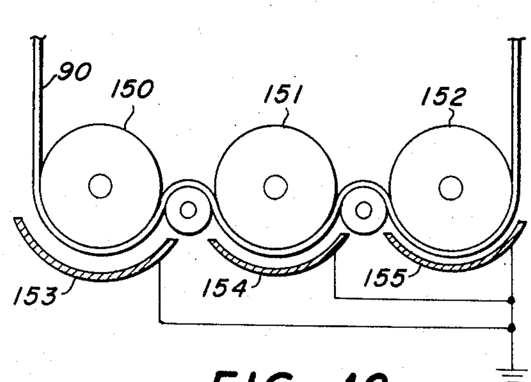


FIG. 19

FIG. 20

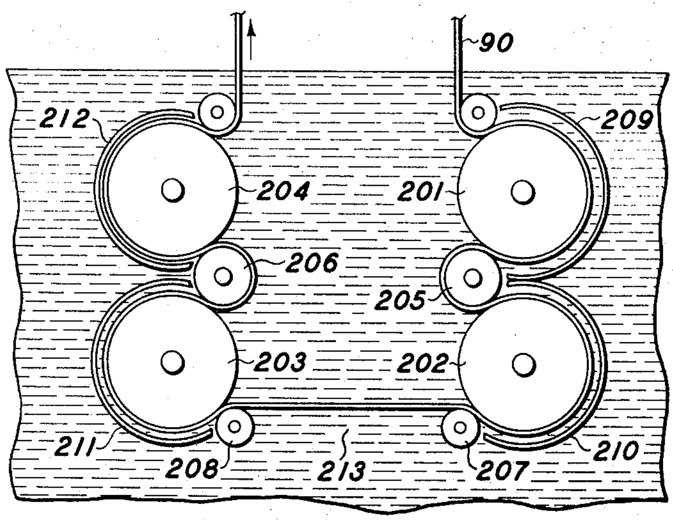


FIG. 21

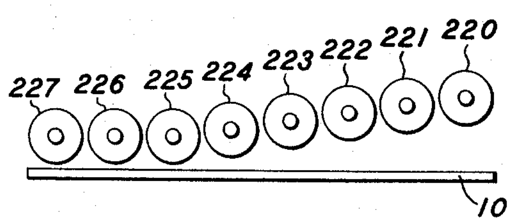


FIG. 22

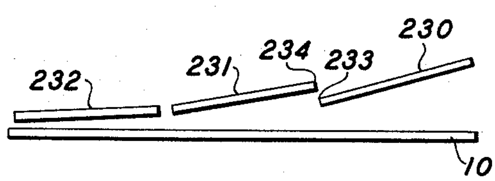
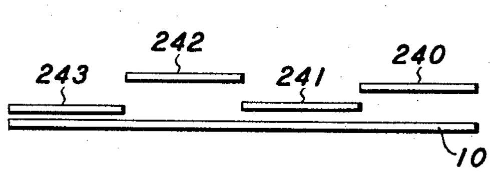


FIG. 23



IMAGING SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to imaging systems and more particularly to high speed liquid development systems for developing electrostatic latent images.

The formation and development of images on the surface of photoconductor material by electrostatic means is well known. The basic electrostatographic process as taught by C. F. Carlson in U.S. Pat. No. 2,297,691 involves placing a uniform electrostatic charge on a photoconductive insulating layer, exposing the layer to a light and shadow image to dissipate the charge on the areas of the layer exposed to the light, and developing the resulting electrostatic latent image by depositing on the image a finely divided electroscopic marking material referred to in the art as "toner." The toner will normally be attracted to those areas of the layer which retain a charge thereby forming a toner image corresponding to the electrostatic latent image. The powder image may then be transferred to a support surface such as paper and permanently affixed to the support by any suitable means such as heat fixing or solvent fixing. Alternatively, the powder image may be fixed to the photoconductor layer if elimination of the powder transfer step is desired. In addition, instead of latent image formation by uniform charging and followed by imagewise exposure, the latent image may be formed by directly charging the layer in image configuration. Other methods are known for applying electroscopic particles to the imaging surface. Included within this group are the "cascade" development technique disclosed by E.N. Wise in U.S. Pat. No. 2,618,552; the powder cloud development technique disclosed by C. F. Carlson in U.S. Pat. No. 2,221,776, and the magnetic brush process disclosed, for example, in U.S. Pat. No. 2,874,063.

Development of an electrostatic latent image may also be achieved with liquid rather than dry developer materials. In conventional liquid development, more commonly referred to as electrophoretic development, an insulating liquid vehicle having finely divided solid material dispersed therein contacts the imaging surface in both charged and uncharged areas. Under the influence of the electric field associated with a charged image pattern, the suspended particles migrate toward the charged portions of the imaging surface separating out of the insulating liquid. This electrophoretic migration of charged particles results in the deposition of the charged particles on the imaging surface in image configuration. Electrophoretic development of an electrostatic latent image may, for example, be obtained by pouring the developer over the image bearing surface, by immersing the imaging surface in a pool of the developer or by presenting the liquid developer on a smooth surface roller and moving the roller against the imaging surface. The liquid development technique has been shown to provide developed images of excellent quality and to provide particular advantages over other development methods in offering ease in handling. Liquid development is also capable of providing high development speed and the development speed of commercial embodiments has recently reached a level of as high as about 10 centimeters per second. However, with the currently available liquid development systems, this development speed is ordinarily practical only for line copy since the development of continuous

tone or halftone images generally require a much slower speed.

