

- [54] XEROGRAPHIC TONER CONCENTRATION
- 
- CONTROL APPARATUS

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- [21] Appl. No.: 372,054

### Related U.S. Application Data

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- [52] U.S. Cl..... 222/52, 222/DIG. 1

- [51] Int. Cl. .... B05b 5/02, G03g 15/00

- [58] **Field of Search** ..... 222/DIG. 1, 52; 250/573,  
250/575, 577, 215, 223; 356/207, 208;  
118/637, 638

- [56]
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*Primary Examiner*—Robert B. Reeves

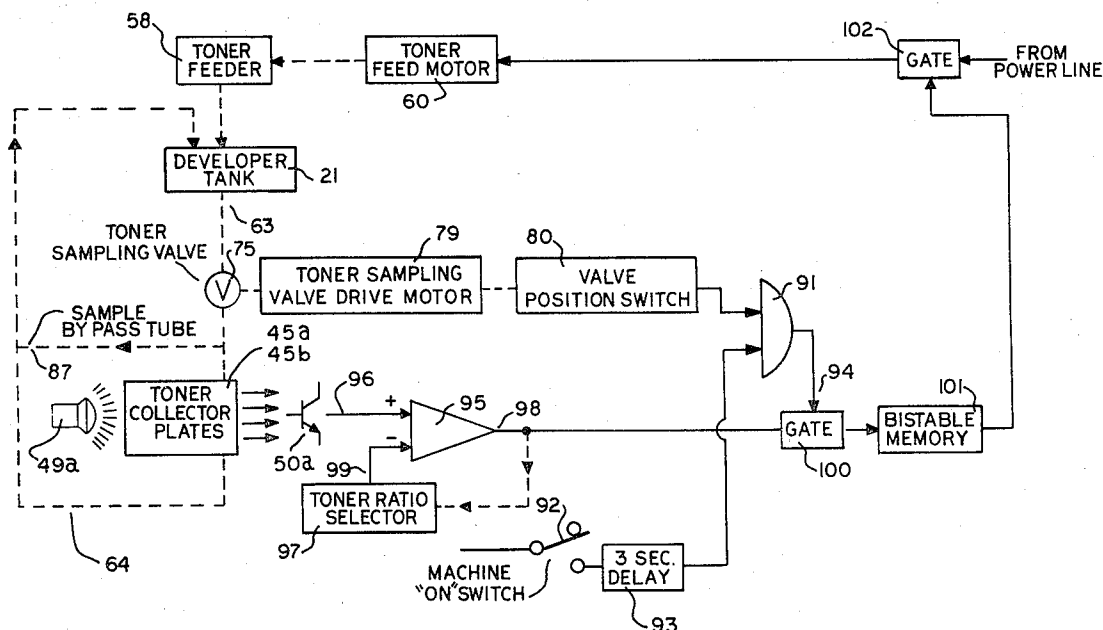
*Assistant Examiner*—Thomas E. Kocovsky

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## [57] ABSTRACT

An arrangement for measuring the concentration of toner powder in a xerographic developer mixture by causing a sample of the developer to impinge upon a transparent plate. By providing the developer sample in the form of a turbulent stream, inclining the plate at the proper angle, and arranging the geometry of the measuring apparatus so that the stream impinges upon the transparent plate with the proper kinetic energy, a layer of toner powder is formed on the surface of a portion of the plate, the thickness of the toner layer increasing and decreasing with corresponding changes in the concentration of toner in the developer mixture. A photoelectric system is employed to monitor the light transmission of the toner-coated plate to provide a measure of toner concentration.

### 33 Claims, 13 Drawing Figures



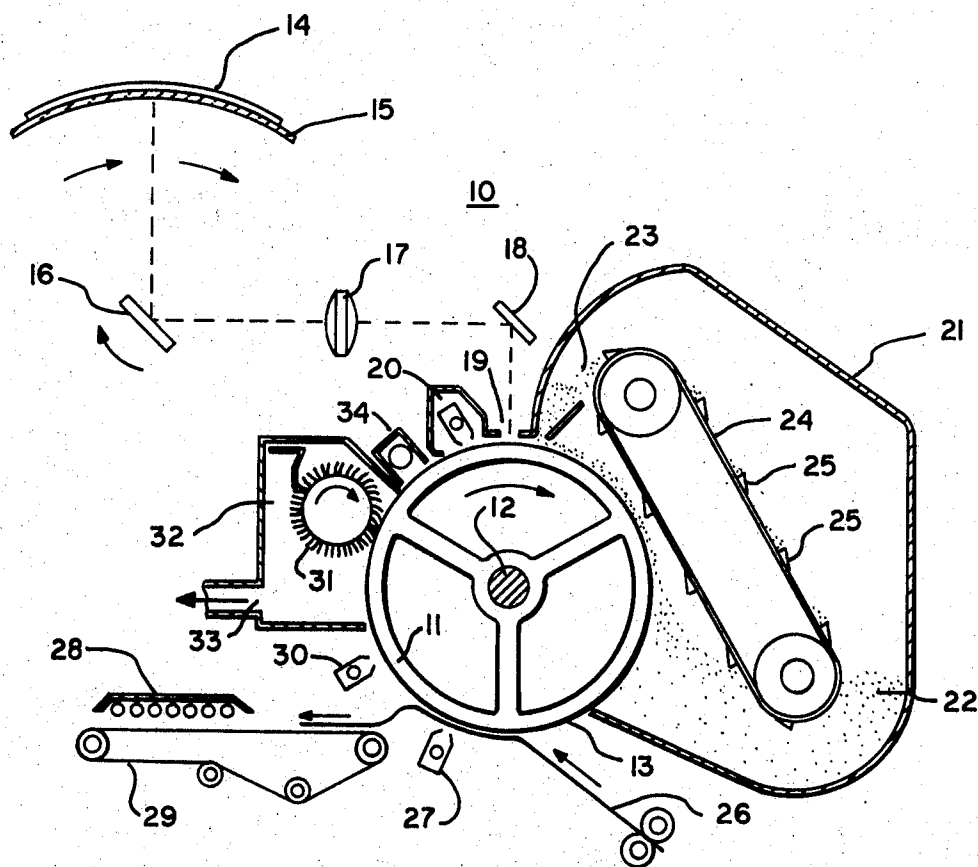


FIG. 1  
(PRIOR ART)

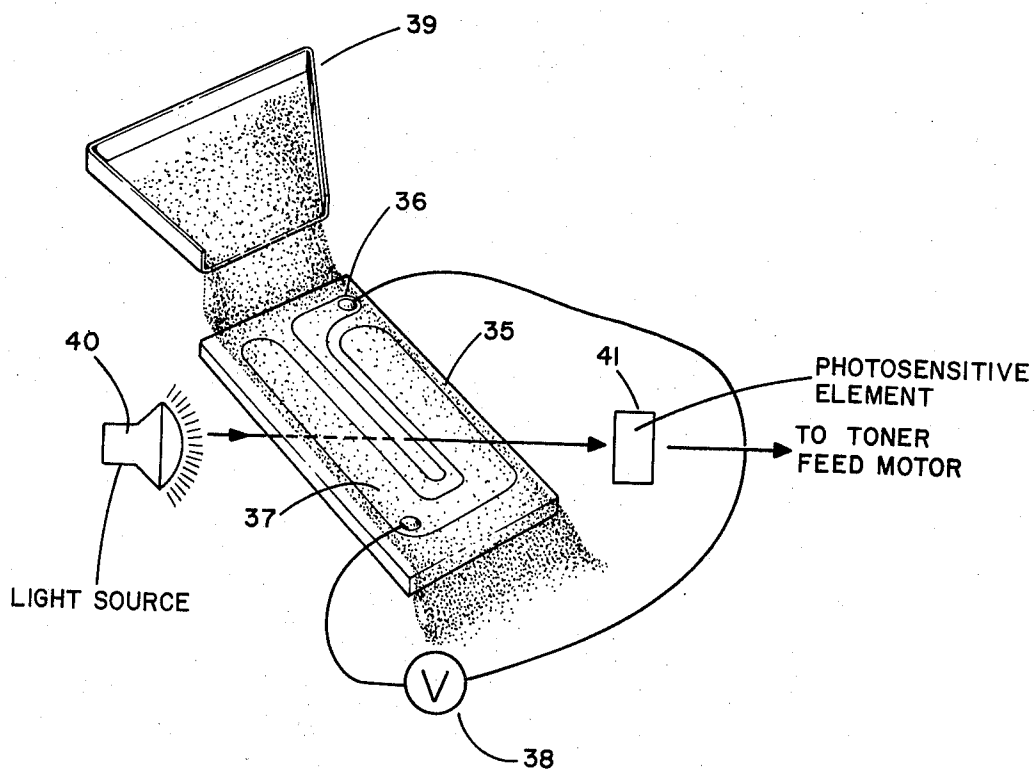
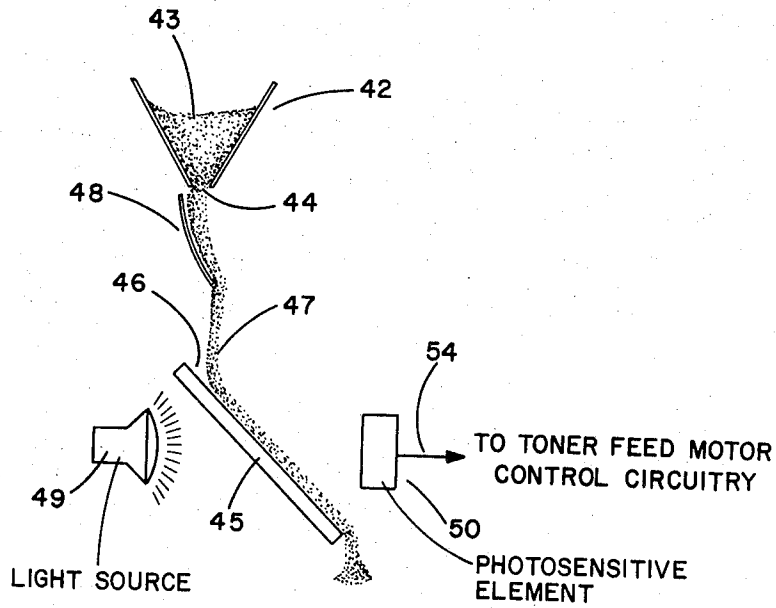
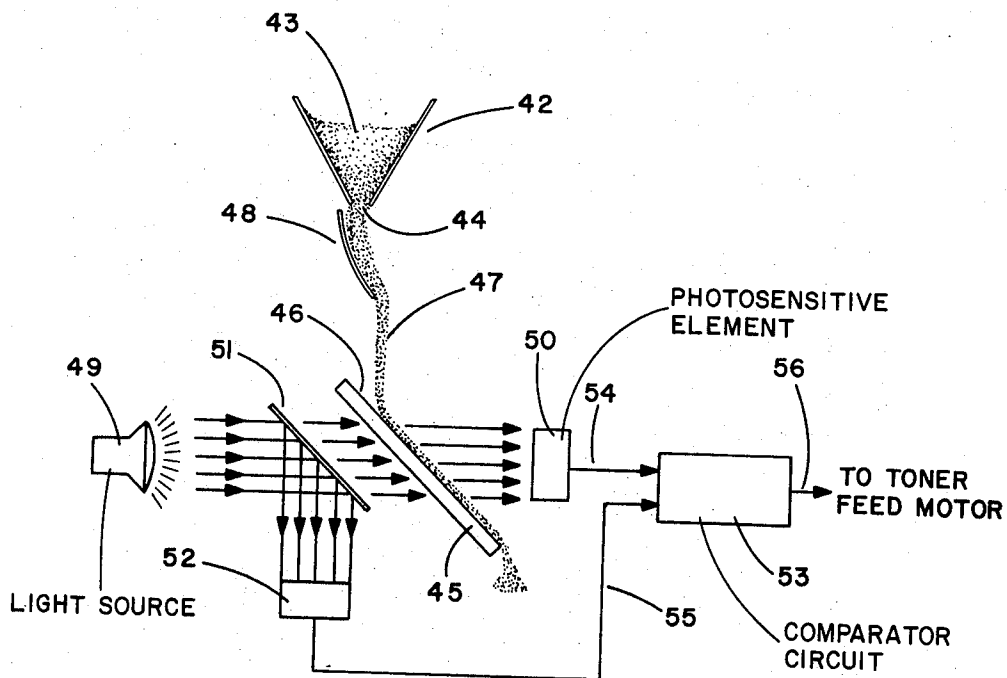


