United States Patent [19]

Powell et al.

[11] **3,876,106**

[45] **Apr. 8, 1975**

[54] **TONER CONCENTRATION MONITORING APPARATUS UTILIZING PROGRAMMABLE DIGITAL COMPUTER**

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[73] Assignee: **Eastman Kodak Company,** Rochester, N.Y.

[22] Filed: **Oct. 1, 1973**

[21] Appl. No.: **402,222**

[52] **U.S. Cl.** **222/57;** 222/DIG. 1; 118/637

[51] **Int. Cl.** **B67d 5/56**

[58] **Field of Search** .... 222/57, 76, DIG. 1; 340/347 AD; 118/637

[56] **References Cited**

UNITED STATES PATENTS

3,742,489	6/1973	Lefevre et al.	340/347 AD
3,777,173	12/1973	Landrith	222/DIG. 1

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Assistant Examiner—Hadd Lane
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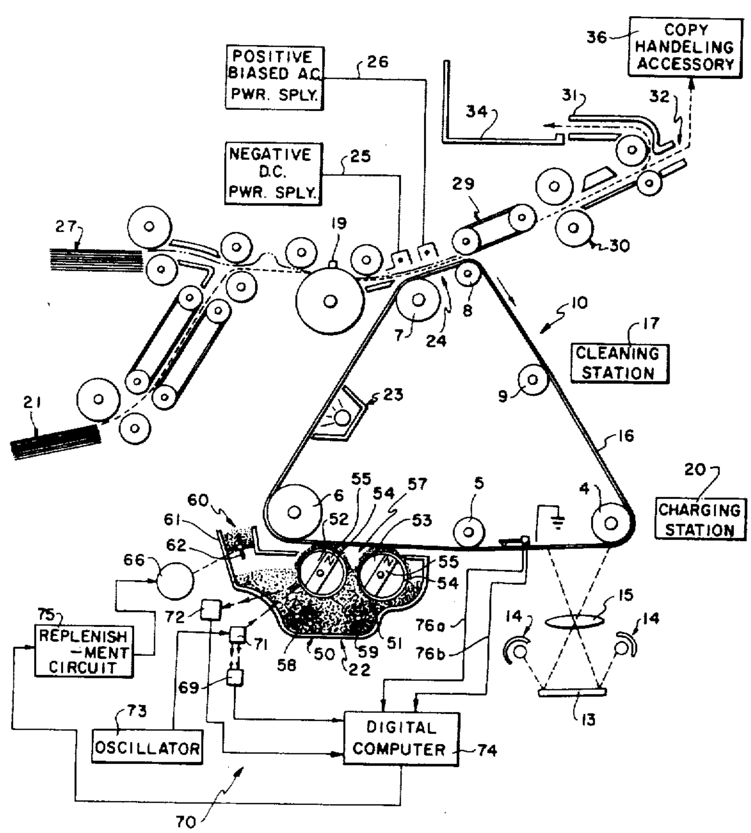
[57] **ABSTRACT**

Apparatus for continuously monitoring the concentration of toner in an electrographic developer mixture of toner and carrier particles at a magnetic brush development station by sensing the reflectivity of such mixture. The apparatus includes a radiation source for illuminating the mixture, first and second photocells for producing analog signals representative of the reflectivity of the mixture and the intensity of the radiation source, respectively. The apparatus further includes digital processing apparatus having an analog to digital converter and a programmable digital computer, having stored program, which in response to the analog signals, produces in accordance with such stored program a representation of the relative proportion of toner particles in the mixture.