In general, the increase in development speed is accompanied by various difficulties, such as low density of the developed image due to shortened development time. This reduction in image density is particularly marked in continuous tone reproduction. Further, the electrostatic latent image of a large area cannot be developed uniformly with the result that there will remain the so-called edge effect wherein an image is developed densely in the edge portion and sparsely at the central portion. To overcome this difficulty, it is necessary to prolong the development period and decrease the gap between the latent image surface and the development electrode which is disposed close to the latent image surface. In addition, the image portion of lower density adjoining the image portion of higher density is deprived of its intrinsic density. This is a defect known as "halo." It has been found that the defect of halo cannot be overcome without further decreasing the distance between the latent image surface and the development electrode. Empirically, it is known that complete elimination of this defect can be accomplished by fixing the gap in the range of about 0.1 to 0.2 mm. However, it has been extremely difficult from a practical standpoint to maintain the gap between the latent image surface and the development electrode so small and uniformly. Maintenance of a fixed distance proves to be all the more difficult particularly where the electrophotographic sensitive material is in the shape of a flexible sheet. A second difficulty observed at higher development speeds is the formation of streaks in the developed image which resemble the tail of a comet. This streaking phenomenon, which has not been completely explained, does not appear, however, when the tangential speed of the liquid developer with respect to the image plane is small. Consequently, in order to prevent this streaking, it is necessary to minimize the relative tangential speed of the liquid developer with respect to the image plane. In addition, in the presence of a development electrode, this streaking phenomenon becomes more frequent with shorter distance between the image plane and the development electrode.

In the field of electrophotography, the liquid development process provides the best image quality in the reproduction of continuous tone image or multicolor image. Typically, this process consists of the steps of uniform electrostatic charging of a photoconductive insulating layer by means, for example, of corona discharge under subdued light. The photoconductive layer may be a photosensitive paper composed, for example, of an electroconductive paper substrate and a photoconductive layer thereover of powdered zinc oxide in an insulating resinous binder. The photoconductive layer is subjected to imagewise exposure of a light and shadow pattern to form an electrostatic latent image thereon which image is developed by contacting the surface of the photoconductive layer with a liquid developer thereby rendering the latent image visible.

While capable of producing satisfactory reproductions, this liquid development process is not free from difficulties. As mentioned above, the development speed is low in order to maintain adequate image density. In addition, the presence of the edge effect renders it impossible to provide reproductions or originals having uniform density in wide portions.

The edge effect is caused by the distribution of the electrostatic field formed by the electrostatic charge pattern of the electrostatic latent image on the surface to be developed. Where the electrostatic charge is distributed uniformly over a wide area, the electric field becomes stronger at the peripheral portion and weaker at the central portion. Thus, the component of said field perpendicular to said surface is not constant within this area, but exhibits a maximum and minimum respectively on the periphery and center of said area. When a sheet provided with such electrostatic image is brought into contact with liquid developer, the development proceeds rapidly in the peripheral portion and slowly in the center portion which produces an uneven density of toner particles. Theoretically, edge effects can be removed by prolonging the development time sufficiently. This, however, is not realizable in actual conditions because of dark decay of the electrostatic latent image during the course of development. In addition, prolonging the developing time is not desirable for practical purposes, since to increase the time results in an overall undesirable slow reproduction rate.

The use of a development electrode placed in the proximity of the imaging surface during development has been proposed to remove the edge effect. Theoretically, smaller distance between the imaging surface and the development electrode leads to improved proportionality between the perpendicular component of electrostatic field and the actual distribution of electrostatic charge and therefore, results in a smaller edge effect. In actual circumstances, however, this is not obtained because low developed image density is obtained due to the insufficient supply of liquid developer as a result of toner depletion, short development time or dark decay of the electrostatic image during prolonged development. Furthermore, occasional contact between flexible imaging surface and the development electrode will result in the destruction of toner image formed during development. These factors have made it very difficult to remove the edge effect completely by reducing the distance between the imaging surface and the development electrode.

Photoconductive insulating layers employed in electrophotography are generally associated with certain retentive potential. When a photoconductive insulating layer is subjected to imagewise exposure after uniform electrostatic charging thereon, the charge in the portions subjected to light irradiation is dissipated while the charge in the portions not exposed to light is retained on said layer. Dissipation of charge appears proportionally to the intensity of light thereby forming an electrostatic latent image corresponding to the original image. In the actual case, however, dissipation of charge becomes unproportional to the light intensity and becomes slower even if the light intensity is increased beyond a certain point. Thus, if the exposure is terminated before complete dissipation of electrostatic charge, the portions of the layer where the charge should be completely dissipated still retain some charge which is observed as retentive potential. On the other hand, if the light exposure is increased so as to dissipate such retentive potential completely, then the charge of other portions may be dissipated excessively beyond the required level thereby rendering it difficult to obtain a latent image faithful to the original image. Consequently, in the current processes, the exposure is carried out so as to permit some retentive potential and fogging resulting therefrom is eliminated by means of suitable methods. Deposition of toner particles in the background areas on the electrophotographic sheet is referred to in the art as fogging. Such retentive potential, if developed without any countermeasure, may give rise to uniform fogging over the background of the image to practically unacceptable image quality.

In order to prevent such fogging due to retentive potential, it has been proposed to apply a direct current voltage to the development electrode so as to form a potential comparable to the retentive potential during development. This method, however, accompanies the following drawbacks when applied to an automatic apparatus in which an electrophotographic recording member is driven continuously. In such apparatus, an electro-photographic recording surface bearing an electrostatic latent image thereon is displaced in facing relationship with said development electrode through liquid developer and the electrostatic charge is gradually but continuously dissipated due to migration through the liquid developer. Stated differently, the retentive charge on a portion of an electrostatographic imaging surface bearing a latent image is decreased during the period in which such portion is kept in facing relationship with a development electrode. Consequently, a constant potential applied to a development electrode cannot completely neutralize the thus varying retentive potential and thus, is incapable of providing reproduction faithful to the original image. Besides, in the prior methods, the potential externally applied should be regulated according to the electrophotographic recording member employed since such members are associated with different retentive potentials. Accordingly, it is necessary to measure the retentive potential by means of suitable methods.