FIG. 2  
(PRIOR ART)



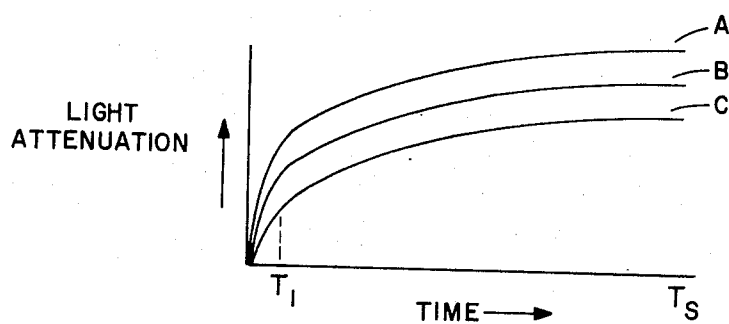


FIG. 5

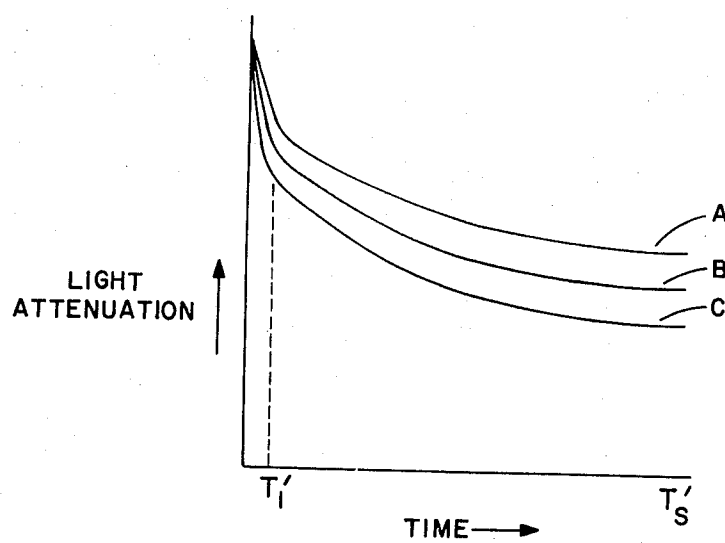


FIG. 6

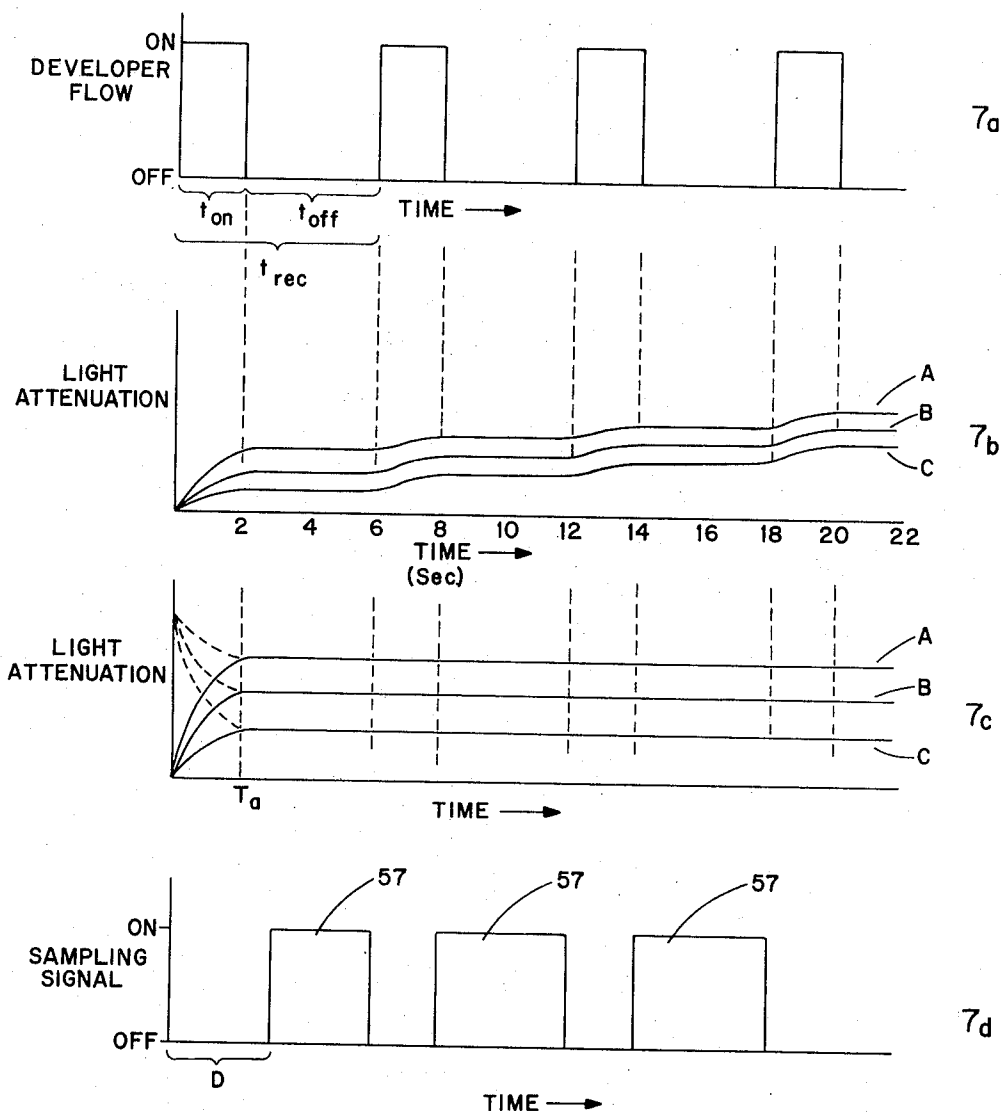


FIG. 7

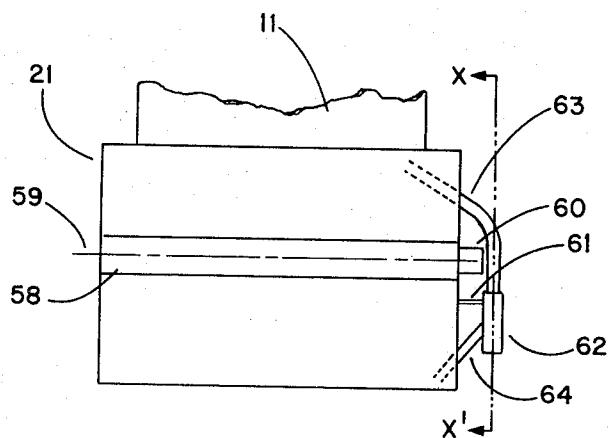


FIG. 8

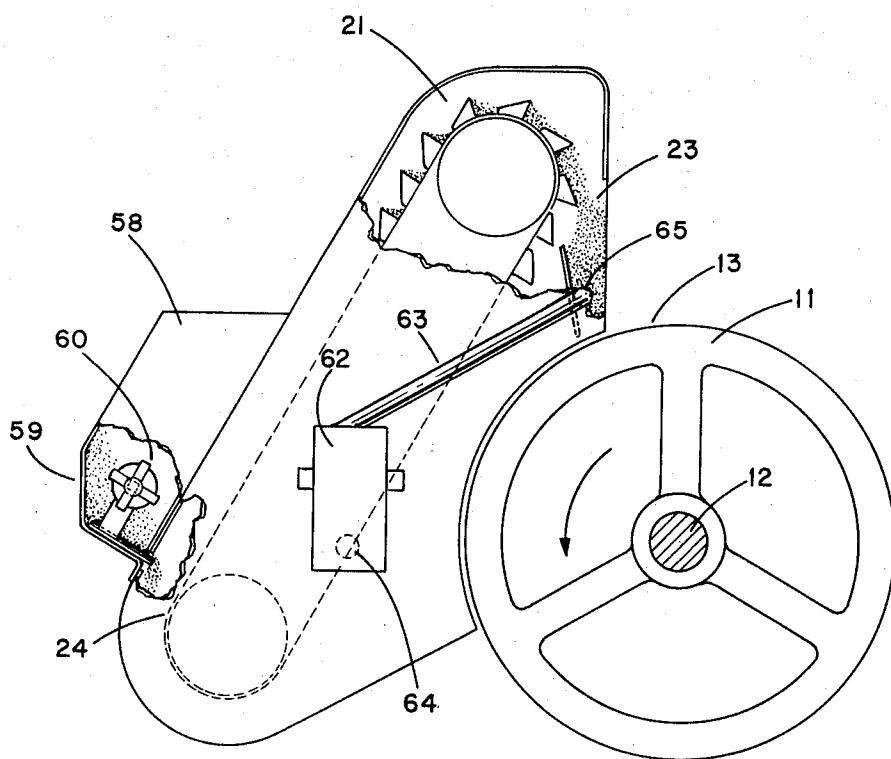


FIG. 9

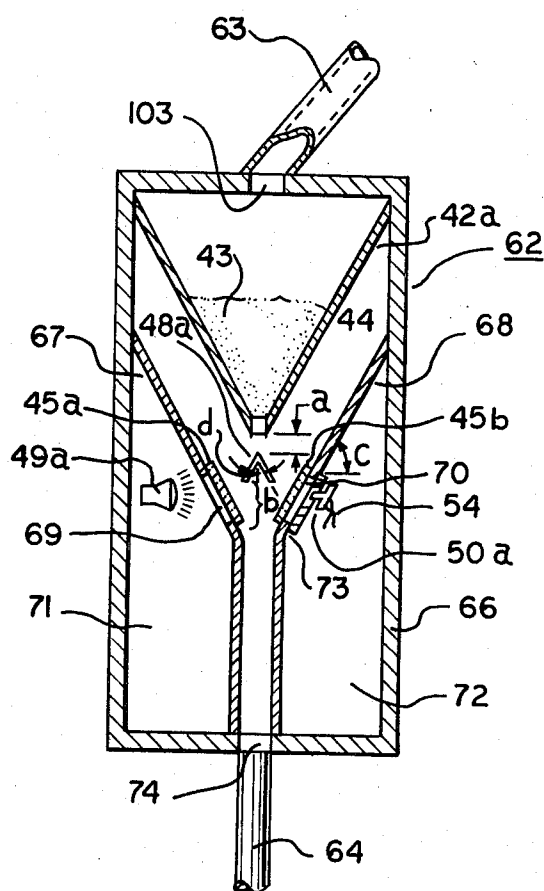


FIG. 10

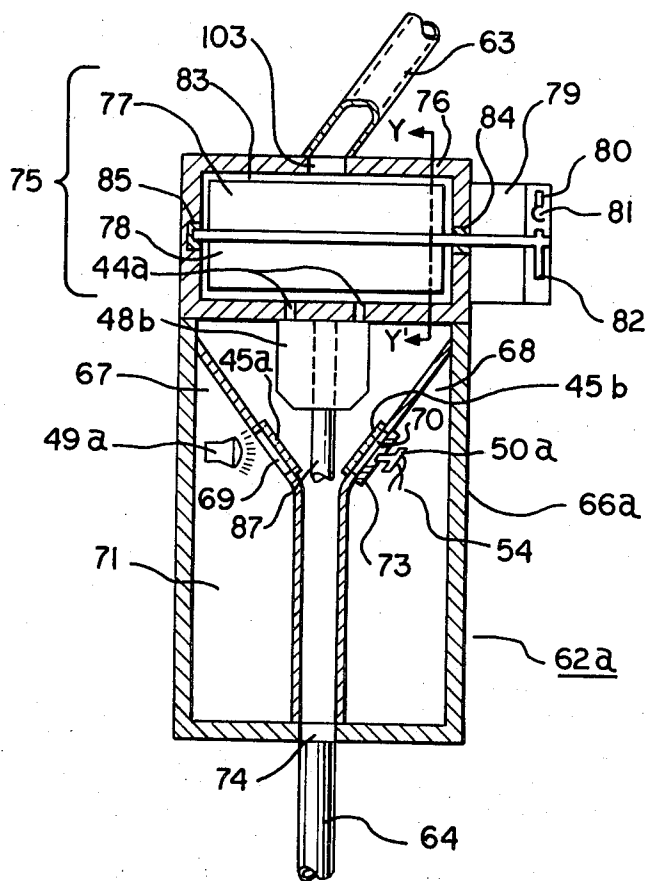


FIG. II

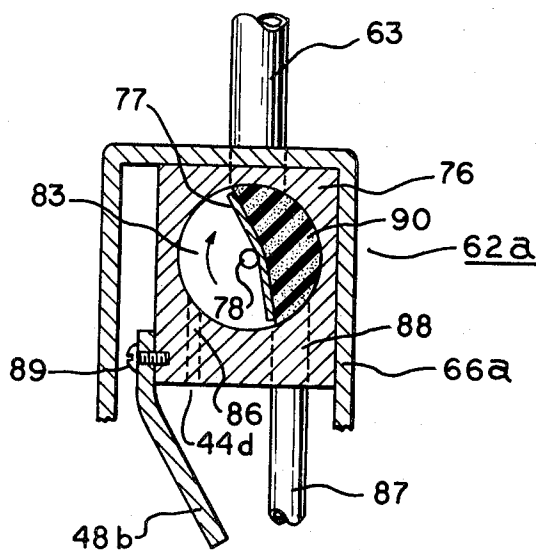
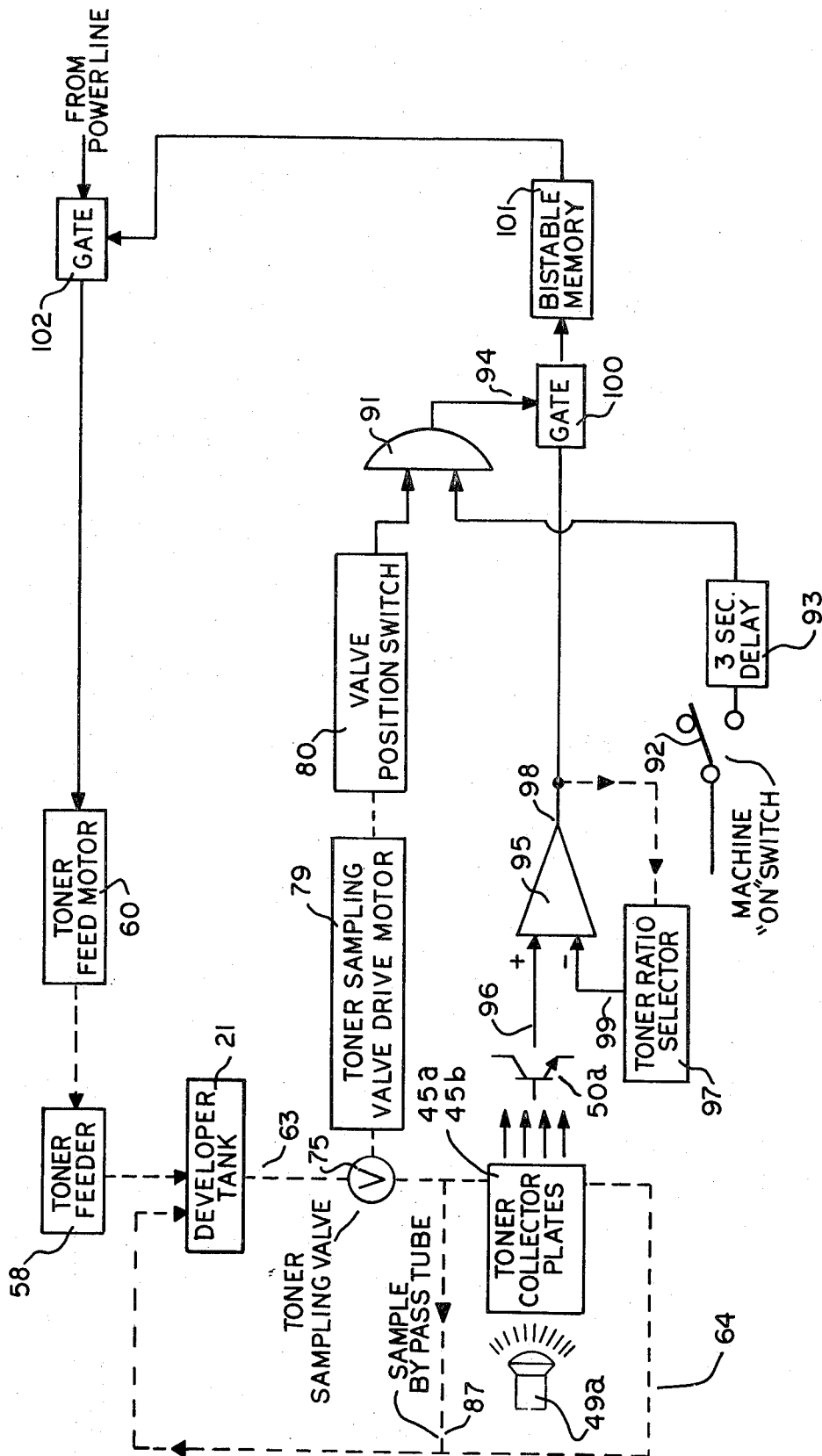


FIG. 12



## XEROGRAPHIC TONER CONCENTRATION CONTROL APPARATUS

This is a Division of application Ser. No. 227,978, filed Feb. 22, 1972, now U.S. Pat. No. 3,777,173.

This invention relates to an apparatus and method for measuring the toner concentration in the developer of a xerographic copying apparatus.

In the practice of xerography, an electrostatic image of a desired pattern is formed on an insulating surface. This is usually accomplished by providing a photoconductive insulating material affixed to a conductive backing, uniformly electrostatically charging the photoconductive surface (typically by a corona charging technique), and subsequently exposing the charged photoconductive surface to an electromagnetic radiation pattern (usually a visible light pattern) of the image to be reproduced. The electromagnetic radiation pattern discharges the photoconductive surface in the areas where the surface is irradiated, thus forming an electrostatic charge pattern on the photoconductive surface corresponding to the pattern of the desired image.

In order to render the image defined by the electrostatic charge pattern visible and permanent, the photoconductive surface is contacted with microscopic particles which may be in the form of a fine powder, the particles having been provided by some means with an electrostatic charge opposite in sign to the charge remaining on those portions of the photoconductor which have not been discharged (or which have only been partially discharged) by the incident electromagnetic radiation. As a result, these microscopic particles (commonly known as "toner") adhere to the photoconductor only in those areas which retain an electrostatic charge, i.e. those areas which have not been irradiated.

The pattern of toner particles, which corresponds to the pattern of the desired image, is subsequently either (i) fused to the photoconductive surface by application of heat or a suitable solvent to form a permanent image, or (ii) transferred to another surface, which may comprise ordinary paper, and subsequently fused thereto by suitable application of heat or solvent.

In order to carry the toner particles to the surface of the photoconductor which has been selectively discharged in accordance with the desired pattern, and to provide toner particles with the desired electrostatic charge, i.e. opposite to the charge remaining on those areas of the photoconductor which have not been discharged by irradiation in accordance with the desired pattern, a granular carrier material, usually in the form of small beads of glass, sand or steel, is provided. The toner, which is usually a pigmented or dyed resin based powder, is mixed with the carrier particles, pellets or beads, which are coated with a material removed in the triboelectric series from the toner material, so that a triboelectric charge is acquired by the toner and the granular carrier upon mutual interaction therebetween. The resulting triboelectric charging effect causes the relatively small (typically on the order of 0.1 to 20 microns) toner particles to adhere to the relatively large (typically on the order of 350 to 500 microns) carrier granules.

When the developer mixture, consisting of carrier granules having electrosopic toner particles adhering thereto by mutual triboelectric interaction, is cascaded

over, poured on, brushed against or otherwise brought into contact with the photoconductive surface having the desired electrostatic image thereon, the toner particles are pulled away from the carrier granules by the stronger attraction of the latent electrostatic image.