5 Claims, 4 Drawing Figures



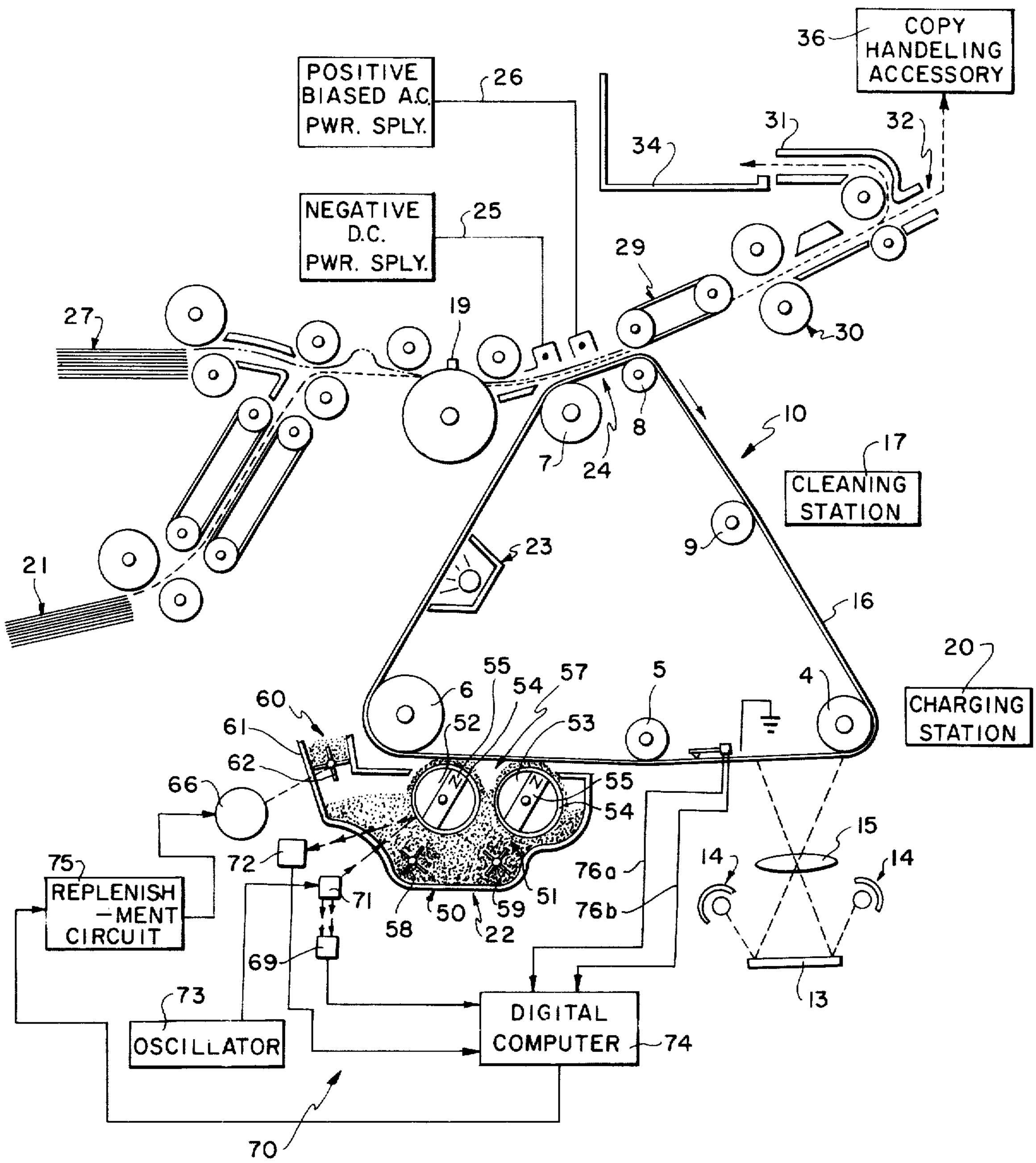

POSITIVE BIASED A.C. PWR. SPLY.
NEGATIVE D.C. PWR. SPLY.
COPY HANDELING ACCESSORY
CLEANING STATION
CHARGING STATION
REPLENISH-MENT CIRCUIT
OSCILLATOR
DIGITAL COMPUTER

FIG. 1

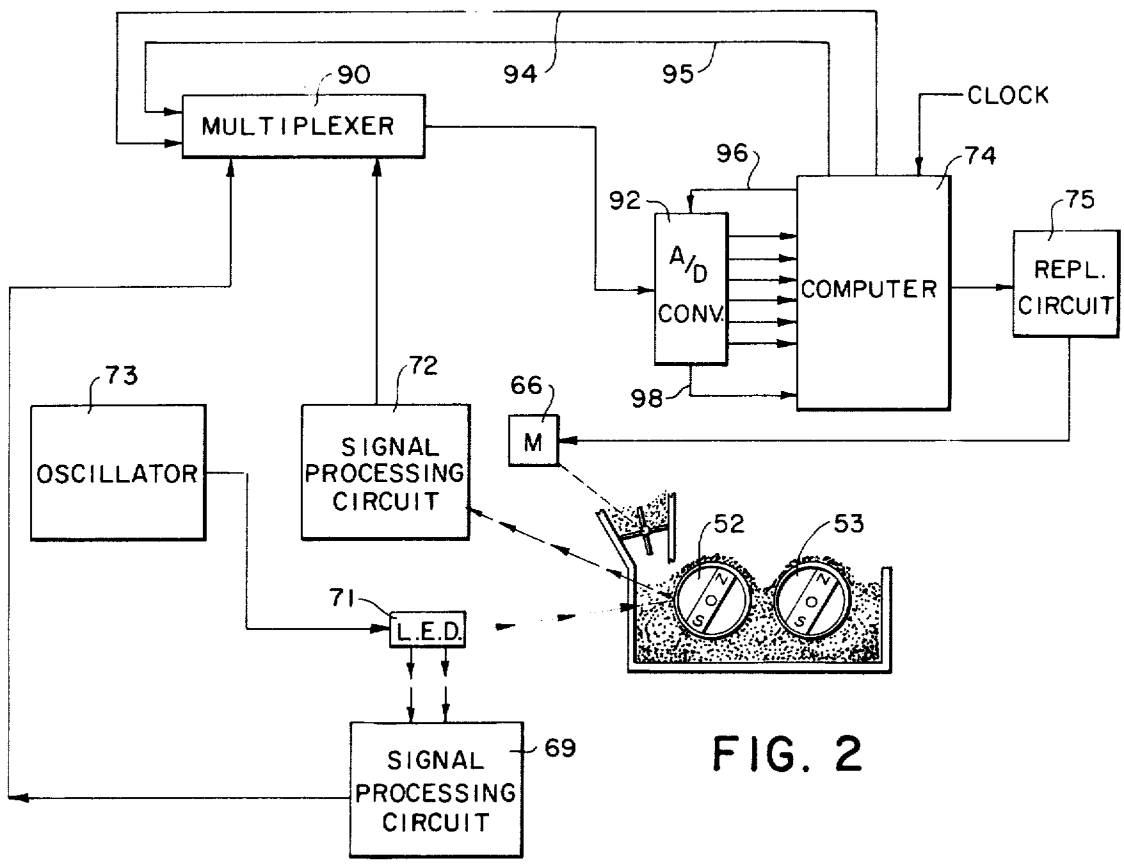

MULTIPLEXER
90
94
95
CLOCK
96
74
92
A/D CONV.
COMPUTER
75
REPL. CIRCUIT
73
OSCILLATOR
72
SIGNAL PROCESSING CIRCUIT
66
M
98
52
53
N
O
S
71
L.E.D.
SIGNAL PROCESSING CIRCUIT
69