SUMMARY OF THE INVENTION

It is therefore an object of this invention to provide a liquid development system which overcomes the above noted deficiencies.

It is another object of this invention to provide a liquid development system providing improved solid area coverage.

It is another object of this invention to provide a liquid development system capable of increased development speed.

It is another object of this invention to provide a liquid development system which produces developed images with substantially no edge effect.

It is another object of this invention to provide a liquid development system which produces high density, nonstreaky developed images.

It is another object of this invention to provide a liquid development system which produces developed images substantially free from fogging in the background areas.

It is another object of this invention to provide a liquid development system which does not require an external electric source for neutralizing retentive potential.

It is another object of this invention to provide a liquid development system which is superior to known liquid development systems.

The above objects and others are accomplished, generally speaking, by providing an electrostatographic imaging member bearing an electrostatic latent image on a recording surface, positioning the recording surface spaced from and facing a development electrode, contacting the recording surface with toner particles whereby at least a portion of the toner particles deposit on the recording surface to form at least a partially image recording surface, and maintaining the field strength of a development electrode weak during the initial period of development and then increasing the field strength of a development electrode during the latter period of development to form a substantially uniform developed image substantially free of streak, halo, edge effect and background deposits.

More specifically, the present invention is based upon the principle that the field strength of a development electrode upon an electrostatic latent image is kept small during the initial stage of development thereby maintaining the electric field due to retentive charge weak so as to be insufficient for attracting toner particles thereby preventing the formation of streak on the developed image, and subsequently increasing the field strength of a development electrode after the retentive charge is substantially attenuated and the boundary portions showing pronounced differences of charge density no longer exist, and terminating development in this state. The effect of a development electrode lies in changing the field configuration of the electrostatic image and to increase the field in the space between the development electrode and large solid areas of charge.

Though the effect of a development electrode can be controlled by various methods, the most common and basic method lies in changing the distance of an electrostatic latent image to a grounded development electrode. This method can be realized in different ways depending upon whether the electrophotographic sheet is driven continuously or intermittently. In addition, the effect of a development electrode can be controlled, for example, by regulating the grounding resistance connected to a development electrode, or by providing a dielectric material on the surface of a development electrode facing an imaging surface bearing an electrostatic latent image and changing the thickness of said material, or further by providing a plurality of development electrodes with respect to a continuously driven electrophotographic sheet and regulating the opening of the electrodes.

In accordance with this invention, development is carried out by decreasing and increasing the field strength of a development electrode at the initial period and at the latter period of development, respectively. However, the practice of this invention can be realized so long as the field strength of a development electrode is increased from the initial period towards the latter period of development, and the process of this invention is not affected by minor fluctuations in the field strength of a development electrode in each period. For example, the distance to a development electrode may be decreased within each period. One may also make the grounding resistance smaller and larger respectively in the initial period and latter period of development.

Thus, the development according to this invention is carried out by varying the field strength of a development electrode, and more particularly by making such field strength smaller and larger respectively in the initial and latter periods of development. The scope of this invention is further disclosed by the following description with respect to an embodiment thereof, for the purpose of simplicity, in which the distance between a grounded development electrode and a surface bearing an electrostatic latent image is varied. However, the scope of this invention remains unchanged when another method is applied. Therefore, if the distance between a development electrode and a surface bearing a latent image is made very small from the start of development, even a minute retentive charge will be faithfully reproduced on the image to cause fogging. At the same time, the low density portions around the boundary where charge density shows rapid change will show halo, and the image developed is apt to show streak phenomenon. Thus, initially, development is carried out at a sufficiently large distance between a development electrode and a surface bearing a latent image in order to suppress the attractive force of the electric field due to retentive charge at a level scarcely attracting toner, to attenuate such retentive charge by means of migration through the liquid developer, and to effect development with strong edge effect at the high density portions adjacent to the boundary where charge density differences are pronounced from one side of the boundary to the other, i.e., the image shows pronounced density change, thereby stressing the peripheral part of the image portion and making the differences in charge density less pronounced. Subsequently, development is carried out at a smaller distance between a development electrode and a surface bearing a latent image. At this time, the retentive charge is already attenuated by dissipating to a level substantially too weak for attracting toner and therefore avoids the formation of fogging. Further, in the imaging surface areas with pronounced differences in charge density, since such pronounced differences are already reduced to less pronounced differences, a smaller distance between a development electrode and a surface bearing a latent image avoids the formation of reversed electric field, and therefore, precludes the halo phenomenon. Also, in the internal part of a high density portion, faithful reproduction of an original image is obtained by combining the initial development with stressed edge effect and the latter development free from said effect. Concerning streaking which is apt to appear at the boundary where charge density shows a pronounced change when the distance between a development electrode and a surface bearing a latent image is small, streaking seldom occurs in the initial development since the distance is large and likewise in the latter development where the distance is made smaller since the pronounced change of charge density is already significantly decreased.

The invention may be further illustrated by reference to the accompanying drawings in which:

FIG. 1 is a schematic cross sectional view of an electrophotographic recording member wherein half of the recording surface is uniformly charged electrostatically.

FIG. 2 is a schematic cross sectional view of the charge distribution pattern on the surface of an electrophotographic recording member electrostatically charged as shown in FIG. 1.

FIG. 3 is a schematic cross sectional view of the distribution of electric field in the vicinity of the surface of an electrophotographic recording member provided with the charge distribution as shown in FIG. 2 in the absence of a development electrode.