These attracted toner particles are subsequently fused to the photoconductor or another surface to form the desired permanent image. The carrier granules are not attracted to the latent electrostatic image, and are eventually returned to the developer reservoir.

As the number of copies produced by the xerographic apparatus increases, toner powder is depleted from the developer mixture, while the carrier granules are not consumed. As a result, the relative concentration of toner in the developer mixture decreases as more and more copies are produced. This effect causes the density of print, i.e. of toner deposited upon the portions of the photoconductor surface which retain charge in accordance with the latent electrostatic image pattern, to decrease, producing copies which are undesirably light and of non-uniform quality.

Since the amount of toner consumed by the xerographic apparatus is dependent not only upon the number of copies produced, but also upon the amount of print produced on each copy, it is virtually impossible to estimate the periods when toner should be added, and the proper quantity of toner to be added at such periods.

Attempts to manually monitor the toner concentration by viewing the density of print on the copies produced by the xerographic apparatus have proven to be impractical, especially in the case of high speed copier-duplicator machines, where a large number of defective copies may be produced before the need for toner replenishment is discovered.

An additional problem encountered with attempts to manually control the toner concentration in a xerographic apparatus is that defective copies and impairment of machine performance can result from addition of an excessive concentration of toner to the developer mixture. On the other hand, an insufficient concentration of toner can result in mechanical damage to the triboelectric coating on the developer beads.

An excessive concentration of toner in the developer mixture results in an undesirable deposit of toner in the image areas, commonly known as "background". Such background causes copies to exhibit poor contrast with blotchy images or poor resolution. Excessive toner concentration also increases the rate of accumulation of toner powder on critical machine components, requiring more frequent replacement of filters and cleaning of such components.

An additional problem resides in the difficulty of removing excess toner from the developer mixture, so that once an excessive amount of toner has been added, it is usually necessary to produce a relatively large number of defective copies (which must be discarded) in order to reduce the toner concentration to an acceptable value.

Accordingly, those skilled in the xerographic art have sought to provide an arrangement for automatically monitoring the concentration of toner in a xerographic developer mixture, and utilizing such an arrangement to automatically control the toner concentration by feeding toner to the developer mixture from a suitable motor operated dispenser when required.

One approach which has been suggested for the measurement of toner concentration involves the provision of a photoelectric sensing arrangement to measure the light transmission through the cloud of toner which is generated within the developer tank due to the disturbances which occur when the developer is transported from the tank to be brought into contact with the photoconductive surface. The density of the toner cloud, and therefore the light transmission through the cloud, varies as a function of the concentration of toner in the developer mixture within the developer tank.

It has been found, however, that the required photoelectric light sources and sensors, which must necessarily be in optical communication with the toner cloud, become permanently coated with toner, resulting in a false indication of high toner concentration.