FIG. 2

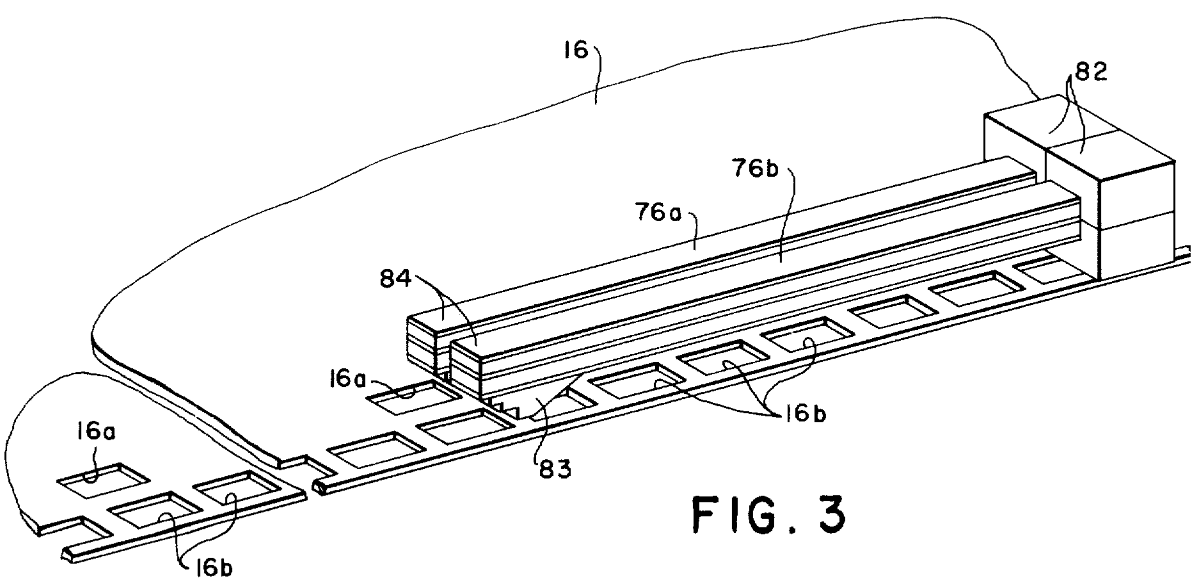

16
82
76b
76a
84
16a
16b
16a
83
16b

FIG. 3

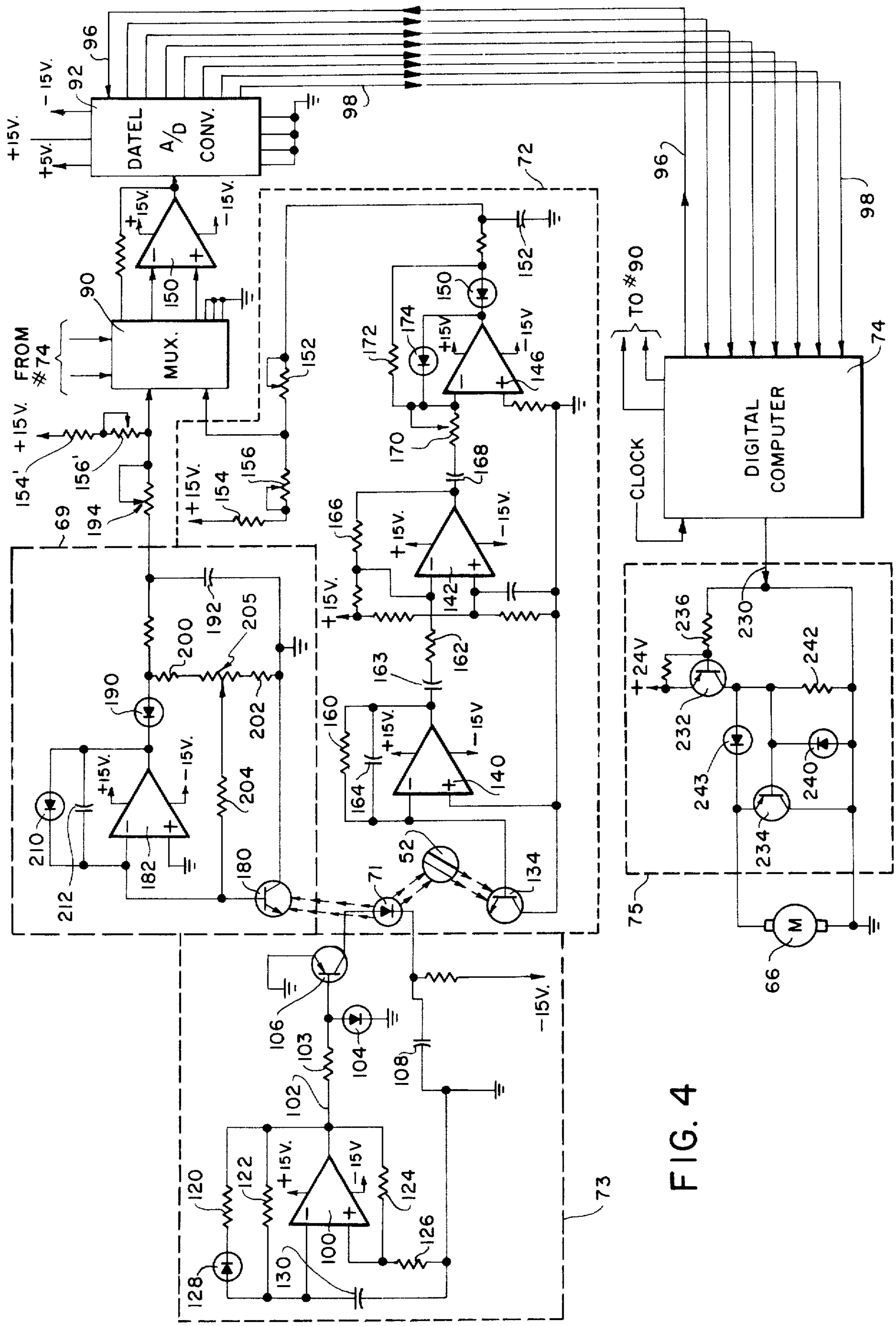


FIG. 4

TONER CONCENTRATION MONITORING APPARATUS UTILIZING PROGRAMMABLE DIGITAL COMPUTER

CROSS REFERENCE TO RELATED APPLICATIONS

Reference is hereby made to commonly-assigned United States patent application Ser. No. 280,397 filed Aug. 14, 1972, entitled, TONER CONCENTRATION AND AUTO BIAS CONTROL APPARATUS, in the name of Conrad Altmann; and commonly-assigned U.S. Pat. No. 3,830,401, issued Aug. 20, 1974, entitled, TONER CONCENTRATION MONITORING APPARATUS, in the name of Bruce Benwood et al.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to apparatus for controlling the concentration of electroscopic toner particles in an electrographic development mixture. More specifically, this invention relates to toner monitoring apparatus of the type wherein toner concentration is determined by sensing the reflectivity of the developer mixture.

2. Description of the Prior Art

In the electrographic reproduction process, the surface of a radiation-sensitive photoconductive member which may comprise a layer of photoconductive material disposed on a conductive backing, is given a uniform electrostatic charge and is then image-wise exposed to a pattern of actinic radiation corresponding to the indicia on a document or the like being reproduced. Such exposure serves to selectively dissipate the uniform charge on the surface, leaving behind a latent electrostatic image which can then be developed by contacting it with an electrographic developer.

In general, electrographic developers comprise a mixture of suitably pigmented or dyed resin-based electroscopic particles, known as toner, and a granular carrier material which functions to carry such toner by generating triboelectric charges thereon. The development of the latent electrostatic image occurs when the developer mixture is brought into contact with the electrostatic image-bearing surface. Such contact is commonly effected by either cascading the mixture over such surface or subjecting the surface to the periphery of one or more rotating magnetic development brushes, the "bristles" of which comprise chain-like arrays of toner-coated carrier particles. Upon contacting the electrostatic image-bearing surface, the toner particles, being charged to a polarity opposite to that of the electrostatic image, are separated from the carrier particles and are selectively deposited in an imagewise configuration on the surface to form a developed or toner image which may thereafter be transferred to a paper receiving sheet and fixed thereto by any suitable means, such as heat, to form a copy of the original document. As toner images are repetitively formed, toner particles are continuously depleted from the development mixture, requiring subsequent replenishment to avoid a gradual reduction in image density.