FIG. 4 is a schematic cross sectional view of the distribution of electric field in the vicinity of the surface of an electrophotographic recording member provided with the charge distribution as shown in FIG. 2 in the presence of a development electrode.

FIG. 5 is a schematic cross sectional view of the charge distribution pattern obtained when the surface of an electrophotographic recording member provided with a uniform retentive electrostatic charge is electrostatically charged as in FIG. 1.

FIG. 6 is a schematic cross sectional view of the distribution of electric field in the vicinity of the surface of an electrophotographic recording member provided with the charge distribution of FIG. 5 when the distance between said surface and a development electrode is small.

FIG. 7 is a schematic cross sectional view of the distribution of electric field in the vicinity of the surface of an electrophotographic recording member provided with the charge distribution of FIG. 5 when the distance between said surface and a development electrode is large.

FIG. 8 is a schematic cross sectional view of the charge distribution pattern in which a uniform low density portion and a uniform high density portion are distributed adjacent to each other.

FIG. 9 is a schematic cross sectional view of the distribution of electric field in the vicinity of the surface of an electrophotographic recording member provided with the distribution of charge shown in FIG. 8 when the distance between said surface and a development electrode is small.

FIG. 10 is a schematic cross sectional view of a charge distribution pattern showing a change from high density to low density.

FIG. 11 is a schematic cross sectional view of the distribution of electric field resulting from the electrostatic charges distributed as shown in FIG. 10.

FIG. 12 is a schematic planar view of the state of development obtained on an electrophotographic recording member with stepwise charge density distribution when liquid developer is made to flow in the direction parallel and perpendicular to said distribution.

FIGS. 13 to 23 are longitudinal cross sectional views of different embodiments of apparatus according to the present invention and are described in detail in the following disclosure.

FIG. 1 illustrates an electrophotographic recording member 10 wherein half of the surface is provided with a uniform electrostatic charge and wherein recording member 10 comprises photoconductive insulating layer 11 selected from materials. known in the art such as amorphous selenium or a photoconductive powder such as photoconductive powdered zinc oxide blended with insulating resin, and electroconductive support material 12 comprising, for example, a metal plate, or an electroconductive plastic film or paper. Support material 12 is usually grounded during the process of development. FIG. 1 shows an example of a latent image comprising a uniform electrostatic positive charge provided on the upper surface of layer 11 and a corresponding negative charge induced at the corresponding half of the lower surface boundary thereof. The electrostatic charge densities are represented by plus σo and minus $\sigma o'$.

In FIG. 2, the distribution of positive electrostatic charge in FIG. 1 is shown graphically with the abscissa representing distance in the horizontal direction and the original point located at the boundary of electrostatic charge in FIG. 1. The electrostatic charge is assumed to be present on the righthand or charged half at a charge density of σ is equal to σo.

FIGS. 3 and 4 are graphs showing a component perpendicular to the surface bearing a latent image of the electric field in the vicinity of said surface caused by the charge distribution shown in FIG. 2. FIG. 3 shows the case where a development electrode is absent or where the distance thereof to the latent image is very large. It is to be noted that the electrostatic charge and the electric field have completely different distributions which is well known as edge effect. It should also be noted that a negative field is formed as shown in FIG. 3 in the lefthand half of the surface where σ is equal to zero in FIG. 2. The electric field is defined as positive when the direction thereof is upward from the surface bearing a latent image as shown in FIG. 1. A negative electric field will be hereinafter referred to as a reversed electric field which is particularly marked in the vicinity of boundary.

FIG. 4 is a graph showing the distribution of electric field when a grounded development electrode is kept in facing relationship with a surface bearing a latent image at a constant distance therefrom. In FIG. 4, the curves A, B and C respectively show the cases where the distance, hereinafter represented by g, between the development electrode and a surface bearing a latent image is relatively large, for example, about 30 millimeters; a little smaller, for example about 3 millimeters; and very small, for example, about 30 microns. As can be seen from this graph, the distributions of electrostatic charge and electric field show considerable correspondence when g is very small. Still in this state, however a small reversed electric field remains and is particularly larger at the vicinity of edge, that is, the boundary represented by the original point. At larger values of g, the reversed electric field becomes larger and the positive electric field becomes smaller.

FIG. 5 shows the electrostatic charge distribution in the case where retentive charge $\sigma o'$ is present. In other words, a charge $\sigma o'$ is not equal to zero is present in the portion left to the original point where $\sigma o'$ is equal to zero is desirable. The electrostatic charge distribution of FIG. 2 only shows an ideal case, and the actual distribution obtained by charging and imagewise exposure is similar to that shown in FIG. 5.

FIG. 6 is a graph showing the distribution of the component perpendicular to a surface bearing a latent image of the electric field in the vicinity of such surface when a grounded development electrode is kept in facing relationship with such surface. As shown in FIG. 6, the electric field in the portion where retentive charge $\sigma o'$ of FIG. 5 is present remains positive, except in the vicinity of boundary of charge distribution, where a negative minimum point remains due to edge effect. If liquid developer, in this case consisting of negatively charged minute toner particles suspended in insulating liquid, is supplied to a surface bearing a latent image in such state of electric field distribution, the toner attractable by the positive electric field adheres also to the left half of the imaging surface where such deposit is undesirable thereby resulting in fogging due to retentive charge.

FIG. 7 is a graph showning the distribution of electric field in the vicinity of a surface bearing a latent image resulting from the electrostatic charge distribution shown in FIG. 5. However, in this case, a larger value of g, corresponding to the curve A in FIG. 4, leads to the cancellation of the positive electric field that would be caused by the portion of charge density $\sigma o'$ shown in the left half to dissipate the positive electric field in the portion where the retentive charge is present. This is because with a larger electrode spacing, the effect of the higher value of charge density σo shown in the right half becomes stronger. Accordingly deposit of toner does not appear in the left half portion.

