

[54] **ELECTROSTATIC SEPARATING
APPARATUS FOR PARTICLES**

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[51] Int. Cl. B03c 7/04
[58] Field of Search 209/127-131, 353-356,
209/313; 198/220

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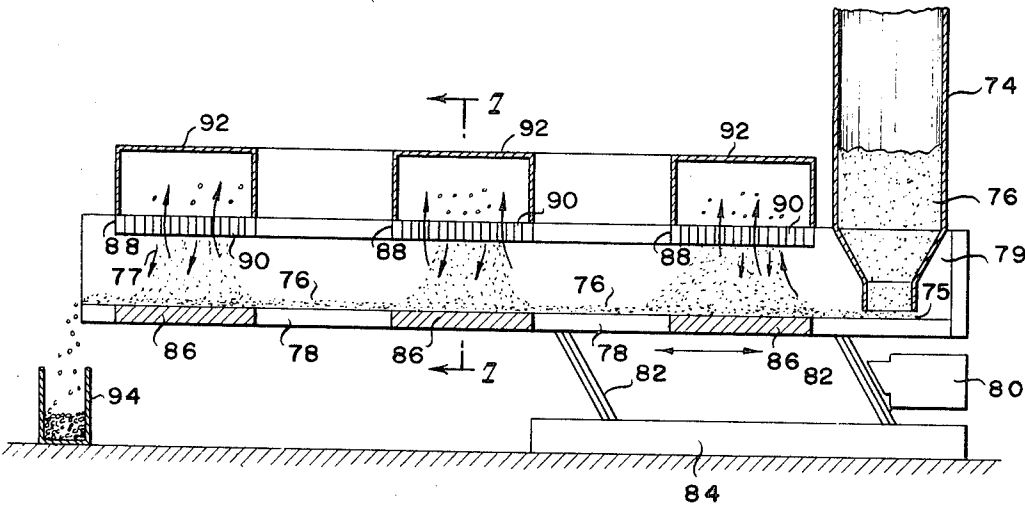
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[57] **ABSTRACT**

The transfer of powder particles of the type which are capable of movement in an electric field which is created by applying potential between two spaced electrodes. The particles are charged and propelled from the first electrode towards the second electrode and due to the particle momentum, they can travel through the second electrode if it is apertured and beyond the second electrode if it is not apertured. Once the particle travels past the second electrode it may be utilized for various useful purposes such as electrostatic printing, particle classifying, or transfer to a series of successively arranged electrodes as in a particle pump.