To avoid the necessity of manual replenishment and the operating difficulties often encountered as a result of over-replenishment, a variety of devices has been heretofore proposed for automatically replenishing toner particles after a predetermined number of copies are made or, alternatively, after the concentration of toner particles in the developer mixture drops below a predetermined level. Exemplary of photoelectric or optical toner concentration monitoring devices is the device disclosed in U.S. Pat. No. 3,233,781 issued to W. J. Grubbs which utilizes the difference in reflectivity exhibited by toner and carrier particles as a means for monitoring the concentration of toner particles in the developer mixture. Toner particles, usually being black and possessing highly absorbing surfaces, reflect less radiant energy than the carrier particles. Thus, the reflectivity of the developer mixture depends upon the relative proportions of the mixed particles. According to the Grubbs disclosure, the reflectance of the developer mixture is monitored by directing energy emanating from an incandescent lamp toward the mixture and detecting the energy reflected by the mixture with a photoconductive cell. Such photocell, together with a similar photocell which is illuminated directly by the lamp and thereby acts as a reference signal, is employed as a variable resistance arm of a bridge circuit which is capable of activating a toner replenishing device in response to a predetermined change in the ratio of photocell outputs, such change being characterized by an unbalance in the circuit.

While operable, photoelectric toner monitoring devices of the type described above have not proven entirely satisfactory in operation, especially over extended periods of time. A principal cause of unsatisfactory performance is due, at least in part, to the incandescent lamp used for illuminating the development mixture, a luminous energy source of relatively low output, unstable intensity and short life, and the fact that spectral characteristics of the lamp are closely akin to the background light, thereby making background discrimination difficult. The reference photocell and bridge circuit of the Grubbs apparatus provide a means to compensate for fluctuations in the intensity of the output of the lamp itself. Nevertheless, a source of uncompensated error in the Grubbs apparatus is the random electrical perturbations, commonly called "noise", which are received and generated by both the detecting and reference photocells. It is difficult in analog control systems to conveniently provide a high degree of noise rejection. Another problem associated with existing optical toner concentration monitors is that if a manufacturer should desire to change the constituents of either the photoconductor or the developer mixture, then most probably this would require some significant redesign of the analog circuitry.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to improve photoelectric devices adapted for monitoring and maintaining substantially constant the relative proportion of mixed materials having divergent reflectance characteristics.

Another object of the invention is to provide an apparatus wherein system parameters can be readily altered to accommodate development changes without incurring hardware redesign alteration costs.

A still further object of the invention is to provide a toner concentration apparatus which makes use of the advantages of digital computation.

A still further object of the invention is to provide toner concentration apparatus which facilitates noise rejection.

These and other objects of the invention are achieved by the provision of a substantially improved apparatus for monitoring, during the operation of an electrographic copier, the reflectivity of the developer used therein.

In the disclosed apparatus, there is provided a source of illumination for illuminating a developer mixture of toner and carrier particles. The apparatus includes first and second photosensitive means, the first being disposed to receive radiation from said source reflected from the mixture and the second being disposed to receive radiation directly from said radiation source. The first and second photosensitive means produce first and second analog signals representative of the reflectivity of the mixture and the intensity of the radiation of said source respectively.

The apparatus further includes a digital processing apparatus which includes a programmable digital computer having a stored program which in response to such first and second analog signals produces in accordance with such stored program a representation of the proportion of toner particles in the mixture. By utilizing a programmable digital computer, if there should be changes in the developer mixture for example, then these changes can be accommodated for by changes only in the software program for the computer thereby eliminated the need by hardward redesign.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic vertical section of an electrophotographic apparatus wherein the invention may be embodied;

FIG. 2 is a block diagram of the toner concentration monitor 70 depicted in FIG. 1;

FIG. 3 is a partial perspective view showing in detail a portion of the photoconductive web and bimorph sensors also shown in FIG. 1; and

FIG. 4 is a detailed electrical schematic of electrical circuitry depicted in block form in FIG. 2.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

To assist the understanding of the present invention, the operation of an electrographic copying machine in which the invention may be used will be briefly described. It is to be understood, however, that the apparatus of the present invention could be used with equal facility and advantage in other copying machines, and, therefore, that the following description of apparatus related to but not forming part of the invention is provided for illustrative purposes only.

Electrographic Copy Apparatus

Reference is now made to FIG. 1 wherein various stations of an electrographic apparatus 10 are schematically illustrated. As in some electrographic copiers, an information medium 13 such as a document is illuminated by radiation from flash lamps 14. Such radiation is reflected from the medium and projected by a lens 15 onto a photosensitive web member 16 to selectively dissipate charge and form an electrostatic latent image. The photosensitive web member 16 which is relatively transparent may include a photoconductive layer with a conductive backing on a polyester support. The photoconductive layer may be formed from, for instance, a heterogeneous photoconductive composition such as disclosed in the commonly assigned U.S. Pat. No. 3,615,414, issued Oct. 24, 1971. The web member 16 is trained about drive rollers 4 through 9 and is uniformly charged at a charging station 20 with a negative DC charge. Assuming that the information on the document 13 is black on a white background, the photoconductive layer of web members 16 is rendered conductive in areas corresponding to the original background, leaving a latent image of negative charge only in areas corresponding to the original black image.

The apparatus 10 further includes a magnetic brush development station 22 at which the moving electrostatic image is contacted by toner particles formed from a fine thermoplastic powder which adheres by electrostatic attraction to the negatively charged portions of the electrostatic image to develop and render such image visible in an image-wise configuration. A post-development erase lamp 23 then illuminates the photoconductive layer of web 16, through the relatively transparent support and conducting layers to reduce photoconducter fatigue (deterioration resulting from prolonged charge) and to facilitate subsequent toner image transfer. The toner remains in its imagewise configuration on the surface of the web member 16 by adhesive and other forces of attraction.

A transfer station 24 is provided to cause toner particles to be transferred in an imagewise configuration to a receiving surface of a copy sheet of paper which is fed from a selected one of two paper supplies 21 and 27 through a registration device 19 and then onto the surface of the web member 16 at the transfer station 24. The transfer station includes a negatively charged DC corona device 25 that applies a negative charge to the back of the paper which draws the paper by electrostatic attraction into intimate contact with the web member 16. Due to the charge gradient between the paper and the photoconductive layer of web member 16, the toner on the web member is transferred in an imagewise configuration onto the paper. The paper and web member 16 then move under an AC corona device 26 which removes the charge from the paper and renders it virtually neutral in charge. A positive bias is applied to the AC power supply for the corona 26 to overcome the tendency of balanced AC corona devices to produce a negative charge.