In the following is a discussion of the phenomenon of halo observed in conventional development methods. FIG. 8 illustrates the distribution of electrostatic charge in which charge density shows pronounced differences at the boundary between a low charge density ($\sigma 1$) portion and a high charge density (σo) portion. The solid line in FIG. 9 shows the distribution of electric field corresponding to an electrostatic charge distribution when *g* is kept at a very small value. If liquid developer is supplied to a surface bearing a latent image while *g* is maintained at a very small value, toner adheres to such surface according to the electric field distribution shown by the solid line of FIG. 9. When development is interrupted at the halfway point, the electrostatic charge distribution after partial neutralization by toner changes to the electrostatic charge distribution shown by the broken line in FIG. 8. Stated differently, the electrostatic charge is approximately neutralized corresponding to the distribution of charge because of a very small value of *g*, except at the boundary of charge distribution. As a result, the electric field distribution resulting from the remaining electrostatic charge takes the form of the broken line shown in FIG. 9 when g is very small. This distribution is almost proportional to the electric field distribution represented by the solid line in FIG. 9, and therefore still retains a negative field portion at the boundary. Thus, when the development electrode is used from the start of development with a very small value of *g*, reversed electric field is maintained at the vicinity of the boundary where the charge density differences are pronounced from one side of the boundary to the other throughout the development to prevent the deposition of toner thereby resulting in the phenomenon of halo.

In the prior art, it is believed that the value of g should be as small as possible, but it is now confirmed that this concept is not necessarily correct unless the condition g is equal to zero is completely satisfied. In practice, the minimum limit of g is usually on the order of about 30 mils, and on the order of about 100 mils in the case of automatic apparatus. A value of *g* 30 to 100 mils ordinarily order results in the formation of a reversed electric field at the boundary and accordingly becomes the cause of halo.

FIG. 10 shows the distribution of remaining electrostatic charge after neutralization by toner when a charge distribution shown by the solid line in FIG. 8 is developed with a relatively large value of *g*, for example, 5 to 10 mm, and development is interrupted at the halfway point. The initial electric field distribution takes the form of FIG. 7 because of a larger value of *g* and consequently the toner begins to deposit at the portion with a stronger electric field at the vicinity of said boundary. As a result, the charge in such portion is selectively neutralized while the charge in other portions distant from said boundary remains almost intact. Strictly speaking, the electrostatic charge is also slightly attenuated during the development because of migration through the liquid developer, resulting in a more shallow distribution as shown in FIG. 10. When a pronounced difference in charge distribution is altered as explained above, the distribution of electric field changes suddenly to take the form of FIG. 11 losing a negative field portion therein.

FIG. 11 shows the distribution of electric field corresponding to the charge distribution of FIG. 10 when the value of g is kept very small. In this case, *g* can be made its smallest within a technically possible range because a very small value of *g* does not give rise to the formation of reversed electric field as shown in FIG. 9 due to the absence of a pronounced difference in the charge density. Besides, a smooth distribution of electric field as shown in FIG. 11 seldom leads to the formation of "halo" and "streak".

A large value of *g*, if maintained throughout the period of development, is favorable with respect to fogging and streak, but generally should be avoided because of extremely slow developing speed and difficulty in obtaining an image of sufficient quality faithful to the latent image and substantially free from edge effect. Consequently, it is necessary to decrease the value of *g* after a suitable period. Such period is variable depending upon several factors such as the characteristics of an electrophotographic recording member, the resistance of a liquid developer, the amount of charge on toner particles, the concentration of toner in a liquid developer, the speed of migration of toner and the like, but is usually in the order of about 30 seconds and can be shorter or longer depending on a given case. For example, in the case of an electrophotographic photosensitive sheet provided with a photosensitive layer comprising zinc oxide and resin, an image of quite satisfactory quality free from halo, fogging and streak can be obtained by development for about 24 seconds at *g* equal to infinity, namely without a development electrode, about 14 seconds at *g* equal to about 2.0 mm and about 14 seconds at *g* equal to about 0.1 mm.

FIG. 12 shows the influence of g in preventing the streak phenomenon. More specifically, FIG. 12 shows the result of development of an electrostatic charge present in step wedge form when liquid developer is made to flow in the direction of the arrow, as illustrated, at a very small value of *g*. The developed image experimentally shows narrow and long streaks as well as wide and short streaks in the direction of flow of liquid developer. Such short streaks vanish while long streaks remain when development is carried out at a larger value of *g*. However, long streaks also vanish when the flow speed of liquid developer is decreased. Furthermore, long streaks do not appear when the flow speed of liquid developer is smaller regardless of the value of *g*, while short streaks persist unless g is made larger. It is also confirmed that short streaks do not vanish even when *g* is made smaller from the halfway point of development. Experimentally, it is confirmed that wide, short streaks can be prevented by effecting development for about 0.3 to about 5 seconds in the absence of a development electrode.

The edge effect formed at the initial stage of development with a large value of *g* seems to persist in the resulting image thereby rendering it difficult to obtain a flat shadow portion, but in fact this effect can be resolved as follows. For example, in the case of a latent image provided with a charge density distribution as shown in FIG. 5, development with a small value of g from the start provides an image faithful to the distribution of electric field as shown in FIG. 6 with some edge effect due to the difference of electric field in portions A and B of FIG. 6. In fact, this effect appears as the density difference in a high density portion and therefore is substantially negligible compared with the halo phenomenom observed in a low density portion. On the other hand, when development is started at a large value of g thereby facilitating the deposition of toner selectively in the edge portion under the electric field distribution shown in FIG. 7 and then continued at a small value of g, an image resulting from development under the electric field distribution shown in FIG. 11 is superimposed to give an overall image free from edge effect, thereby enabling the reproduction of a flat shadow portion.