1 Claims, 13 Drawing Figures



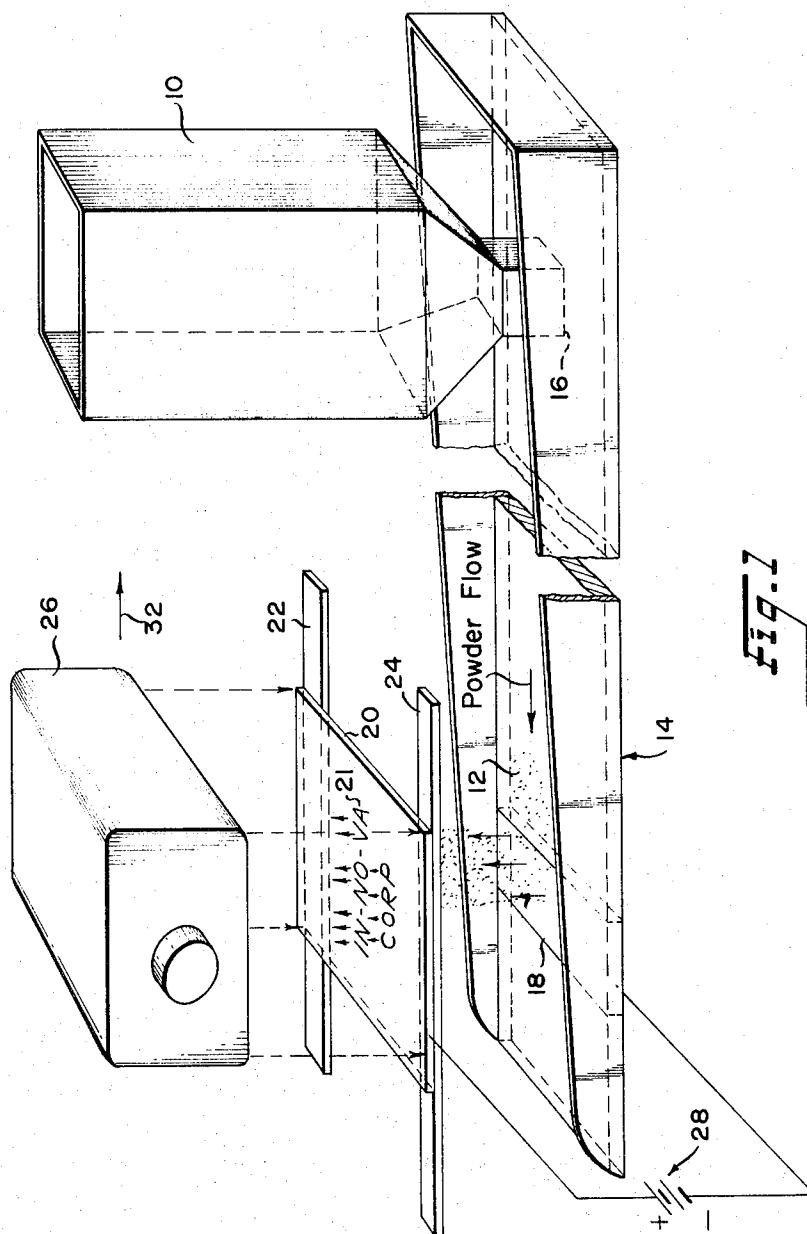


Fig. 1

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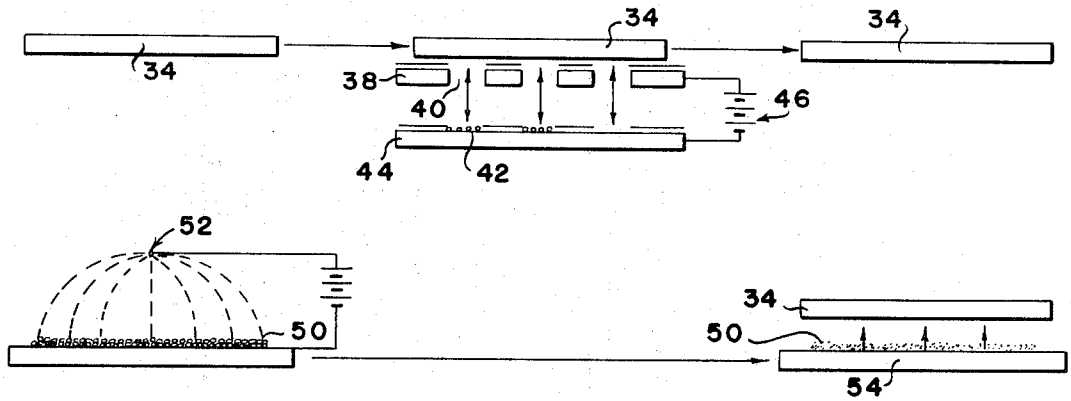