Another approach to the measurement of toner concentration has been to provide sample areas of photoconductive material on the photoconductive surface but outside the area on which the desired image is to be produced. The photoconductive sample area or areas are charged in accordance with a predetermined pattern when the machine is in operation, and toner is deposited on the charged sample areas by bringing a portion of the developer mixture into contact therewith. The density of the toner so deposited on the sample areas is then measured optically, or by any other suitable technique. The measured density of the toner so deposited is presumably a function of the concentration of toner in the developer within the developer tank. Such a sample deposition system has not proven satisfactory, however, in part because (i) the amount of toner deposited on the sample pattern is affected by variations in various machine operating parameters, and (ii) the continuous exposure of the sample area results in fatigue of the photoconductive material therein, characterized by a decrease in photoconductivity, a lower rate of toner deposition for a given toner concentration, and an indication of a lower toner concentration than is actually present in the developer mixture.

An improved version of the technique of "developing" a sample area which has been electrostatically charged involves the provision of an "artificial" electrostatic charge pattern formed by application of a voltage between adjacent conductive electrodes, thus providing a DC electric field therebetween. See, e.g., U.S. Pat. No. 3,430,606. When a portion of the developer mixture is passed over the electrodes, or over an insulating surface adjacent the electrodes, toner particles are caused to deposit on that electrode which has a charge opposite to that of the toner particles. By periodically reversing the polarity of the voltage applied between the electrodes, the toner particles are caused to periodically be repelled by one electrode and attracted by the other. By employing transparent electrodes adjacent a transparent insulator such as glass, and measuring the variation in light transmission through the deposited toner layer, an indication of toner concentration may be provided. Such an arrangement, while workable, requires conductive electrodes, a voltage source of periodically variable polarity and relatively elaborate electronic sensing circuitry.

Still another toner concentration measuring technique is described in U.S. Pat. No. 3,610,205. However, this technique is limited to arrangements wherein the toner and carrier particles have different optical characteristics, and is of limited versatility.

As herein described, there is provided apparatus for measuring the toner concentration in the developer of a xerographic copying apparatus. The measuring apparatus includes a toner collecting plate, and supply means for providing a stream of the developer containing the toner whose concentration is to be measured. The developer stream is directed onto a surface of the collecting plate to cause toner particles to be dislodged from the carrier beads, pellets or granules to which the toner particles are electroscopically adherent to deposit a layer of toner on at least a portion of the collecting plate. The developer stream removes toner from the collecting plate when the concentration of toner in the stream decreases. Means is provided for sensing the amount of toner deposited in the form of the aforementioned layer.

In the drawing:

FIG. 1 shows a conventional xerographic copying apparatus with which the present invention may be employed.

FIG. 2 illustrates, in schematic form, a toner concentration measuring technique according to the prior art.

FIG. 3 is a schematic representation which illustrates the principle of an embodiment of the present invention.

FIG. 4 is a schematic representation which illustrates the principle of an alternative embodiment of the invention.

FIGS. 5 and 6 show graphs useful in explaining the operation of the invention.

FIG. 7 shows graphs useful in explaining the operation of the preferred embodiment of the invention.

FIG. 8 is an elevation view of the developer tank employed in the apparatus of FIG. 1, with a toner concentration analyzing device according to the present invention affixed thereto.

FIG. 9 is a side elevation view, in partial cross-section, of the developer tank arrangement shown in FIG. 8.

FIG. 10 shows a front cross-sectional elevation view of a toner concentration analyzer according to an embodiment of the invention, taken along the cutting plane X-X' as shown in FIG. 8.

FIG. 11 shows a front cross-sectional elevation view of a toner concentration analyzer according to a preferred embodiment of the invention, taken along the cutting plane X-X' as shown in FIG. 8.

FIG. 12 shows a side elevation cross-sectional view of a portion of the toner concentration analyzer shown in FIG. 11, taken along the cutting plane Y-Y'.

FIG. 13 is a block diagram of a toner concentration control system employing the toner concentration analyzer illustrated in FIGS. 11 and 12.

The xerographic copying apparatus 10 shown in FIG. 1, which apparatus is typical of the prior art, comprises a number of operating stations situated about the periphery of a rotatable drum 11. The drum 11 is rotatably mounted on an axle 12, and is continually rotated by a suitable drive motor (not shown) while copies are to be made. The outer surface 13 of the drum 11 is coated with a relatively hard photoconductive material, such as vitreous selenium.

A document 14 bearing an image to be copied is placed (face down) on a curved transparent support plate 15. The image to be copied is then illuminated by a suitable light source (not shown) through the transparent support plate 15, and scanned by a rotatable

mirror 16, which reflects light from the document 14 through a lens 17 and a fixed mirror 18 onto the photoconductive surface 13 of the rotating drum 11, through the exposure slot 19.

The rotation of the scanning mirror 16 is accurately synchronized with the rotation of the drum 11, so that the linear velocity at which the surface of the document 14 is scanned is equal to the linear velocity of the photoconductive layer 13 disposed on the outer periphery of the drum 11.

Prior to exposure to the image information bearing light beam through the aperture 19, the photoconductive surface 13 of the drum 11 is passed under a corona emitter or corotron 20, which charges the photoconductive surface 13 to establish a uniform electrostatic charge density thereon.

Upon passing beneath the masking aperture 19, the charged photoconductive surface 13 is selectively discharged in accordance with the pattern of the image on the document 14 to be copied, resulting in the formation of a latent electrostatic image on at least a portion of the photoconductive surface 13 (the size of the portion of the photoconductive surface which contains the latent electrostatic image is dependent upon the size of the document 14 to be copied).

As the drum 11 continues to rotate, the latent electrostatic image on the photoconductive surface 13 enters the developer tank 21. Situated in the lower portion or sump region of the developer tank 21 is a granular developer mixture 22, which consists of resin coated steel beads and toner powder. The material of the resin coating is removed from the toner powder material in the triboelectric series.

The developer mixture is continually carried from the sump region of the developer tank to a hopper 23 at or near the top of the developer tank by means of a conveyor belt 24 having a plurality of carrier buckets 25 affixed thereto.

As the drum 11 continues to rotate, the developer mixture in the hopper 23 continually flows out the orifice at the bottom of the hopper, and cascades over the photoconductive surface 13 of the drum. As the developer mixture cascades over the photoconductive surface, toner particles are attracted away from the moving carrier beads and adhere to the charged portions of the photoconductive surface, thus converting the latent electrostatic image thereon to a corresponding visible pattern of pigmented or dyed toner particles. The developer mixture (less any toner particles which have adhered to the latent electrostatic image on the photoconductive surface 13 of the drum 11) falls back into the sump of the developer tank 21 after the developer has cascaded over the photoconductive surface 13.

Upon further rotation of the drum 11, the pattern of toner particles (the toner particles being electroscopically adherent to the charged areas of the latent electrostatic image on the photoconductive surface 13) is brought into juxtaposition with a moving paper 26, which is caused to progress at a velocity equal to the peripheral velocity of the drum 11, so that there is substantially to relative motion between the paper 26 and the adjacent portion of the periphery of the drum 11. As the toner pattern (corresponding to the latent electrostatic image which in turn corresponds to the image of the document 14) passes the moving paper 26 in contact therewith, an image transfer corona emitter or corotron 27 attracts the toner particles away from the

photoconductive surface 13 and onto the adjacent portion of the moving paper 26. The toner pattern is thus transferred onto the moving paper 26, and is then passed under a radiant heater or fuser 28 which fuses the toner particle pattern to the paper 26 to form a permanent copy of the image on the document 14.

The paper 26 is moved along beneath the fuser 28 by a moving belt 29.

After the toner pattern has been transferred from the photoconductive surface 13 of the drum 11 onto the paper 26, some residual toner particles remain on the drum surface. In order to remove these residual toner particles, the photoconductive surface 13 is subsequently exposed to a further corona emitting device or corotron 30 which neutralizes any residual charge remaining on the photoconductive surface, thus reducing or cancelling the electrostatic attraction between the residual toner particles and the adjacent photoconductor surface.

A rotating brush 31 situated in a dust-tight compartment 32 mechanically removes any remaining toner particles from the photoconductive surface 13 of the drum 11, the toner particles so removed being drawn out through the conduit 33 by air pressure as a result of the application of a suitable vacuum source (not shown) to the conduit 33. Before the toner-laden air is returned to the atmosphere, it is filtered by suitable means (not shown) to remove the toner particles therefrom.

After the residual toner particles have been removed from the photoconductive surface 13 by the action of the brush 31 and the vacuum source associated therewith, the photoconductive surface 13 is irradiated by light from a suitable light source 34, to insure substantially complete discharge of the photoconductive surface.

Thereafter the corona emitter or corotron 20 recharges the photoconductive surface 13 in a uniform manner in preparation for the next cycle of machine operation.

The developer 22 employed in the apparatus 10 may be of any suitable conventional type. For example, the following composition has been found to provide excellent results:

Carrier: steel beads having an average diameter on the order of 350 to 500 microns, coated with an acrylic or styrene copolymer mixed with a suitable triboelectric activating dye such as Hansa yellow, the weight of the resin coating being on the order of 0.3 percent of the total carrier bead weight.

Toner: a thermoplastic styrene-based resin or copolymer mixed with a suitable pigment such as carbon black.

Toner Concentration: Ratio of toner to developer (toner plus carrier)—0.5 percent by weight.

In order to maintain uniform quality of print produced on the paper 26, the concentration of toner within the developer 22 must maintain with a particular range. As previously mentioned, a number of systems have been proposed for measuring the concentration of toner in the developer mixture 22, and automatically dispensing additional toner into the sump of the developer tank 21 to mix with the developer 22 and maintain the toner concentration therein within the desired range. One such system is illustrated in FIG. 2.

As illustrated schematically in FIG. 2, a glass plate 35 is provided having suitably contoured transparent elec-

trodes 36 and 37 disposed thereon. A variable polarity DC voltage is applied between the electrodes 36 and 37 by means of a suitable voltage source 38, the polarity of the voltage produced by the source 38 being reversed at regular intervals.

A sample of developer from the developer tank 21 is removed therefrom through a suitable conduit and caused to cascade over the glass plate 35 and the electrodes 36 and 37 by a hopper of proper configuration, illustrated schematically as 39. The electric field produced between the electrodes 36 and 37 by the voltage source 38 simulates that of a latent electrostatic image such as is formed on the photoconductive surface 13 of drum 11 during normal operation of the apparatus 10. As developer leaves the hopper 39 and cascades over the electrodes 36 and 37, toner particles are attracted away from the carrier granules to which they are electroscopically adherent, and toward the electrode which at that time has a charge opposite in polarity to that of the toner particles. Presumably, the density of the "image" deposited upon the aforementioned electrode varies in accordance with the concentration of toner in the developer mixture. The resulting variation in light transmission through the transparent plate 35 and the conductive electrodes may then be measured by illumination thereof with a suitable light source 40, while monitoring the transmission therethrough by means of a suitable photosensitive element 41. The output signals developed by the photosensitive element 41, which presumably vary in accordance with the toner concentration in the developer mixture, may then be utilized to control the operation of a toner dispenser to vary the rate at which toner is added to the developer 22 within the developer tank 21.

The aforementioned toner concentration measuring arrangement, as described with reference to FIG. 2, is disclosed in more detail in U.S. Pat. No. 3,430,606.

A disadvantage of the arrangement illustrated in FIG. 2 is the need for providing transparent conductive electrodes, and for biasing these electrodes with a DC voltage of periodically varying polarity. Unless the polarity of the applied voltage is varied at regular intervals, toner continues to accumulate on one of the electrodes, giving a false indication of high toner concentration.

Another disadvantage of the arrangement illustrated in FIG. 2 is the need for relatively elaborate circuitry to process the signal obtained from the photosensitive element 41, which has a generally sawtooth waveform as a result of periodic reversal of the polarity of the voltage generated by the source 38.