Thus, since the formation of retentive potential is practically unavoidable in electrophotography, development with a small distance to the development electrode from the start of development will inevitably lead to fogging because the electric field resulting from such retentive potential becomes large. In accordance with this invention, fogging can be prevented by making the distance between the development electrode and the electrostatic latent image large, including up to infinity, thereby attenuating such retentive potential.

At the boundary where charge density differences are pronounced from one side of the boundary to the other, the low density portion adjacent thereto shows no deposition of toner to give halo whereas the high density portion adjacent to said boundary results in a density higher than that in the more distant portion giving rise to edge effect. This problem cannot be resolved completely unless the distance between a development electrode and an electrostatic latent image is theoretically reduced to zero. According to this invention, however, edge effect is reduced as to be negligibly small by effecting development first at a large value, including up to infinity, of such distance and then reducing such distance.

When a latent image is developed with liquid developer having a relative speed difference thereto, the image shows streak at the portion where the charge density shows a steep change. Such streak is apt to appear when the distance between a development electrode and an electrostatic latent image is smaller at a constant speed difference between liquid developer and such latent image, and also when such change of charge density is steeper. In accordance with this invention, streak can be substantially prevented by effecting development first at a large distance between a development electrode and a surface bearing a latent image to intensify edge portions thereby rendering the change of charge density less steep, and then at a smaller distance.

This invention is further illustrated by reference to the accompanying drawings of developing apparatus embodying the invention.

In FIG. 13 showing a schematic cross sectional view of an example of apparatus that may be employed in the process of this invention, represented are a grounded metal development electrode 80 of plate shape, an endless belt 81 made, for example, of metal, metal mesh, plastic, rubber and the like, driven around two rollers 82 and 83, and an electrophotographic sheet, hereinafter referred to as sheet 10, bearing an electrostatic latent image thereon and conveyed from right to left by means of belt 81. The electroconductive layer of sheet 10 is grounded directly or through belt 81. The sheet conveying surface of belt 81 is slightly inclined so as to let the liquid developer flow from right to left. Liquid developer stored in container 84 is fed by means of a pump, not represented, to a pipe 85 and then supplied onto sheet 10 through holes or slits provided in pipe 85. The distance g between development electrode 80 and the surface bearing a latent image is assumed as g_1 when sheet 10 enters facing relationship with development electrode 80 and as g_2 when said facing relationship is terminated. In an example according to FIG. 13, the conditions employed are as follows: g_1 is about 10 mm, g_2 is about 0.2 mm, the length in longitudinal direction of development electrode 80 is about 80 cm, advancing speed of sheet 10 is about 2 cm/sec and resistivity of liquid developer is about 10^{11} ohm-cm. Though the value of g shows linear change from g_1 to g_2 in FIG. 13, nonlinear change may alternatively be employed according to the decay characteristics of retentive charge. After the completion of development, the liquid developer is removed from sheet 10 by means, for example, of a pair of squeeze rollers 86 and 87, and successively sheet 10 is subjected to fixing or drying.

FIG. 14 shows an example of a case in which the value of g shows discontinuous changes. Though the structure of FIG. 13 meets the purpose when a development electrode and a surface bearing a latent image are mutually displaced continuously at a constant relative speed with facing relationship, it is necessary to vary discontinuously at certain points in order to realize uniform processing for each frame when a continuous web is driven intermittently. In this drawing, an electrophotographic recording member 90 of continuous web form, hereinafter referred to as web 90, is electrostatically charged by means of a conventional charging device, not shown, and then subjected to imagewise exposure by an exposing device 91 to form an electrostatic latent image thereon. The whole web 90 is stationary during imagewise exposure, and then is advanced by one frame to forward said latent image to a development stage. In FIG. 14 showing an example in which the web is intermittently advanced frame by frame, web 90 is advanced around rollers 92 and 93, immersed in liquid developer 94 contained in container 95 and at the same time, enters facing relationship with development electrode 96. When the latent image constituting one frame just reaches facing relationship with development electrode 96, web 90 is brought to a standstill, during which time the succeeding frame is subjected to imagewise exposure. Web 90 is again advanced when imagewise exposure is completed to bring the new latent image into facing relationship with development electrode 96 and to bring the preceeding latent image into facing relationship with development electrode 97. Thus, a latent image is developed while it is successively brought into facing relationship with a series of development electrodes, 96, 97, 98 and 99. Development electrodes 96, 97, 98 and 99 are so arranged that the surface bearing a latent image is at a constant distance to each single development electrode but at different distances to different development electrodes, and more specifically at a shorter distance at the later stage of development. The number of such development electrodes is suitably determined according to the actual requirement. After the completion of development, web **90** is removed from liquid developer **94** by means of roller **100**, treated by a pair of squeeze rollers **101** and **102** to remove liquid developer therefrom, dried, and taken up on a reel. In an apparatus according to FIG. **14**, an example of conditions employed is as follows: the distance from web **90** to development electrode **96** is about 10 mm, the distance to development electrode **97** is about 2 mm, the distance to development electrode **98** is about 0.5 mm, the distance to development electrode **99** is about 0.1 mm, imagewise exposure time is about 15 seconds, the advancing speed of web **90** is about 5 cm/sec and the resistivity of liquid developer **94** is about 5×10^{11} ohm-cm. Development with this apparatus provides an image substantially free from fogging, edge effect and halo.