Fig. 2

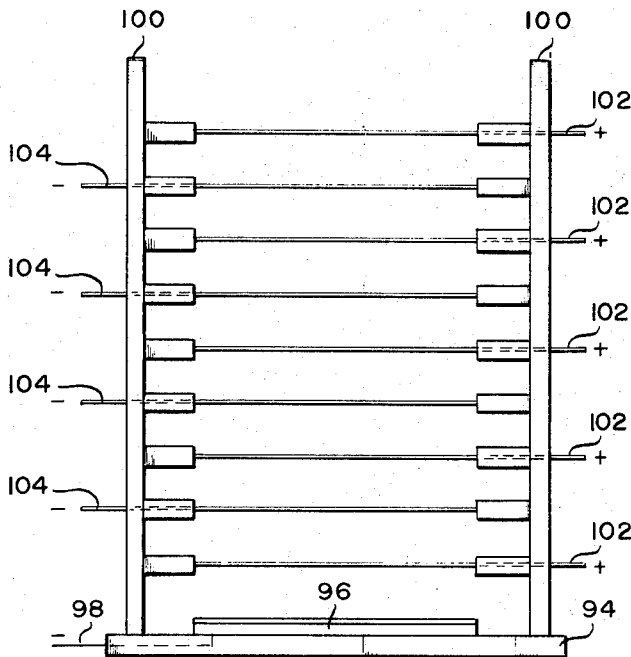


Fig. 3

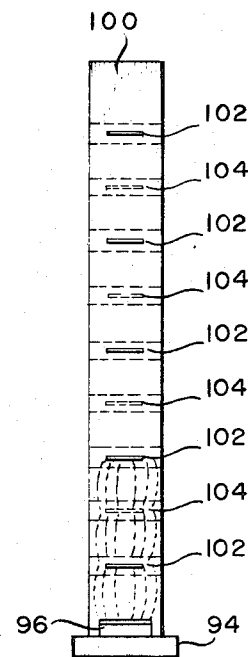


Fig. 4

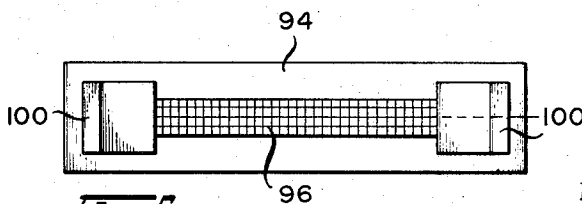
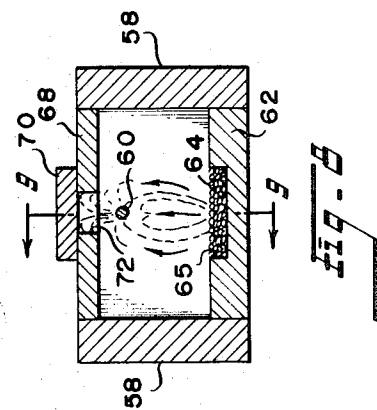