In the aforementioned arrangement, as illustrated in FIG. 2 and described in U.S. Pat. No. 3,430,606, developer is cascaded over the plate 35 in relatively turbulence-free fashion. If the electrodes 36 and 37 and the voltage source 38 were not provided, a layer of toner would accumulate on the entire exposed surface of plate 35, the thickness of the toner layer increasing until nearly all the light transmitted through the plate 35 by the light source 40 was blocked. Thus the device shown in FIG. 2 would be useless for providing a measurement of toner concentration without the electrodes 36 and 37 and the source 38.

Another arrangement, disclosed in U.S. Pat. No. 3,610,205, describes a system for determining the toner concentration in the developer of a xerographic copying apparatus in the particular case where the

toner and carrier particles have different optical characteristics. As shown in FIGS. 1 and 6 of this reference, the developer mixture is caused to smoothly slide over the interior surface 36 of a transparent window 35.

Light from a source 37 is transmitted through the window 35 and reflected by the developer mixture. The reflected light is measured by an arrangement comprising the photosensor 40, amplifier 56 and meter 58.

In the aforementioned arrangement, since the toner and carrier particles have different optical qualities, the total amount of light reflected by the developer mixture depends upon the relative proportions of such particles, i.e. on the toner concentration.

In order for the arrangement shown in U.S. Pat. No. 3,610,205 to operate effectively, it is essential that the developer mixture slide across the interior surface 36 of the transparent window 35 in such a manner that deposition of toner on the surface 36 is minimized. The structure according to the present invention, on the other hand, is capable of measuring the toner concentration of developer mixtures in which the toner and carrier particles have the same optical qualities. In the arrangement described in the instant application, the developer mixture is formed into a stream which is caused to impinge upon the transparent collecting plate in order to deposit a toner layer thereon, the optical transmission of the deposited toner layer providing an accurate measure of toner concentration in the developer mixture. According to the instant invention, the developer stream is directed onto the collecting plate with sufficient kinetic energy to dislodge toner particles from the carrier beads to which they are electroscopically adherent. In contradistinction, the dislodging of toner particles from their associated carrier beads is deliberately avoided in the structure of U.S. Pat. No. 3,610,205.

In U.S. Pat. No. 3,610,205, toner concentration is measured by, in effect, determining the relative amounts of light reflected by the carrier and toner particles respectively. On the other hand, the structure herein described determines toner concentration by measuring the optical transmission of a deposited toner layer, the carrier beads flowing across the optical path having an insignificant effect upon this measurement.

Thus, while the arrangement of U.S. Pat. No. 3,610,205 seeks to avoid the deposition of a toner layer on the transparent surface to be optically illuminated, the structure herein described seeks to dislodge toner particles from the associated carrier beads to form a toner layer on the transparent collecting plate, such that the density of the toner layer increases and decreases with corresponding variations in the toner concentration within the developer mixture.

The operation of the toner concentration measuring arrangement according to the present invention is based in part upon the discovery that, by causing the developer mixture to impinge upon a collecting plate with a proper value of kinetic energy and in a substantially turbulent manner, a layer of toner is deposited on a portion of the collecting plate, which layer increases and decreases in thickness or density as the concentration of toner in the developer mixture varies correspondingly.

The principle of operation of the present invention will be more clearly understood by reference to FIGS. 3 and 4, which illustrate a feature of the toner concen-

tration measurement arrangement according to an embodiment of the present invention.

As illustrated in FIG. 3, a developer sample storage hopper 42 contains a sample of developer mixture 43, which has the same toner concentration as the developer mixture 22 within the developer tank 21 (see FIG. 1). An orifice 44 at the bottom of the hopper 42 permits the developer sample 43 to flow from the hopper at a rate limited by the size of the orifice. Situated below the orifice 44 is a transparent collecting plate 45, upon surface 46 of which a stream of developer emanating from the orifice 44 of the hopper 42 is caused to impinge.

A developer stream deflecting member 48, preferably in the form of a suitable shaped conductive plate, is situated in the path of the developer stream 47. The purpose of the deflector plate 48 is to introduce a substantial amount of turbulence into the developer stream 47, and to direct the stream 47 onto the surface 46 of the transparent collecting plate 45.

By properly selecting the size and shape of the orifice 44, the configuration of the deflecting plate 48, the angle of inclination of the collecting plate 45, the relative spacings between the orifice 44 and the portion of the deflecting plate 48 immediately beneath the orifice, the inclination of the deflecting plate 48, and the vertical distance between the point at which the stream 47 impinges upon the collecting plate 45 and the portion of the deflecting plate 48 above said point, the developer stream 47 is caused to impinge upon the surface 46 of the collecting plate 45 with kinetic energy sufficient to dislodge toner particles from the developer carrier beads to which the particles are electroscopically adherent, so that the dislodged toner particles are deposited on at least a portion of the collecting plate 45. At the same time, the kinetic energy and turbulence of the developer stream 47 are sufficient to remove toner particles from the aforementioned collecting plate portion when the concentration of toner in the developer stream 47 decreases.

If the kinetic energy and turbulence of the developer stream 47 are too low, the aforementioned effects will not occur and toner will build up on the collecting plate 45 to give a false indication of high toner concentration. If the kinetic energy of the stream 47 impinging on the collecting plate 45 is too great, damage will result to the triboelectric resin coating on the carrier granules, and the uniformity of the deposited toner layer will be disturbed by splattering effects.

It has not proven possible to specify the required range of kinetic energy and turbulence of the developer stream in terms of specific parameters, since it is difficult if not impossible to measure these quantities. In practice, the apparatus shown in FIG. 3 in schematic form is assembled, and the inclination of the deflector plate 48 is varied until the toner layer deposited on a portion of the surface 46 of the collecting plate 45 exhibits the desired increase and decrease of thickness or density with increase or decrease of toner concentration in the developer sample 43. In order to measure the amount of toner deposited in the form of the aforementioned layer on a portion of the collecting plate 45, a photoelectric system comprising a light source 49 and a photosensitive element 50 is aligned so that light transmitted from the source 49 to the element 50 passes through the portion of the collecting plate 45 upon which is deposited a layer of toner which in-

creases and decreases in thickness or density as the concentration of toner in the developer mixture increases or decreases. The light transmitted through this portion of the collecting plate, as sensed by the photosensitive element 50, is converted to an electrical output signal which is utilized to control a toner dispenser by controlling the operation of a motor which releases toner from the dispenser into the sump of the developer tank 21 when the toner concentration in the developer is low.

Preferably, the deflecting plate 48 is electrically conductive and is grounded to avoid undesirable electrostatic interaction with the developer mixture. Suitable materials for the plate 48 are steel or aluminum.

While the collecting plate 45 may comprise a suitable transparent insulating material such as glass, it is not necessary that the collecting plate 45 be transparent, provided that a suitable technique (such as, e.g. a capacitance measuring arrangement) is employed to measure the amount of toner deposited in the form of the aforementioned layer on a portion of the collecting plate 45. No adverse effects have been detected resulting from the use of a conductive toner collecting surface to receive the toner stream 47, rather than an electrically insulating surface.

In order to provide an accurate measurement of toner concentration, as determined by the light attenuation introduced by the deposited toner layer, it is highly desirable that the light source 49 be of constant intensity, and that the photoelectric system (comprising light source 49 and photosensitive element 50) be arranged in such a manner that toner does not accumulate on the surfaces of the light source and photosensitive element, since such toner accumulation would give a false indication of high toner concentration.

With an arrangement of the general type schematically illustrated in FIG. 3, a dynamic range of light intensity on the order of 90:1 has been obtained. That is, the output signal derived from the photosensitive element 50 has been observed to vary over a 90:1 range as the concentration of toner within the developer mixture 43 was varied from a relatively low (0.4 percent by weight) to a relatively high (0.75 percent by weight) value. With such a dynamic range, variations in the intensity of the light generated by the source 49 on the order of  $\pm 10$  percent can be tolerated without substantially adversely affecting the performance of the concentration measurement system.

Where very great toner concentration measurement accuracy is desired, or where substantial variations in power line voltages are to be expected, the intensity of the light generated by the source 49 may be maintained constant by (i) driving the light source from a regulated power supply, or (ii) employing an additional photosensitive element in conjunction with a feedback control system to continuously monitor the intensity of the light generated by the source 49 and feed back an error signal to maintain the intensity at a desired value.

Alternatively, where it is desired to minimize the effect of variation of the intensity of the light generated by the source 49, the arrangement shown in FIG. 4 may be employed.

The arrangement illustrated schematically in FIG. 4 operates in a generally similar manner to that of FIG. 3, the parts of FIG. 4 which correspond to those of FIG. 3 being identified by the same reference numerals.

In the arrangement of FIG. 4, as in the system illustrated schematically in FIG. 3, a layer of toner is deposited on the surface 46 of the transparent collecting plate 45, which layer varies in thickness or density in accordance with variations in the concentration of toner within the developer mixture 43. The arrangement for sensing the light attenuation of the deposited toner layer differs, however, from that of FIG. 3 in that additional elements are provided, viz. a light splitter 51, a second photosensitive element 52, and a comparator circuit 53. The light splitter 51, which may be in the form of a half-silvered mirror or other conventional optical element, divides the light beam emanating from the source 49 into two portions, one portion being directed through the transparent plate 45 and the other portion being directed to the photosensitive element 52. Preferably, the light from the source 49 is divided into unequal portions by the splitter 51, the portion of greatest intensity being directed toward the transparent collecting plate 45.

The output signals by the photosensitive elements 50 and 52 on lines 54 and 55 respectively, are combined within the comparator 53, which may take the form of a bridge of the general type illustrated in FIG. 6 of the aforementioned U.S. Pat. No. 3,430,606, or alternatively may comprise a differential amplifier for providing an output signal proportional to the difference between the signals on lines 54 and 55. The comparator 53 also includes circuitry for comparing the derived signal, indicative of toner concentration, with a reference signal indicative of a desired toner concentration, and providing a control signal on line 56 to dispense toner to the developer tank 21 at the proper rate, by controlling a suitable toner feed motor coupled to a toner dispenser which is coupled to the developer tank 21.

By use of the arrangement shown in FIG. 4, variations in the intensity of light generated by the source 49 affect the signals on both lines 54 and 55, such effects being substantially cancelled out by the comparator 53.

With the arrangement shown in FIGS. 3 and 4, it has been observed that when a collecting plate 45 which is initially clean (free of toner) is subjected to a developer stream 47, the rate of deposition of a toner layer on the surface 46 of the collecting plate 45 is initially quite rapid, the rate of deposition thereafter tapering off and finally stabilizing, resulting in a substantially constant light attenuation introduced by the deposited toner layer (this light attenuation value remaining substantially constant even though the developer stream 47 continues to flow across the surface 46 of the collecting plate 45), the stabilized light attenuation value corresponding to the concentration of toner within the developer mixture 43 and developer stream 47.

This phenomenon is more clearly illustrated in FIG. 5, which shows the variation in light attenuation introduced by the toner layer deposited on the portion of the collecting plate 45 in the path of the light beam transmitted from the source 49 to the photosensitive element 50, as sensed by the output signal produced by the photosensitive element. In FIG. 5, the variation in light attenuation with time is shown for the case where the developer stream 47 is caused to impinge upon an initially clean collecting plate 45. The curves A, B, and C correspond to results obtained with developer streams having relatively high, moderate and low respective toner concentrations.