FIG. **15** shows a schematic cross sectional side view of another example of apparatus that may be employed in the process of this invention. The apparatus shown in FIG. **15** is characterized by the use of a nonlinearly spaced development electrode **110** instead of a linearly spaced development electrode of the type illustrated in FIG. **13.** Development electrode **110** comprises a portion **111** wherein the value of g decreases linearly and portion **112** wherein g is kept at a small constant value. The process shown in FIG. **15** is preferable when the retentive charge can be sufficiently dissipated while a surface bearing a latent image is facing portion **111** of development electrode **110.**

FIG. **16** shows a schematic cross sectional side view of still another example of apparatus that may be employed in the process of this invention which is characterized by the presence of slits **121, 122, 123,** and **124** in the development electrode shown in FIG. **13.** In the apparatus shown in FIG. **13,** the flow speed of liquid developer gradually increases as it flows across a surface bearing a latent image due to decreasing value of *g*. Consequently, this fact may lead to the formation of streak in the flow direction of liquid developer from high density portions and thus, deteriorate image quality markedly. The slits shown in FIG. **16** are provided in order to prevent the aforementioned drawback. By employing the apparatus of FIG. **16,** the flow speed of liquid developer is not increased as much when the value of g is smaller since the liquid developer can escape to the space above the development electrode through the slits.

FIG. **17** shows a schematic cross sectional side view of still another embodiment of apparatus that may be employed in the process of this invention. In this embodiment, development electrodes **131, 132** and **133** are provided parallel to web **81** and with gradually decreasing values of g, which is largest at **131** and smallest at **133.** The apparatus of this embodiment is capable of providing an effect similar to that obtainable with the apparatus of FIG. **16** since development electrodes **131, 132** and **133** are provided with spacings therebetween through which liquid developer can escape to the space above said development electrodes. Though the development electrodes are assumed to be flat in the apparatus of FIGS. **16** and **17,** development electrodes of almost any arbitrary shape may be satisfactorily employed in the process of this invention.

FIG. **18** shows a schematic cross sectional side view of an example of developing apparatus employing a semicylindrical development electrode **141** in which continuous sheet **142** bearing a latent image on the external surface thereof is continuously driven at a constant speed around drum **143.** Development electrode **141** of semicylindrical shape is eccentrically mounted with respect to the axis of drum **143** thereby enabling larger and smaller *g* at the initial and later stages of development respectively. When a latent image to be developed is present on the internal surface of sheet **142,** drum **143** is replaced by an eccentrically mounted stationary drum **144,** and sheet **142** is driven by rotating rollers located at both extremities of drum **144** having a peripheral shape identical with aforementioned drum **143.**

FIG. **19** shows a modification of the apparatus of FIG. **14** and employs curved development electrodes. In this embodiment, continuous web **90** bearing a latent image on the external surface thereof is driven around drums **150, 151** and **152** to which semicylindrical development electrodes **153, 154** and **155** are attached respectively. The value of *g* is constant for each electrode but is less at the latter stage of development. In this embodiment web **90** can be driven either continuously or intermittently.

In the above embodiments the development electrodes and the surface bearing a latent image are mutually displaced in a direction parallel to said surface, but it is also obviously possible to interrupt such mutual displacement during development and to cause time-dependent changes in the value of *g*.

FIGS. **20 – 23** show schematic cross sectional side views of examples of apparatus in which the distance between a development electrode and an electrostatic latent image surface is decreased during development or in which a development electrode is lacking.

In FIG. **20** showing an example of developing apparatus employing development electrodes provided with a cylindrical surface, continuous web **90** is driven around drums **201, 202, 203** and **204** and the running direction thereof is changed by rollers **205, 206, 207** and **208.** Development electrodes **209, 210, 211** and **212** are arranged so as that the distance between a development electrode and a surface bearing an electrostatic latent image is largest, for example, about 10 mm, in the unit containing development electrode **209** and smallest, for example, about 0.1 mm, in the unit containing development electrode **212.** Between rollers **207** and **208** is provided space **213** where a development electrode is absent. The diameter of drums **201, 202, 203** and **204** as well as the dimension of space **213** can be arbitrarily determined when web **90** is advanced continuously, but these factors should be determined so that the image of one frame can be enclosed within the portion contacting said drums or within said space when the web is driven intermittently. A space without development electrode such as **213** is provided in order to install a pump between drums **202** and **203** or to obtain spacing for maintenance.

FIG. **21** shows an example in which development electrodes **220** through **227** of roller shape are employed so as to gradually decrease the distance to sheet **10.** In this embodiment, the distance between the development electrodes and sheet **10** is larger than the spacings between the electrodes, and thus, this embodiment may also be considered as an embodiment where the distance may be increased between the electrodes. In this case, however, it is to be noted that the object of this invention is achieved where the distance between the electrodes and sheet **10** is large before said distance becomes sufficiently small.

FIG. **22** shows an example of developing apparatus employing inclined development electrodes **230, 231** and **232** in which the rear end **233** of electrode **230** is located closer to a surface bearing an electrostatic latent image than front end **234** of electrode **231**. This embodiment is within the scope of this invention when the object of this invention is achieved by electrode **230**.

FIG. **23** shows an example of apparatus employing four development electrodes **240** through **243** which are parallel to sheet **10** and are located successively closer to a surface bearing a latent image except development electrode **242**. The distance between electrode **242** and sheet **10** is made larger in order to supply liquid developer through electrode **242**.

The initial stage of development in the process of this invention is defined as a period extending to about the time when reversed electric field is no longer formed in the distribution of electric field even if a development electrode is used with substantially maximum developing effect thereof. The latter stage is defined as a period succeeding said initial stage and until the electrostatic charge is substantially dissipated.