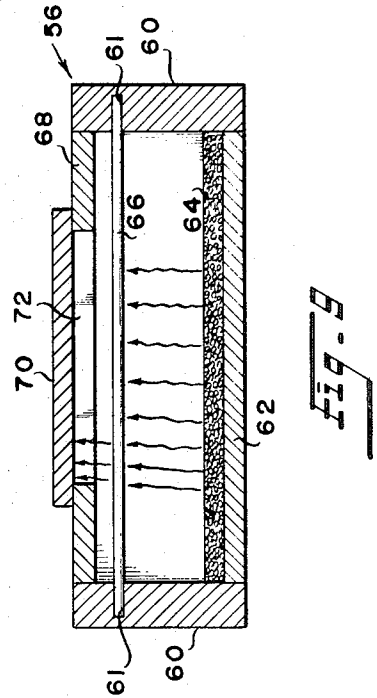
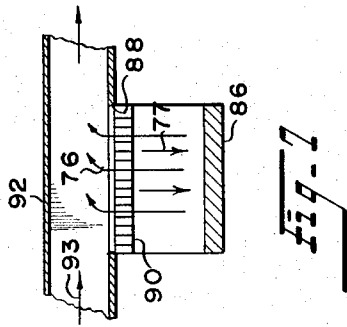
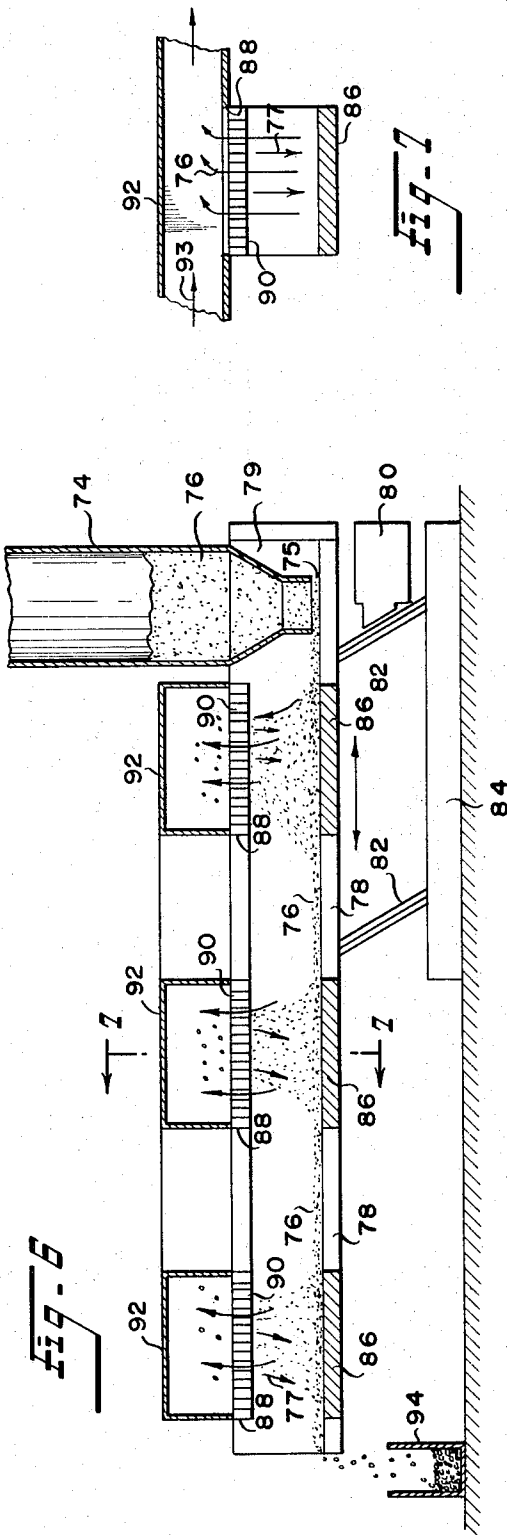


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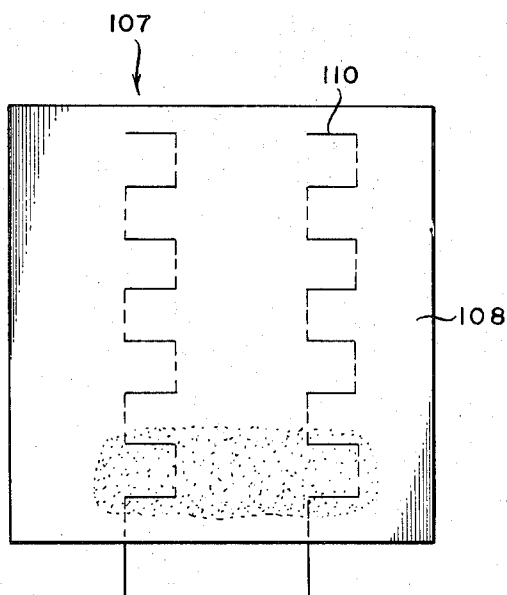