From FIG. 5, it is seen that the rate of increase of light attenuation is high for an initial time  $T_1$  (typically on the order of 3 to 10 seconds for a developer flow rate on the order of 2 to 7 grams per second), and thereafter tapers off, eventually approaching a stable equilibrium value at time  $T_s$ , which is typically on the order of 1 to 3 minutes for the aforementioned developer flow rate. The value of light attenuation (and thus of thickness or density of the deposited toner layer) reached at time  $T_1$  is typically on the order of one-half the final value at which the light attenuation stabilizes at time  $T_s$ .

FIG. 6 shows curves similar to those of FIG. 5, for the case in which the developer stream 47 is caused to impinge upon a collecting plate 45 which is initially quite "dirty" i.e. heavily coated with toner. The measured light attenuation (and thus the thickness or density of the deposited toner layer) rapidly decreases for an initial time period  $T_1'$ , the rate of decrease of light attenuation then tapering off, with the light attenuation finally stabilizing at a time  $T_s'$  and at values corresponding substantially to those shown in FIG. 5 for corresponding concentrations of toner in the developer stream 47. The curves A, B, and C of FIG. 6 correspond to toner concentration within the developer stream 47 which are identical to the toner concentrations represented by the corresponding curves A, B, and C of FIG. 5.

Thus the curves shown in FIGS. 5 and 6 indicate that, for a given concentration of toner within the developer stream 47, the light attenuation introduced by the deposited toner layer, as measured by the photosensitive element 50, stabilizes at a substantially constant value which is relatively independent of the amount of toner initially present on the collector plate 45 before the developer stream 47 is caused to impinge thereon. Generally speaking, it has been found that the value at which the measured light attenuation stabilizes is in all cases an accurate measure of toner concentration.

While the reasons for the phenomena discussed above in connection with FIGS. 3-6 are not thoroughly understood, it is believed that the developer stream 47 continually deposits toner particles on the collector plate 45 and "cleans" toner particles from the collecting plate, thus establishing a dynamic equilibrium at a toner layer thickness or density corresponding to the toner concentration within the developer stream 47. It has been found that, when the developer stream 47 is caused to cascade over the surface 46 of the collecting plate 45 in a substantially non-turbulent fashion (as in the case of the structure illustrated in FIG. 3 of the aforementioned U.S. Pat. No. 3,430,606) curves generally similar to those of FIG. 5 (but differing somewhat in shape) are obtained, but the "cleaning" phenomenon illustrated by the curves of FIG. 6 does not occur. However, when the deflecting member 48 of the proper configuration is provided, and the distances between the various elements shown in FIG. 3 as well as the orientations of said elements are properly selected, as previously described, so as to impart sufficient kinetic energy and turbulence to the developer stream 47, the curves illustrated in FIGS. 5 and 6 are obtained. With such an arrangement, it has been found that the stabilized value of light attenuation, as measured by the photosensitive element 50, accurately "tracks" increases and decreases in toner concentration within the developer stream 47.

One of the practical difficulties encountered in attempting to obtain a high level of performance from the arrangement shown schematically in FIGS. 3 and 4, and a difficulty also inherent in the arrangement shown in U.S. Pat. No. 3,430,606, results from the fact that the developer stream, which contains opaque carrier beads as well as toner particles, is at all times flowing past the photoelectric sensing system, thus introducing undesirable background noise.

An experiment was undertaken to periodically interrupt the flow of the developer stream 47, and measure the light attenuation introduced by the deposited toner layer only during those periods when developer was not flowing across the surface 46 of the collecting plate 45. When this was done, a rather unexpected and surprising result was obtained, this result best being illustrated by the curves shown in FIG. 7.

The various curves shown in FIGS. 7a-7d are drawn to a common time base, and are vertically aligned.

FIG. 7a illustrates the manner in which the developer stream 47 is turned on and off on a periodic basis. It has been found advantageous to periodically turn the developer stream on for a time  $t_{on}$  on the order of 1 to 3 seconds, with the developer flow being turned off for time periods  $t_{off}$  on the order of 3 to 7 seconds, the period  $t_{rec}$  between recurrences of developer flow being on the order of 4 to 10 seconds.

FIG. 7b illustrates the manner in which the measured light attenuation (caused by the deposited toner layer on the collecting plate 45) would ordinarily be expected to vary with time, when flow of the developer stream 47 is periodically interrupted in the manner shown in FIG. 7a. The curves shown in FIG. 7b correspond to those shown in FIG. 5 for the case where flow of the developer stream 47 is continuous, the developer stream flow rates being essentially the same.

As shown in FIG. 7b, one would ordinarily expect the light attenuation to increase by small increments during successive periods of developer flow, and to remain constant during the periods between, when developer is not impinging on the surface 46 of the collecting plate 45. One would also expect the light attenuation to ultimately stabilize at a value substantially equal to that shown in FIG. 5.

Rather surprisingly, the actual light attenuation curves obtained, as shown in FIG. 7c, differ quite markedly from the theoretical curves shown in FIG. 7b. The solid curves of FIG. 7c correspond to the case where a developer stream 47 is caused to periodically impinge upon an initially clean collecting plate 45, while the dashed curves correspond to the case where the developer stream 47 is caused to periodically impinge upon an initially dirty collecting plate 45. The curves, A, B, and C of FIG. 7c correspond to developer streams having toner concentrations identical to those represented by the corresponding curves of FIGS. 5, 6 and 7b.

As seen in FIG. 7c, the measured light attenuation, instead of gradually ascending to the value represented by the corresponding curve of FIG. 5 or FIG. 6 for the case of a continuous developer stream, rapidly rises to, and stabilizes at a light attenuation level somewhat below the stabilized level reached when a continuous developer stream is employed. While for the sake of simplicity the curves shown in FIG. 7c illustrate stabilization of the measured light attenuation at a time  $T_a$  which corresponds to a single developer flow interval (see FIG. 7a), in practice it has been found that, for de-

veloper flow intervals on the order of 1 to 3 seconds, at a flow rate on the order of 2 to 7 grams per second (3 grams per second being typical) with the period between recurrences being on the order of 4 to 10 seconds, several developer flow intervals are required for stabilization of the measured light attenuation, the stabilization time  $T_a$  being on the order of 15 to 20 seconds for these parameters.

Thus it has been found that, with intermittent developer flow as described above in connection with FIGS. 7a to 7c, a stabilized light attenuation reading which provides an accurate indication of the toner concentration within the developer stream can be obtained (starting with a very clean or very dirty collecting plate 45) in much less time (15 to 20 seconds) than is required for the case where a continuous developer stream is employed (1 to 3 minutes). Actually, the performance of the intermittent developer flow arrangement is even better than the aforementioned Figures would indicate, since in practice the concentration of toner in the developer stream varies at a relatively slow rate, so that the intermittent developer flow measurement arrangement described above provides very rapid response in normal machine operation.

Another advantage of the intermittent flow arrangement is that such an arrangement permits the light attenuation to be measured, if desired, only during those periods when developer is not flowing onto the collecting plate, thus eliminating the spurious background noise effects caused by interruption of the light beam by the developer carrier beads.

FIG. 7d illustrates the manner in which light attenuation is measured, the periods of measurement occurring between the periods of developer flow (see FIG. 7a which is vertically aligned with FIG. 7d) and being indicated by the numerals 57. It has been found that initial transients in developer flow due to start-up of the apparatus 10, and to initial disturbances within the developer tank 21, result in spurious light attenuation measurements during an initial period of a few seconds after the apparatus 10 is turned on, and the drum 11 and developer carrier belt 24 begin to move. Accordingly, as shown in FIG. 7d, measurement of light attenuation is inhibited for an initial period D which may typically be on the order of 3 seconds.

FIG. 8 illustrates a practical system, utilizing the principles previously described, for measuring and controlling the concentration of toner in the developer mixture situated within the sump of the developer tank 21 (see FIG. 1).

Affixed to the developer tank 21, as shown in FIG. 8, is a toner dispenser 58. Situated within the toner dispenser 58 is a rotatable shaft 59 which may be rotated by a toner dispenser motor 60. Secured to the shaft 59 and disposed within the housing of the toner dispenser 58 are a plurality of fingers for transferring toner from the dispenser 58 to the sump of the developer tank 21, and a cam which drives an agitating member to allow toner to be transferred from the dispenser 58 to the sump of the developer tank 21 whenever the toner feed motor 60 rotates the shaft 59. The aforementioned structural elements of the toner dispenser 58 are not shown in detail in FIG. 8.

Secured to a side wall of the developer tank 21 by means of a bracket 61 is a toner concentration analyzing device 62, which incorporates the elements indicated schematically in FIGS. 3 and 4.

The developer whose toner concentration is to be analyzed is transferred from the hopper of the developer tank 21 to the toner concentration analyzer 62 by means of a supply conduit 63, this developer sample being returned to the sump of the developer tank 21 by means of the return conduit 64. The toner concentration analyzer 62, and the supply and return conduits 63 and 64, are situated in such a manner that developer flows through these elements by gravity, no additional active elements being required to provide the desired developer flow through the analyzer 62.

As shown in FIG. 9, the supply tube 63 has an open upper end 65 positioned within the hopper 23 below the normal level of developer in said hopper. The size of the supply tube 63 is chosen to be sufficiently large to provide reliable nonclogging flow of developer therethrough, while being sufficiently small so that the normal operation of the apparatus 10 is not disturbed thereby.

The toner concentration analyzer 62 shown in FIGS. 8 and 9 may be of the continuous flow type shown in FIG. 10, comprising a metallic housing 66, preferably of aluminum, having an upper aperture 103 therein through which developer is transferred from the supply conduit 63 to provide a supply sample 43 in the developer supply sample storage hopper 42a. A lower aperture 74 permits developer to leave the analyzer 62 to be returned to the sump of the developer tank 21 by the return conduit 64. The hopper 42a is preferably constructed of aluminum, is of generally pyramidal or conical cross-section, and is secured at its upper end to the interior wall of the housing 66.

An orifice 44 at the bottom of the hopper 42a permits the developer sample 43 to flow therethrough, and to be deflected by the developer stream deflecting member 48a, which is preferably electrically conductive and constructed of a suitable metal such as steel or aluminum.

The orifice 44 is preferably of rectangular cross-section, measuring  $\frac{1}{8} \times \frac{1}{4}$  inch. The deflecting member 48a is preferably shaped in the form of an inverted V, with the apex thereof situated directly below the orifice 44 and spaced therefrom by a vertical distance equal to three-sixteenths inch. The angle  $d$  which each outer surface of the deflecting member 48a makes with the vertical is preferably on the order of 30 degrees.

The cross-sectional area of the orifice 44 is preferably small compared to that of the supply conduit 63, so that a developer supply sample accumulates in the hopper 42a and the rate of flow of developer from the hopper 42a is limited by the size of the orifice 44.

Situated below and adjacent to the deflecting member 48a (which is secured at its opposite ends to the housing 66 and electrically grounded) are a pair of baffles 67 and 68, each baffle having an inclined upper portion and a vertically oriented lower portion.

Preferably, the upper inclined portions of the baffles 67 and 68 are arranged so that the normals to the inclined surfaces are oriented at an angle of  $30^\circ$  to  $75^\circ$  with respect to the vertical, an angle of 60 degrees being preferred. This angle is the same as the angle  $c$  which the inclined upper portion of each baffle makes with the horizontal.

The vertically oriented lower portions of the baffles 67 and 68 are spaced in close proximity to one another, to form a channel therebetween which communicates with the return conduit 64. An additional baffle mem-

ber, not shown in FIG. 10, is situated between the vertically oriented lower portions of the baffles 67 and 68 and inclined in a direction perpendicular to the drawing, this additional baffle cooperating with the vertically oriented lower portions of the baffles 67 and 68 to form a funnel for guiding developer emanating from the orifice 44 into the return conduit 64.

Apertures 69 and 70 are formed in the inclined upper portions of the baffles 67 and 68 respectively, adjacent the vertically oriented lower portions thereof. Transparent collecting plates 45a and 45b, preferably of glass, are secured to the upper inclined portions of the baffles 67 and 68 adjacent the apertures 69 and 70 respectively.