When the paper reaches the position on the web member 16 just above the roller 8, the web member bends sharply around the roller and the beam strength of the paper coupled with the momentum of the moving paper causes the paper to continue in an essentially straight-line path and leave the web member 16. A vacuum transport member 29 is located above the photoconductor at this point to convey the paper to move in such straight-line path into a fusing station 30. At the fusing station 30, the toner is heated and fused to the paper to provide a final substantially permanent copy. This copy follows either of the paths labeled 31 or 32 in exiting from the machine to either a hopper 34 or copy handling accessory 36 such as a sorter. Finally, a cleaning station 17 is provided in which residual toner is removed from the photoconductive layer of the web member 16 prior to charging. In certain known modifications of this same apparatus, one or more of these stations may be eliminated or modified. For a more complete description of the general organization of such as electrographic apparatus, reference is made to commonly-assigned U.S. Pat. No. 3,746,443 issued July 17, 1972, entitled, MAGNETICALLY CONTROLLED MACHINE PROGRAMMER, to Hickey.

Development Station

The development station 22 of the electrophotographic apparatus described hereinabove is of the magnetic brush variety, commonly comprising a trough 50 for containing an electrographic developer 51 and a pair of conventional magnetic development brushes 52 and 53 for applying the developer to the electrostatic image-bearing surface of web member 16. Each brush generally includes a rotatable mounted aluminum cylinder 54 having at least one magnetic pole piece 55, interiorly disposed in a fixed position along the longitudinal axis thereof. As previously mentioned, electrographic developer 51 generally comprises a mixture of toner and carrier particles which adhere to each other under the influence of triboelectric forces. In magnetic brush development, the carrier particles are fabricated from a magnetically attractable material so as to be attracted to the surface of cylinder 54 by the magnetic field produced by the internal pole pieces 55 to form chain-like arrays which may resemble the bristles of a brush. A pair of rotating mixing augers 58 and 59 serve to continuously circulate the developer laterally through trough 50 and maintain the relative concentrations of the developer components substantially constant throughout the trough. Typically, drive means (not shown) are provided for rotating the development brushes in a direction such that the movement of the brushes in the vicinity of contact with web member 16 is in a direction opposite the direction of travel of such web.

As cylinders 54 rotate, developer 51 collects on the outer surfaces thereof under the influence of the magnetic field produced by the internal pole pieces 55. As the electrostatic image-bearing surface of web member 16 tangentially contacts with the developer-bearing cylinders, toner is stripped from the carrier particles, due to the stronger electrostatic forces, and selectively deposited on the web member to form toner images. As the cylinders 54 continue to rotate, the partially denuded carrier particles used in forming the toner images are moved beyond the influence of pole pieces 55 and fall back into the main body of the developer to be recoated with toner. As successive toner images are formed, the concentration of toner in the developer gradually diminishes, the ultimate result being toner images of gradually decreasing density. An example of an exemplary magnetic development station 22 is more fully disclosed in commonly assigned U.S. Pat. No. 3,543,720 to Drexler et al.

A conventional toner replenisher 60 is activated by a toner concentration monitor (to be described) to maintain the concentration of toner at or above the level required for high quality copies. The replenisher 60 includes a hopper 61 which defines an opening in which is disposed a paddle wheel 62 which may also be in the form of a brush or soft fibrous roller. The wheel 62 is driven by a motor 66. When the motor 66 is energized, it rotates the paddle wheel 62 causing toner to be fed into the trough 50 thereby increasing the concentration of toner in the developer. An example of a conventional toner replenisher is set forth in U.S. Pat. No. 3,409,901. Since the carrier and toner components of the developer commonly possess divergent reflectance characteristics, with toner having a lower reflectivity than the carrier component, the reflectance of the developer 51 is an accurate measure of the relative concentrations of its two major components. The higher the concentration of the carrier particles, the higher the reflectance of the developer. Stated otherwise, the developer 51 reflectance is inversely proportional to the toner concentration.

Toner Concentration Monitor Apparatus

In accordance with the invention, there is provided improved toner concentration monitor apparatus 70 to continuously monitor the concentration of toner in the mixture 51. Monitoring of the reflectance of the developer 51 is accomplished by directing the output of radiant energy source 71, preferably a light emitting diode, toward a portion of the developer where the concentration is representative of the average toner concentration throughout the developer. In the magnetic brush development station 22, the toner concentration on the downstream development brush (i.e., brush 52) between the points where the brush surface emerges from the development mix and first contacts the surface of web member 16 is usually characteristic of the average toner concentration. Between such points, the surface of the development brush comprises fresh developer which has not yet been subjected to the localized depletion of toner which results from development of the electrostatic image. Alternatively, toner concentration can be monitored on the upstream development brush (i.e., brush 53) between the points where the brush surface loses contact with the surface of web member 16 and re-enters the developer. To eliminate the effect of localized toner depletion from the surface of the upstream development brush, a comb-like member (not shown) having teeth extending into the brush surface (such a member is disclosed in the above-cited Benwood et al. Patent Application) can be used to agitate the developer carried by the brush before being subjected to the toner monitoring operation.

The use of a light-emitting (LED) diode 71 as the source of radiation from which developer reflectance is determined offers the advantages over conventional sources of long-term stability, collimated output, fast response time, compactness and physical durability. Because of its fast response time, the LED can be electronically pulsed at electronic speeds. The LED 71 is actually periodically energized at a selected frequency by means of a conventional pulse generator. Light reflected from off the brush 52 is received and processed by signal processing circuitry 72. Light from LED 71 is also received directly by signal processing circuit 69. Circuits 69 and 72 are shown at this point for the sake of convenience in the disclosure as applying signals directly into a programmable digital computer 74. The circuits 69 and 72 will be understood to include filters having band passes centered on the frequency of the oscillator 73. This will aid in noise rejection. As will be seen when FIG. 2 is discussed, these signals are actually multiplexed and converted to a digital format prior to being received by the computer 74. The computer 74 also receives input signals from a pair of electromechanical transducers 76*a* and 76*b* (referred to herein as "bimorph sensors" which sense perforations in the web member 16. In response to these signals, the computer 74 solves a toner concentration control equation (later described) and in accordance therewith actuates the motor 66.