Furthermore, if retentive charge is not attenuated sufficiently while development is carried out with the suppressed effect of a development electrode in changing the field configuration of the electrostatic image and increasing the field in the space between the development electrode and large solid areas of charge rendering the change of charge density less pronounced in the portions where charge density shows pronounced differences, it is desirable to prevent fogging by applying a bias potential of the same polarity and potential as the retentive potential between a development electrode and the electroconductive support of an electrophotographic recording member so as to repel toner from a surface bearing a latent image. This method is preferable when the retentive charge density is very large.

Any suitable material, such as conventional binder plates, may be employed in the photoreceptor sheet of this invention. Preferably, the material should resist dissolving or swelling when contacted with the liquid developer. For example, while photosensitive paper comprising zinc oxide and an insulating binder layer are discussed above, it is to be understood that other imaging members may be employed and that the choice of particular imaging member and particular development system may be readily determined by one skilled in the art. For example, cadmium sulfide, zinc sulfide, zinc selenide, cadmium selenide, titanium dioxide, phthalocyanine and polyvinyl carbazole may be employed as a photoconductive material. In addition, other suitable electrostatographic imaging members may be employed.

Any suitable conventional developer may be employed in the system of this invention. Typical developers include liquid developers which contain electroscopic marking particles dispersed in an insulating liquid vehicle and may also contain control agents and suspending agents for their well known functions. The electroscopic marking particles are conventionally dispersed and suspended in the liquid by stirring or agitation and where a highly uniform and stable suspension is desired, the suspension may be passed through a colloid mill. For optimum results, toner particles having an average diameter of less than about 1 micron are preferred because higher resolution images and more stable developer mixtures are achieved.

The expression "development electrode" as used herein in the specification and in the claims is intended to include one or more electrodes.

Although particular embodiments have been set forth using the development system and technique of this invention, these are merely intended as illustrations of the present invention. Various other suitable systems and techniques such as those mentioned above may be substituted for those described with similar results. Other modifications of the present invention will occur to those skilled in the art upon a reading of the present disclosure which modifications are intended to be included within the scope of this invention.

What is claimed is:

1. A method of forming images comprising providing an electrostatographic imaging member having a recording surface bearing an electrostatic latent image, said recording surface having an electric field in the image regions and an electric field in the image-free regions, said electric field in said image regions having a direction opposite to said electric field in said image-free regions, said image regions having a peak electric field strength within said image regions adjacent the boundary between said image regions and said image-free regions, with said peak electric field strength within said image regions sloping to lower electric field strengths in regions within said image regions remote from said boundary, positioning said recording surface spaced from and facing a development electrode, increasing the electric field of said recording surface with said development electrode sufficient to reduce said sloping of said electric field strength in said image regions but insufficient to cause the direction of said electric field in said image-free regions to align in the same direction as said electric field in said image regions, contacting said recording surface with toner particles until sufficient toner particles deposit in said image regions having said peak electric field strength to reduce the charge density of said electrostatic latent image in said image regions having said peak electric field strength by at least partial neutralization to a level below the electrostatic charge density in said image regions remote from said boundary, and increasing said electric field of said recording surface with said development electrode whereby said toner particles deposit in said image regions remote from said boundary at a greater rate than at said image regions adjacent said boundary.

2. A method according to claim **1** including maintaining said electric field strength in said image-free regions insufficient for attracting toner particles to said image-free regions.

3. A method according to claim **1** wherein said toner particles are suspended in an insulating carrier liquid.

4. A method according to claim **1** wherein said development electrode comprises a plurality of development electrodes.

5. A method according to claim **4** including positioning said recording surface spaced from and facing said plurality of development electrodes at sequentially decreasing perpendicular distances from said plurality of development electrodes.

6. A method according to claim 5 including intermittently advancing said recording surface.

7. A method according to claim 4 including positioning said plurality of development electrodes at sequentially decreasing perpendicular distances from said recording surface wherein the edge of the first development electrode adjacent the next electrode is positioned closer to said recording surface than the confronting edge of said next development electrode.

8. A method according to claim 4 including positioning at least one of said plurality of development electrodes at a greater distance from said recording surface than a preceding development electrode.

9. A method according to claim 1 including positioning said recording surface spaced from and facing said development electrode at substantially continuously decreasing linear distances from said development electrode.

10. A method according to claim 1 wherein said recording surface is spaced from and facing said development electrode at a distance of about 10 millimeters upon initial contact of said recording surface with said toner particles and at a distance of about 0.2 millimeter prior to termination of contact of said recording surface with said toner particles.

11. A method according to claim 1 wherein said recording surface is spaced from and facing said development electrode at progressively diminishing distances while said charge density of said electrostatic latent image in said image regions having said peak electric field strength is being reduced to a level below said electrostatic charge density in said regions within said image regions remote from said boundary.

12. A method according to claim 1 including moving at least a portion of said toner particles through openings in said development electrode.

13. A method according to claim 1 including transporting along an arcuate path said recording surface spaced from and facing said development electrode wherein said development electrode comprises an arcuate development electrode positioned at decreasing radial distances from said arcuate path.

14. A method according to claim 13 wherein said arcuate path comprises a plurality of arcuate paths and said arcuate development electrode comprises a plurality of arcuate development electrodes successively positioned at decreasing radial distances from said plurality of arcuate paths.

15. A method according to claim 1 wherein said development electrode comprises a plurality of cylindrical development electrodes positioned at successively diminishing distances from said recording surface.

16. A method according to claim 1 including positioning said recording surface spaced from and facing said development electrode at substantially continuously decreasing linear distances from said recording surface for the initial period of development and positioning said recording surface spaced from and facing said development electrode at a constant distance from said recording surface until development is terminated.

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