The baffles 67 and 68 are secured to the housing 66 in a substantially dust-tight manner, the collecting plates 45a and 45b being similarly secured to the corresponding baffles, so that the baffle 67 and collecting plate 45a cooperate with the adjacent portion of the housing 66 to form a dust-tight enclosure 71, while the baffle 68 and collecting plate 45b cooperate with the adjacent portion of the housing 66 to form a second dust-tight enclosure 72.

A light source 49a, which may for example be an incandescent lamp or a light emitting semiconductor diode, is situated within the enclosure 71 and oriented to project a beam of light through the aperture 69, collecting plates 45a and 45b, and the aperture 70 to illuminate the photosensitive element 50a with light which varies in intensity in accordance with the amount of toner deposited in the form of a layer on those portions of the collecting plates 45a and 45b which are in the path of the light beam.

The photosensitive element 50a, which may for example comprise a suitable phototransistor, is secured to a block of insulating material 73, which in turn is secured to the upper inclined portion of the baffle 68 adjacent the aperture 70 therein. The insulating block 73 is provided with a hole therethrough which permits light from the source 49a to reach the phototransistor or other photosensitive element 50a.

In operation, whenever there is developer in the hopper 23 of the developer tank 21, a sample of such developer is transported to the hopper 42a by the supply conduit 63. The developer sample 43 flows out the bottom of the hopper 42a through the orifice 44 therein, the rate of flow of developer being determined primarily by the orifice size.

The stream of developer flowing through the orifice 44 strikes the deflecting member 48a, which introduces a substantial amount of turbulence into the developer stream and divides the stream into two streamlets. Each streamlet formed by the deflecting member 48a impinges upon a corresponding one of the collecting plates 45a and 45b. Preferably, the vertical distance the point at which each streamlet impinges upon one of the collecting plates and the point on the deflecting member 48a above the point of impingement is on the order of 0.25 inch.

As the developer streamlets impinge upon and flow across the collecting plates 45a and 45b, the amount of deposited toner increases or decreases in accordance with variations in the concentration of toner in the streamlets, which concentration is substantially equal to the concentration of toner in the developer sample 43, in the developer within the hopper 23, and in the developer 22 within the sump of the developer tank 21.

Thus the signal derived at the output of the photo-transistor or other photosensitive element 54 varies in accordance with variations in the concentration of toner in sump of the developer tank 21.

Since the toner concentration analyzer 62 provides measure of the concentration of toner within the developer stream emanating from the orifice 44, a substantial time lag may result, when the hopper 42a is fully or nearly full, before the analyzer 62 provides an indication of change in the concentration of toner entering the hopper 42a through the supply conduit 63. In order to reduce this time lag, a suitable bypass conduit (not shown in FIG. 10) may be provided to continually remove a portion of the developer 43 from the lower portion of the hopper 42a, and to return the developer so removed directly to the sump of the developer tank 21 without causing such developer to flow across or impinge upon the collecting plates 45a and 45b.

An alternative form of toner concentration analyzer, which operates on the periodically interrupted flow basis previously discussed in connection with FIG. 7, is shown in FIGS. 11 and 12.

As shown in FIG. 11, the toner concentration analyzer 62a incorporates a toner sample supply valve 75 in the upper portion of the body thereof. The toner sample supply valve 75 includes a valve body 76 which is secured to the housing 66a of the concentration analyzer 62a (the valve body 76 forming a part of the analyzer housing), a rotatable vane 77 mounted for rotation on a shaft 78, a valve drive motor 79 for continually rotating the shaft 78 (the vane 77 being affixed to the shaft 78), and a valve position switch 80 including a switching element 81 and a cam 82 affixed to the shaft 78 for providing a gating signal responsive to the angular position of the vane 77, said gating signal indicating the times at which the position of the vane 77 is such that developer is not permitted to flow through the orifices 44a.

The valve body 76 is provided with a cylindrical chamber 83 within which the vane 77 rotates. Developer from the supply conduit 63 enters the chamber 83 through an aperture 103 in the valve body 76 communicating therewith.

During those periods when the vane 77 is oriented so that developer may flow through the orifices 44a, the developer streams leaving the orifices 44a are deflected by the inclined developer stream deflecting plate 48b (which is preferably electrically conductive and grounded, steel and aluminum being preferred for the plate material) onto the exposed surfaces of the glass collecting plates 45a and 45b.

The arrangement and operation of the remaining elements of the toner concentration analyzer 62a is similar to that of the corresponding elements of the analyzer 62 shown in FIG. 10, corresponding parts being identified by the same reference numerals.

The shaft 78, to which the vane 77 and cam 82 are affixed, extends into the valve chamber 83 through an aperture therein, in which a shaft support bearing 84 is provided. An end thrust bearing 85 is provided to support the end of the shaft 78 which is remote from the valve drive motor 79.

The orifices 44a communicate with the valve chamber 83 through holes 86 (see FIG. 12) in the valve body 76.

A bypass tube 87 communicates with the valve chamber 83 through a hole 88 in the valve body, the lower

end of the bypass tube 87 being disposed near the top of and closely adjacent to the channel defined by the lower vertically oriented portions of the baffles 67 and 68. The inner diameter of the bypass tube 87, and the size of the hole 88 are selected so as to continually remove a portion of the developer situated within the cavity 83, to insure that the developer streams emanating from the orifices 44a and deflected by the deflecting member 48b to impinge upon the collecting plates 45a and 45b are at all times an up-to-date sample of the developer 22 within the sump of the developer tank 21, i.e. to insure that the concentration of toner in the streams impinging upon the collecting plates is substantially the same as the concentration of toner in the developer situated within the sump of the developer tank 21.

As seen in FIG. 12, the inclined developer stream deflecting member 48b is secured to the valve body 76 at the upper end of the deflecting member by means of screws 89. The deflecting member 48b may be bent to change its angle of inclination and to thereby vary the manner in which the developer streams deflected thereby are perturbed, so as to provide the proper variation of thickness or density of the deposited toner layer on the collecting plates 45a and 45b with increase or decrease of toner concentration in the developer streams.

As shown in FIG. 12, the rotating valve element comprises the vane 77, which is preferably made of steel, and a mass of polyurethane foam 90 bonded thereto. The width of the vane 77 is sufficiently less than the diameter of the chamber 83 so that developer carrier beads do not bind between the edges of the vane 77 and the walls of the chamber 83. The mass of polyurethane foam 90 is in low friction contact with the chamber walls, and serves to preclude leakage of developer or toner through the clearance space between the edges of the vane 77 and the walls of the chamber 83.

As the valve element (consisting of the vane 77 and the polyurethane mass 90) rotated, it alternately (i) permits developer from the supply conduit 63 to enter the valve chamber 83, (ii) permits a portion of the developer within the chamber 83 to exit via the hole 88 and bypass tube 87, and (iii) permits developer within the chamber 83 to exit through the holes 86 in the form of streams which are deflected by the deflecting member 48b onto the collecting plates 45a and 45b.

Suitable circuitry for utilizing the toner concentration analyzer 62a, as shown in FIGS. 11 and 12, to control the toner concentration of the developer 22 within the developer tank 21, is illustrated in FIG. 13.

The dashed lines in FIG. 13 indicate mechanical connections and developer flow, whereas the solid lines indicate electrical connections.

As previously described, upon application of electric power thereto, the toner feed motor 60, which is mechanically connected to the toner feeder or dispenser 58, commences to rotate, causing the dispenser 58 to release toner into the sump of the developer tank 21. A sample of the developer within the hopper 23 of the developer tank 21 is caused to periodically flow across the toner collector plates 45a and 45b, developer flow across the collector plates being periodically interrupted by the toner sampling valve 75. Developer removed from the hopper 23 by the supply conduit 63 is returned to the sump of the developer tank 21 by the

sample bypass tube 87 and the developer sample return conduit 64.

The rotary vane 77 of the valve 75 (and the urethane mass 90 bonded to the vane 77) is continually rotated by the toner sampling valve drive motor 79, to which is mechanically coupled a valve position switch 80. The electrical output signal of the valve position switch 80, which indicates when the vane position is such that developer is not permitted to flow through the orifices 44a and across the collecting plates 45a and 45b, is connected to a logical AND circuit 91.

A machine "on" switch 92, which provides a signal when the apparatus 10 is in operation, is coupled to the logical AND gate 91 through a delay circuit 93, which may typically introduce a delay D on the order of 3 seconds.

The resultant signal output of the logical AND circuit 91 on line 94 indicates when a reliable indication of toner concentration is provided by measurement of the light attenuation introduced by the toner layers on the portions of the collecting plates 45a and 45b which are in the path of the light beam transmitted from the light source 49a to the phototransistor or other photosensitive element 50a. The sampling signal on line 94 has the waveform shown in FIG. 7d.

A toner concentration signal determined by the photocurrent through the phototransistor 50a is provided to differential amplifier 95 on line 96.

A reference voltage indicative of a desired toner concentration is provided to an oppositely poled input terminal of differential amplifier 95 by the toner ratio selector 97, the output voltage of differential amplifier 95 on line 98 having a relatively high or low value, depending upon whether the measured toner concentration, as indicated by the toner concentration signal on line 96, is above or below the desired toner concentration as set by the toner ratio selector switch 97. Since the internal gain of the differential amplifier 95 is quite high, the toner concentration correction signal appearing on line 98 is essentially two-valued, i.e. high or low depending upon the polarity of the voltage difference between the signal on line 96 and the signal provided to the differential amplifier 95 by the toner ratio selector switch 97. If desired, the response sensitivity of the differential amplifier 95 may be further enhanced by providing positive feedback from the output line 98 to vary the signal provided to the input of the differential amplifier 95 on line 99 by the toner ratio selector switch 97.

The sampling signal on line 94 (see FIG. 7d) controls the gate 100 to couple the concentration correction signal on line 98 to a bistable memory 101, which stores the concentration correction signal during the period between reliable measurements thereof, the concentration correction signal on line 98 being permitted to update the memory 101 whenever the sampling signal on line 94 indicates that the concentration correction signal is a reliable measure of the concentration of toner within the developer tank 21.

The output of bistable memory 101, which may be a set-reset bistable multivibrator or other conventional circuit, is employed to control a power distribution gate 102, which provides electric power to the toner feed motor 60 whenever the content of the bistable memory indicates that the concentration of toner within the developer tank 21 is lower than the desired value. When the content of bistable memory 101 indicates that the

concentration of toner within the developer tank 21 is greater than the desired value, the gate 102 is disabled, disconnecting power from the toner feed motor 60, and allowing toner to be depleted from the developer tank 21 as copies are produced by the apparatus 10, until such time as the content of bistable memory 101 again indicates that the concentration of toner in the developer within the developer tank 21 has dropped below the desired value. In this manner, the toner concentration in the developer 22 situated within the sump of the developer tank 21 is continuously and automatically controlled within close limits.

It is claimed:

1. Apparatus for controlling the toner concentration in the developer of a xerographic copying apparatus, comprising:

- a toner collecting plate;
- supply means for periodically providing a stream of said developer, said supply means including a developer sample chamber, and an orifice communicating with said chamber for limiting the rate of flow of the developer in said stream;
- a supply conduit for transporting said developer to said chamber from the developer tank of said copying apparatus;
- a valve element comprising a rotatable vane within said chamber for permitting developer to enter said chamber from said supply conduit during a first recurrent time interval and for permitting developer to leave said chamber through said orifice during a second recurrent time interval;
- a valve drive motor for rotating said vane;
- means for directing said periodic stream onto a surface of said collecting plate to (i) cause toner particles to be dislodged from the developer carrier granules to which the particles are electroscopically adherent to deposit a layer of toner on at least a portion of said collecting plate and (ii) remove toner from said collecting plate portion when the concentration of toner in said periodic stream decreases;
- means for sensing the amount of toner deposited in the form of said layer on said collecting plate portion during intervals when said stream is not impinging on said collecting plate; and
- control means coupled to said sensing means for varying the concentration of toner in the developer within said tank in accordance with the amount of toner deposited in the form of said layer on said collecting plate portion.