Reference should now be made to FIG. 3 which shows in detail a portion of the web member 16 having along its border two rows of indicia or perforations 16*a* and 16*b*. Between adjacent perforations 16*a* is defined an image area. By that it is meant an image area is a place across the entire width of the web member **16** wherein a charge pattern corresponding to an image may be placed. The row **16*b*** defines a predetermined number of equally spaced perforations or sprocket holes disposed between adjacent perforations **16*a*** which too are equally spaced along the web member **16.** The distance between adjacent perforations **16*a*** being much greater than that between adjacent perforations **16*b*.** As shown, there is provided a bimorph sensor **76*a*** which is adapted to sense the perforations **16*a*** and provide a signal to the digital computer **74,** each time a perforation **16*a*** is sensed. A second bimorph sensor **76*b*** is adapted to provide a clock pulse to the computer **74,** each time a perforation **16*b*** is sensed. Only this clock pulse line is shown in FIGS. **2** and **4** since the pulse from the sensor **74*a*** is not directly concerned with this invention. The reason both lines have been shown in FIGS. **1** and **3** is because the computer **74** uses the pulses from both bimorph sensors **76*a*** and **76*b*** to control and synchronize the various work stations of the electrophotographic operation. In operation, upon receiving a clock pulse from a bimorph sensor **76*a*,** the computer **74** enables the start line **96** (briefly seen in FIG. **2**) which causes a digital word having six bits to be stored in a storage location which could be by semi-conductor memory devices, not shown. Two words for each clock pulse (corresponding to an increment of a charged image area) are sequentially accepted by the computer and then processed by the signals produced by circuits **69** and **72** respectively. The computer is programmed to operate upon clock signals from the bimorph sensor **76*b*** and determine the concentration of toner in the mixture. This will be described more fully in the sections of this disclosure entitled, COMPUTER OPERATION. The computer is also used to control other functions such as synchronizing the operation of the sheet feeding apparatus and operating the exposure lamps **14** at appropriate times in the machine cycle. The computer **74** may take various other forms known in the art some of which are commercially available as programmable minicomputers and programmable microprocessors. Specific examples are, Model 8008 Micro-Computer manufactured by Intel Corporation of Santa Clara, California; GEPAC 30— manufactured by the General Electric Corporation; Interdata Model I or Varian Data Machines Model 520/*i*. The instructions and method of programming such minicomputers is set forth in the textbook, "Minicomputers for Engineers and Scientists", Gravino Korn (1973).

An example of bimorph sensors **76*a*** and **76*b*** which may be suitable for use with the present invention is described in commonly assigned U.S. Pat. No. 3,723,650 in the name of Bradley et al, issued Mar. 27, 1973, entitled, METHOD AND APPARATUS FOR DERIVING THE VELOCITY AND RELATIVE POSITION OF CONTINUOUSLY MOVING INFORMATION BEARING MEDIA. Briefly, such bimorph sensors include a piezoelectric crystal **82** which has attached thereto a single step sensor **83** element, the distal ends **84** of which bear on and slide against the moving web member **16.** When a perforation in the member moves beneath the distal end of the sensor element, the end abruptly drops over the leading edge of the perforation and distorts or otherwise induces mechanical movement of its associated transducer. As the web member **16** continues to move, the distal end **84** of the sensor element **83** is forced out of the perforation by engagement with the trailing edge of the perforation, and once again the sensor element distorts its associated piezoelectric transducer. By means of electrodes or other suitable current collecting means attached to the sensors, voltage signals generated by the distortion of the transducer are transmitted to the computer **74.** Other types of perforation sensors which produce output signals such as optical perforation sensors or other types of ceramic transducers responsive to compression, bending or other forms of physical distortion may be substituted for the depicted bimorph sensors.

Turning now to FIG. **2,** there is shown a more detailed block diagram of the toner concentration monitor **70** in accordance with the invention. As shown, the oscillator **73** provides a drive current for the LED **71** which illuminates the brush **52** with light in the infrared portion of the spectrum and having a frequency determined by the oscillator **73.** The spectral region where developer reflectance is monitored should be chosen in accordance with the availability and course requirements of commercial light-emitting diodes and photodetectors kept in mind; however, an important requirement is that the wave length at which there is a reflectance disparity between toner and carrier should be maximized to the greatest extent possible to provide improved system sensitivity. Light from the brush **52** is reflected to illuminate the signal processing circuit **72** which includes as a detector device a phototransistor operating between the base and collecting junctions as a photovoltaic cell. The detected signal is amplified and converted to a DC level by the circuit **72** and then applied to an analog multiplexer **90** which at the appropriate time, selected by the computer **74,** provides such signal to an analog to digital (A/D) converter **92.**

Since a variation in the intensity of the light from LED **71** could cause a signal to be produced by the circuit **72,** which could indicate a wrong toner concentration, the toner concentration monitor compensates for variations in light intensity. Towards this end, the circuit **69** receives light directly from the LED. In a preferred embodiment, the energy output of the LED **71** may be coupled to a detector of the circuit **69** by means of a conventional light pipe. By means of this arrangement, problems of toner dust in the optical path may be minimized. The circuit **69** detects the light, amplifies and converts it to a DC level in much the same manner as the circuit **72.** The signal is also applied to the multiplexer **90** which, at the appropriate time feeds its multiplexed output to the A/D converter **92** which in turn applies a corresponding six bit digital word into the computer **74.** The arrangement is such that if the concentration of toner in the mixture is at the desired level, then both analog input signals (from circuits **69** and **72,** respectively) will be at the same amplitude.

In order to process signals from the circuits **69** and **72** the computer **74** produces multiplexer channel address select signals to sequentially switch inputs to the A/D converter **92.** These signals are sequentially produced after a perforation **16*b*** has been detected by sensor **76*b*.** Thereafter, start signals are produced in the lead **96** which causes the A/D converter **92** to perform a conversion of input analog data into six bit digital words. Upon completion of each such A/D conversion process, the converter produces a completion signal to the computer **74** in a lead **98** which causes the computer in the appropriate sequence in its program to accept the data from A/D converter **92.** As just noted, the sequencing of the computer is in turn coordinated as a function of the input clock signals provided by the transducer **82** upon sensing the perforations in the film. The computer **74** operates upon these input digital words and determines the toner concentration. If the computer determines toner is to be added to the mixture, it provides an output signal to the replenishment circuit **75** which in turn energizes the replenishment motor **66.** The circuit **75** will continue to receive these output signals until the computer **74** determines that the toner concentration is back within a desired range. A feature of the invention is that the computer may be programmed to monitor the magnitude of toner concentration and provide output alert signals if the toner concentration becomes either too high or too low.

In FIG. **4,** there is shown an electrical schematic diagram of many of the circuit elements shown in block form in FIG. **2.** The oscillator circuit **73** will first be described. The oscillator **73** includes an operational amplifier **100** connected in an astable multivibrating configuration and is adapted to provide an output signal through a line **102** to a resistor **103** to the base electrode of a drive transistor **106.** A diode **104** is provided to protect the transistor **106** from reverse polarity of the recuring signal. The oscillator may for a specific example operate at a frequency of one KHz at a 20 percent nominal duty cycle. The transistor **106** operates as an amplifier to provide the required current levels for driving the LED **71.** Capacitor **108** provides energy storage for LED **71** to minimize the power supply loading and reduce noise. The operational amplifier **100** includes a series of feedback resistors **120, 122, 124** and **126,** a diode **128,** and an oscillator timing capacitor **130.** These circuit elements operate in a well-known manner and need not be described further here. For a complete description of wave generators which employ operational amplifiers and for further description of other operational oscillator circuits which may be used in accordance with the invention, reference is made to Chapter 10 of the Burr-Brown "Operational Amplifiers" book (1971) by Tobey et al., published by McGraw-Hill, New York (1971).

The detecting and signal processing circuit **72** which receives light reflected from the brush **53** will now be described. A detector for such circuit **72** is shown as a phototransistor **134** which may be, for example, a Fairchild FPT-100 Phototransistor. The phototransistor produces current in response to the reflected infrared energy from the developer mixture to drive the inverting input of an operational amplifier **140.** The phototransistor **134** operates as a photovoltaic cell via its collector-base junction. As shown, there are three cascaded operational amplifiers **140, 142** and **146,** in circuitry **72** which raise the signal level of the one KHz signal to say, for example, a minus 6 volt peak. The operational amplifier **146** also acts as a demodulator in combination with the diode **150** and capacitor **152** to convert the signal to a nominal DC level of, about 4 volts. To effectively utilize the analog to digital converter **92,** only that portion of the concentration signal that represents the excursion range is to be digitized. For a specific example, for a minus 4 volt DC $\pm$ 0.1 volts DC which represents the limits of toner concentration control, only the AC excursion or 0.2 volt need be digitized to cover the full range of 0–5 volts of the converter. To accomplish this function, a further operational amplifier **150** is provided at the output of the multiplexer **90.** This technique would ordinarily raise the nominal level of the signal beyond the range of the converter **92.** Therefore, the signal is offset by the subtracting action of a **15** volt source coupled to resistors **154** and **156** which are disposed at the input to the multiplexer **90.** In this manner, the amplified control signal applied to the A/D converter **92** can be shifted back to the centerpoint (2.5 volts) of the 0–5 voltage range of the converter. It should be noted that at the other input to the multiplexer **90** there is provided an identical offset voltage producing circuit having resistors **154** and **156.**

Turning back again to the input portion of the circuit **72,** the operational amplifier **140** serves as a current-to-voltage transducer for converting the current from the phototransistor **134** to a voltage signal. A resistor **160** sets the gain of the amplifier **140** and also a feedback capacitor **164** is provided. A resistor **162** and a capacitor **163** coupled the first and second operational amplifier. The second operational amplifier **142** also includes feedback resistor **166** and is coupled by a capacitor **168** to the inverting port of the operational amplifier **146** via an adjustable resistor **170.** Also, the amplifier **146** includes a conventional feedback resistor **172** and feedback diode **174.**

Circuit **69** includes a phototransistor **180** which, like phototransistor **134,** may for a specific example be a Fairchild FPT-100 phototransistor. Light from the LED **71** directly illuminates the phototransistor **180** which is coupled to the non-inverting port of an operational amplifier **182.** Since the signal received by the photocell **180** is much higher than the signal received by the photocell **134,** only a single amplifier stage which includes the operational amplifier **182** is needed. At the output of the amplifier **182** is a diode **190** and a capacitor **192** which provides the demodulation function similar to that described at the output of operational amplifier **146.** Adjustment of the input signal to the multiplexer **90** is accomplished by means of a potentiometer **194** which changes the gain of an amplifier **150.** The level of this signal is adjusted to be substantially equal to the nominal concentration control voltage (2.5 volts DC) as also described in connection with circuit **72.** In operation, amplifier **182** converts current pulses to voltage pulses of a proportional amplitude. The overall gain of the amplifier is determined by feedback resistors **200, 202** and **204** and potentiometer **205.** The amplifier **182** also includes conventional feedback diode **210** and capacitor **212.**

It should be noted that the multiplexer **90** has been shown only in block form since it is of a type which may be readily purchased commercially. An example of a multiplexer which has been found to perform satisfactorily is the Intersil Model IH 5010. Similarly, numerous analog to digital converters are available and one which is especially suitable for use with the invention is Model ADC-ECONOVERTER manufactured by Datel System, Inc., of Canton, Massachusetts.

The replenishment circuit **75** will now be described. In accordance with the invention, to operate the replenishment motor **66** an output line **230** from the computer **74** is grounded or de-energized. Energizing the line **230** is effective to turn the motor **66** off. Towards this end, the circuit **75** includes two PNP transistors **232** and **234.** The lead **230** is directly coupled through a resistor **236** to the base electrode of the transistor **232**. Transistor **232** turns to an energized condition when the voltage applied on lead line **230** is grounded by forward bias in the base-emitter junction of the transistor **232**. At such time, due to the forward voltage drop across diode **234**, which reverse biases the base-emitter junction of transistor **234**, the transistor **234** is held in a turned-off condition. The transistor **234** is adapted to provide a braking function for the motor **66**. With the transistor **234** turned off, a voltage is applied across the motor **66** sufficient to energize same. When the line **230** is energized, the transistor **232** turns off. The motor **66** now acts as a generator having the same polarity as it had while running as a motor. The transistor **234** is forward biased through resistor **242**. Therefore, it turns on and short circuits the armature of the motor **66** to ground, thereby stopping the motor. It should be noted that the diode **240** acts as a transient suppressor for any momentary reverse polarity spikes caused by armature brush switching. The amount per unit time of toner dispensed by using this technique is a constant when the motor **66** is energized. This factor is recognized by equation **3** in the control parameters of the computer described hereinafter.

Computer Operation

It is a feature of this invention that the calculations and decision processes concerning the concentration of toner in the developer are done in the programmable computer **74**. Thus, changes are made in the developer, they can be accommodated by making suitable alterations to the computer software without changing any of the hardware of the monitor **70**. The computer **74** should be programmed to solve equations (1), (2), and (3) hereinafter set forth. Such a program is clearly within the skill of the programmer having ordinary skill in the art and hence the details of such program need not be given here. It should be noted, however, that the computation process is initiated each time a clock pulse from the sensor **76*b*** is received by the computer **74**.