2. Apparatus according to claim 1, further including means for deriving a toner concentration signal from said sensing means, said control means including (i) means for comparing said toner concentration signal with a reference signal indicative of a desired toner concentration to generate a concentration correction signal, (ii) a memory, (iii) gating means for coupling said concentration correction signal to said memory at times other than those corresponding to each said second recurrent time interval, and (iv) toner dispensing means for varying the supply of toner to the developer within said tank in accordance with the content of said memory.

3. Apparatus according to claim 2, further including signal delay means for inhibiting the operation of said gating means to prevent coupling of said concentration correction signal to said memory for a predetermined

initial period after operation of the copying apparatus is initiated.

4. Apparatus for controlling the toner concentration of the developer in the developer tank of a xerographic copying apparatus, comprising:

a developer sample chamber;

a supply conduit for transporting a portion of the developer in said tank to said chamber;

at least two orifices communicating with said chamber;

a valve in said chamber for periodically permitting developer in said chamber to flow through said orifices in streams;

at least one developer stream deflecting element situated below said orifices for disrupting the flow of developer in said streams;

first and second inclined light transmissive toner collecting plates situated in the paths of respective ones of said streams;

the vertical distances between said orifices and said deflecting element, the orientation and shape of said deflecting element, and the vertical distance between the portion of said deflecting element which contacts said streams and the portions of said collecting plates which contact said streams being selected to cause said streams to impinge upon said collecting plate portions with kinetic energy sufficient to dislodge toner particles from the developer carrier beads to which the particles are electroscopically adherent, said dislodged toner particles being deposited upon said collecting plate portions, the kinetic energy and turbulence of said developer streams being sufficient to remove toner particles from said collecting plate portions when the concentration of toner in said streams decreases, said kinetic energy being sufficiently low so that the developer is not damaged by impact with said collecting plates;

at least one light source for illuminating said collecting plate portions;

a photosensitive element for generating a toner concentration signal responsive to the light from said source which is transmitted through said collecting plate portions;

control means coupled to said photosensitive element for varying the concentration of toner in the developer within said tank in accordance with said toner concentration signal;

gating means coupled to said valve for preventing utilization of said toner concentration signal by said control means when said developer streams are flowing through said orifices to impinge upon said collecting plates; and

conduit means for returning the developer in said streams to said tank after the streams have impinged on said collecting plates.

5. Apparatus according to claim 4, wherein said collecting plates are disposed below said deflecting element and the normals to said plates are inclined at an angle on the order of 30° to 75° with respect to the vertical.

6. Apparatus according to claim 5, wherein said angles are on the order of 60°.

7. Apparatus according to claim 5, wherein the vertical distances between said orifices and the adjacent portions of said deflecting element directly beneath said orifices are on the order of three-sixteenth inch.

8. Apparatus according to claim 7, wherein the vertical distances between said collecting plate portions and the parts of said deflecting element above said plate portions are on the order of 0.25 inch.

9. Apparatus according to claim 4, further including a bypass conduit for returning a portion of any developer in said chamber to said developer tank without permitting said developer portion to impinge on said collecting plates, said developer portion being returned at a sufficient rate to insure that the concentration of toner in the developer within said chamber is at all times substantially equal to the concentration of toner in the developer within said tank.

10. Apparatus according to claim 9, wherein said light source and said photosensitive element are situated in dust-free compartments.

11. Apparatus according to claim 10, wherein the carrier beads of said developer comprise steel pellets having a coating thereon of a material removed from the material of said toner in the triboelectric series.

12. Apparatus according to claim 11, wherein said deflecting element is electrically conductive.

13. Apparatus according to claim 12, wherein said deflecting element is grounded.

14. Apparatus according to claim 12, wherein said deflecting element comprises aluminum.

15. Apparatus for controlling the toner concentration of the developer in the developer tank of a xerographic copying apparatus, comprising:

a toner collecting plate;

flow control supply means including a periodically operated valve assembly for providing a stream of said developer only at recurrent periodic intervals; means for directing said periodic stream onto a surface of said collecting plate to (i) cause toner particles to be dislodged from the developer carrier granules to which the particles are electroscopically adherent to deposit a layer of toner on at least a portion of said collecting plate and (ii) remove toner from said collecting plate portion when the concentration of toner in said periodic stream decreases;

means for sensing the amount of toner deposited in the form of said layer on said collecting plate portion, said sensing means including gating means coupled to said valve assembly for rendering said sensing means operative only at times between said intervals when said stream is not impinging on said collecting plate; and

control means coupled to said sensing means for varying the concentration of toner in the developer within said tank in accordance with the amount of toner deposited in the form of said layer on said collecting plate portion.

16. Apparatus according to claim 15, further including means for introducing a substantial amount of turbulence into said periodic stream.

17. Apparatus according to claim 16, wherein the kinetic energy of said stream is sufficiently low so that the developer in said stream is not damaged by impact with said collecting plate.

18. Apparatus according to claim 15, wherein said toner collecting plate is light transmissive and said sensing means includes a light source for illuminating said collecting plate and a photosensitive element for detecting the light transmitted through said plate by said source.

19. Apparatus according to claim 18, wherein said light source and photosensitive element are situated in first and second respective dust-free housings.

20. Apparatus according to claim 15, wherein said supply means includes an orifice for limiting the rate of flow of the developer in said stream.

21. Apparatus according to claim 20, wherein said supply means includes a developer sample chamber, said orifice communicating with said chamber.

22. Apparatus according to claim 21, further including a supply conduit for transporting said developer to said chamber.

23. Apparatus according to claim 22, further comprising a valve element within said chamber for permitting developer to enter said chamber from said supply conduit during a first recurrent time interval and for permitting developer to leave said chamber through said orifice during a second recurrent time interval.

24. Apparatus according to claim 20, further including a developer stream deflecting member disposed below said orifice for introducing a substantial amount of turbulence into said stream.

25. Apparatus according to claim 24, wherein the normal to the collecting plate is inclined at an angle on the order of 30 to 75 degrees with respect to the vertical.

26. Apparatus according to claim 25, wherein said angle is on the order of 60°.

27. Apparatus for controlling the toner concentration of the developer in the developer tank of a xerographic copying apparatus, comprising:

a developer sample chamber;

a supply conduit for transporting a portion of the developer in said tank to said chamber;

at least two orifices communicating with said chamber;

a valve in said chamber for periodically permitting developer in said chamber to flow through said orifices in streams;

at least one developer stream deflecting element situated below said orifices for disrupting the flow of developer in said streams;

first and second inclined light transmissive toner collecting plates situated in the paths of respective ones of said streams;

the vertical distances between said orifices and said deflecting element, the orientation and shape of said deflecting element, and the vertical distance between the portion of said deflecting element which contacts said streams and the portions of said collecting plates which contact said streams being selected to cause said streams to impinge upon said collecting plate portions with kinetic energy sufficient to dislodge toner particles from the developer carrier beads to which the particles are electroscopically adherent, said dislodged toner particles being deposited upon said collecting plate portions, the kinetic energy and turbulence of said developer streams being sufficient to remove toner particles from said collecting plate portions when the concentration of toner in said streams decreases, said kinetic energy being sufficiently low so that the developer is not damaged by impact with said collecting plates;

at least one light source for illuminating said collecting plate portions;

a photosensitive element for generating a toner concentration signal responsive to the light from said source which is transmitted through said collecting plate portions;

means coupled to said photosensitive element for varying the concentration of toner in the developer within said tank in accordance with said toner concentration signal, said concentration varying means including (i) means for comparing said toner concentration signal with a reference signal indicative of a desired toner concentration to generate a concentration correction signal, (ii) a memory, (iii) gating means for coupling said concentration correction signal to said memory at times other than those corresponding to the times when developer is flowing through said orifices, and (iv) toner dispensing means for varying the supply of toner to the developer within said tank in accordance with the content of said memory; and

conduit means for returning the developer in said streams to said tank after the streams have impinged on said collecting plates.

28. Apparatus according to claim 27, further including signal delay means for inhibiting the operation of said gating means to prevent coupling of said concentration correction signal to said memory for a predetermined initial period after operation of the copying apparatus is initiated.

29. Apparatus for controlling the toner concentration in the developer of a xerographic copying apparatus, comprising:

a toner collecting plate;

flow control supply means for providing a stream of said developer only at recurrent periodic intervals;

means for directing said periodic stream onto a surface of said collecting plate to (i) cause toner particles to be dislodged from the developer carrier granules to which the particles are electroscopically adherent to deposit a layer of toner on at least a portion of said collecting plate and (ii) remove toner from said collecting plate portion when the concentration of toner in said periodic stream decreases;

means for sensing the amount of toner deposited in the form of said layer on said collecting plate portion, said sensing means being operative only at times between said intervals when said stream is not impinging on said collecting plate;

means for deriving a toner concentration signal from said sensing means; and

control means for varying the concentration of toner in the developer within said tank in accordance with said toner concentration signal, said control means including (i) means for comparing said toner concentration signal with a reference signal indicative of a desired toner concentration to generate a concentration correction signal, (ii) a memory, (iii) gating means for coupling said concentration correction signal to said memory at times other than those corresponding to each of said recurrent periodic intervals, and (iv) toner dispensing means for varying the supply of toner to the developer within said tank in accordance with the content of said memory.

30. Apparatus according to claim 29, further including signal delay means for inhibiting the operation of said gating means to prevent coupling of said concen-

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tration correction signal to said memory for a predetermined initial period after operation of the copying apparatus is initiated.

31. Apparatus for controlling the toner concentration in the developer of a xerographic copying apparatus, comprising:

a toner collecting plate;

flow control supply means for providing a stream of said developer only at recurrent periodic intervals, said supply means including (i) a developer sample chamber and (ii) an orifice communicating with said chamber for limiting the rate of flow of the developer in said stream;

a supply conduit for transporting said developer to said chamber;

a valve element comprising a rotatable vane within said chamber for permitting developer to enter said chamber from said supply conduit during a first recurrent time interval and for permitting developer to leave said chamber through said orifice during a second recurrent time interval;

a valve drive motor for rotating said vane;

means for directing the periodic stream leaving said chamber onto a surface of said collecting plate to (i) cause toner particles to be dislodged from the developer carrier granules to which the particles are electroscopically adherent to deposit a layer of toner on at least a portion of said collecting plate and (ii) remove toner from said collecting plate portion when the concentration of toner in said periodic stream decreases;

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means for sensing the amount of toner deposited in the form of said layer on said collecting plate portion, said sensing means being operative only at times between said intervals when said stream is not impinging on said collecting plate;

means for deriving a toner concentration signal from said sensing means; and

control means for varying the concentration of toner in the developer within said apparatus in accordance with said toner concentration signal, said control means including (i) means for comparing said toner concentration signal with a reference signal indicative of a desired toner concentration to generate a concentration correction signal, (ii) a memory, (iii) gating means for coupling said concentration correction signal to said memory at times other than those corresponding to each said second recurrent time interval, and (iv) toner dispensing means for varying the supply of toner to the developer within said apparatus in accordance with the content of said memory.

32. Apparatus according to claim 31, further including means responsive to the angular position of said vane for generating a gating signal at times other than those corresponding to each said second recurrent time interval.

33. Apparatus according to claim 32, wherein said second recurrent time interval is on the order of 1 to 3 seconds, the period between recurrences of said second interval being on the order of 4 to 10 seconds.

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