1. Control Parameters: The following basic equations describe the control function:

(1) $V_o = K_{PRO}E + K_{INT} \int E\, dt$

(2) $E = \alpha R - \alpha C$

wherein:

V_o = output voltage to control replenisher

K_{PRO} = controller proportional gain constant

K_{INT} = controller integral gain constant

E = concentration error

αR = system reference concentration voltage or set point

αC = system detected concentration voltage at any given time

K_{PRO} = 0.45 control volts/unit error

K_{INT} = 0.10 control volts/sec./unit error

As noted above, the present invention utilizes a pulse duration modulation technique of control. The amount of toner being dispensed is therefore constant while the replenisher mechanism is energized and the toner dispensing rate is controlled by the time period the replenisher mechanism is turned ON. The V_o voltage of equation (1) is converted to time or duty cycle as follows:

(3) $t_{on} = K_c V_o T$

wherein:

t_{on} = time replenisher is ON per cycle

K_c = replenisher control gain

T = time proportioning base period

K_c = 0.2 duty cycle/control volts

T = 1 second

Replenisher OFF if $t_{on} = 0$

Replenisher ON 100% duty cycle if $t_{on} = T$

2 Computer Processing of Data: The computer **74** receives two signals as data inputs respectively produced by circuits **72** and **69**. The first signal represents the reflectivity of the developer at any given time and the second signal is a reference representing the energy output level of the LED **71** at any given time. To enable the computer **74** to compensate for variations in LED energy output, the concentration signal is first divided by the reference signal to obtain a normalized value of unity that represents a nominal known system condition. If the reference signal shifts due to aging of the LED or ambient temperature changes, the concentration voltage shifts by the same amount and the normalized control value remains unaffected. Therefore, any changes in the normalized signal represent only toner concentration level changes.

The normalized signal is next subtracted from the desired set point or nominal control point value to create an error signal E. This error signal is used in the basic system control equation (1) for the proportional integral controller.

The computer numerically integrates the error voltage in a well known manner by simple addition and accumulation of the error signals for each data sampling period. The sampling rate for this system is once per second. The integrated value is then multiplied by the K_{INT} constant of equation (1). This value is summed with the error signal multiplied by the K_{PRO} constant of equation (1) to obtain a V_o value.

The computer is adapted to determine the time duration for actuation of the replenisher mechanism by use of equation (3). This computation is converted to the number of clock pulse periods that the replenisher drive mechanism is held energized.

As an auxiliary function the computer may continually compare the value of the digitized concentration voltage with two stored constant values in computer memory. These two constant values represent upper and lower limits of concentration allowed by the system. If the concentration voltage fails to remain within these limits the computer provides an output alarm signal for activating a warning device (not shown) for appropriate action by the system.

The toner concentration monitor disclosed herein has been found to be extremely sensitive to minute changes in the reflectivity of the mixture being monitored, and exceptionally stable over extended periods of operation. For these reasons, it has been found useful in maintaining the relative proportions of mixed materials substantially constant over extended periods even when the reflectance disparity of such materials is very small. For instance, a change in toner concentration of from 0 to 7 percent (7 percent toner concentration producing total saturation or coverage of the carrier particles with toner) results in a 25 percent change in the reflectivity of the developer mixture. Since, for many developers, it is desirable to maintain the toner concentration within the range of 2.75 percent to 3.75 percent, it may be appreciated that toner concentration monitors must be sufficiently sensitive to detect changes in the reflectivity of the developer of the order of 1 percent. By taking into account the changes in the density of the atmospheric environment in which the monitoring apparatus is employed as well as the gradual accumulation of mixed materials on the external surfaces of such apparatus, the reflecting monitoring systems have also been found to possess the stability required for maintaining the toner concentration within the required range for several months of continued use.

The invention has been described in detail with reference to a preferred embodiment thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

We claim:

1. In apparatus for monitoring in a developer the proportion of carrier and toner particles having divergent reflectance characteristics, the improvement comprising:

a. a radiation source for projecting radiant energy upon the mixture to illuminate a portion thereof;

b. first and second photosensitive means, said first photosensitive means being disposed to receive radiation from said source which is reflected from the mixture and said second photosensitive means being disposed to receive radiation directly from said source, said first and second photosensitive means being adapted to produce first and second analog signals representative of the reflectivity of said mixture and the intensity of radiation of said source, respectively;

c. analog to digital conversion means responsive to said first and second analog signals to respectively produce first and second digital signals corresponding thereto; and

d. programmable digital computation means having a stored program and being responsive to said first and second digital signals for producing in accordance with said stored program a representation of the proportion of toner particles in the mixture.

2. The invention as set forth in claim **1** including actuable toner replenishing means for adding toner particles to the developer and wherein said programmable digital computation means actuates said actuable toner replenishing means when the proportion of toner particles in the developer is below a predetermined level.

3. The invention as set forth in claim **2** including a multiplexer responsive to said first and second analog signals for multiplexing such signals to said analog to digital converter means.

4. In apparatus for monitoring the proportion of a mixture of carrier and toner particles having divergent reflectance characteristics, the improvement comprising:

a. a radiation source for projecting radiant energy on the mixture to illuminate a portion thereof;

b. first and second photosensitive means, said first photosensitive means being disposed to receive radiation from said source which is reflected from the mixture and said second photosensitive means being disposed to receive radiation directly from said source, said first and second photosensitive means being adapted to produce first and second analog signals representative of the reflectivity of said mixture and the intensity of radiation of said source, respectively;

c. a multiplexer responsive to said first and second analog signals for sequentially multiplexing such signals;

d. an analog to digital converter responsive to said sequentially multiplexed analog signals to produce first and second digital signals corresponding thereto; and

e. a programmable digital computer having a stored program and being responsive to said first and second digital signals for producing in accordance with said stored program a representation of the proportion of the toner particles in the mixture.

5. The invention as set forth in claim **4** wherein said program is adapted to solve the following control equations:

a. $V_o = K_{Pro}E + K_{INT} \int E\, d t$

b. $E = \alpha R - \alpha C$, and

c. $t_{on} = K_c V_o T$

wherein:

V_o = output voltage to control replenisher

K_{PRO} = controller proportional gain constant

K_{INT} = controller integral gain constant

E = concentration error

αR = system reference concentration voltage or set point

αC = system detected concentration voltage at any given time

t_{on} = time replenisher is ON per cycle

K_c = replenisher control gain

T = time proportioning base period

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