Fig. 10

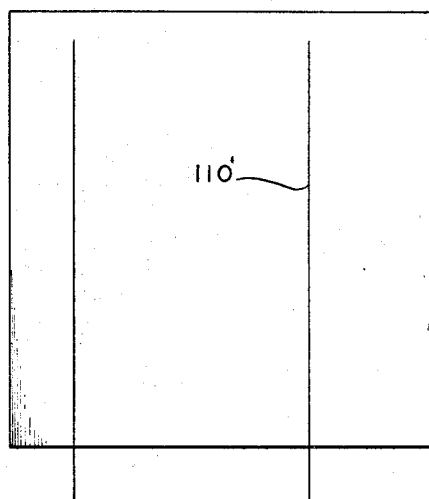


Fig. 11

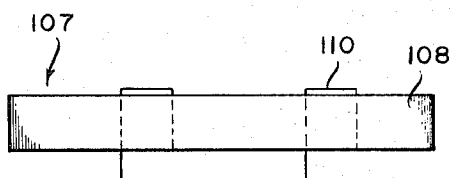


Fig. 12

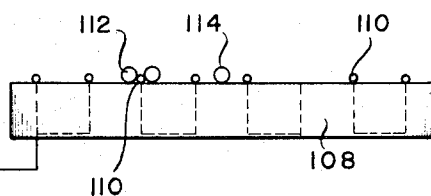


Fig. 13

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ELECTROSTATIC SEPARATING APPARATUS FOR PARTICLES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is directed towards the transfer of dry powder particles capable of moving in an electric field, such as conductive particles or charged, nonconductive particles. The electric field may be created between two or more electrodes by applying a potential between the electrodes, wherein the particles travel from a first or charging electrode towards the second electrode. The momentum of the particle is dependent upon the size of the particle and the speed at which it travels, which in turn is proportional to the force applied to the particle by the electric field. A particle traveling with sufficient momentum is allowed to travel through or beyond the second electrode where it is utilized for such useful purposes as electrostatic printing of particles onto a conductive or nonconductive substrate, classification of dry powders or the pumping or successive transferring of powder or like particles through the use of a series of successively arranged electrodes.

2. Description of the Prior Art

The concept of transferring dry powder or like particles between two electrodes having a potential difference between them is well known in the art. This concept is widely used in the area of electrostatic printing of dry powder particles. However, in all of the prior art devices known to date, including those concerned with electrostatic printing, the particle transfer has occurred between a first transfer electrode and a second collecting electrode wherein the substrate or article to be coated or printed is passed between the first and second electrodes so that the particles in route to the second electrode will first engage the surface of the substrate or article being coated. Consequently, in known particle transfer devices, in the absence of a substrate to be coated, the path of the transferred particle is defined between the first and second electrodes, creating the electric field. These presently known devices, therefore, substantially limit the application of particle transfer apparatus in that the particles are contained within the area defined by the two electrodes and the usefulness and versatility of such a particle transfer device is thereby restricted. Furthermore, even in the area of electrostatic printing, the printing apparatus generally has to be designed so that the article or substrate being coated is allowed to pass between the two electrodes thereby offering additional problems to the mass production of electrostatic printed articles such as containers or the like.

In one electrostatic printing device, which is generally representative of electrostatic printers known in the prior art, powder particles are delivered to a first electrode and travel, due to a force imparted to the particle by an electric field towards a second electrode arranged inside a container of nonconductive material. The particles flow from the first electrode towards the second electrode and through a stencil which defines the indicia to be printed on the outside surface of the container. In that the second electrode is arranged within the container, the powder particles first contact the outside surface and printing is thereby accomplished. The problems present with this type of device are evident when it is desired to mass print a plurality of like containers in as little time as possible. Because the printing is desired on the outside surface of the container only, and in that the surface or portion of every container to be printed must pass between the first and second electrode, it is evident that with this type of arrangement a plurality of containers cannot readily be presented to the printing station in rapid successive fashion which is characteristic of modern day mass production methods.

SUMMARY OF THE INVENTION

The present invention is directed towards the transfer of powder or like powder particles which are capable of movement in an electric field, e.g., a conductive powder or a

charged, nonconductive powder, wherein the electric field is created between two electrodes such that the momentum of the particles after leaving the first or charging electrode enables them to travel towards the second electrode and, due to the momentum of the particles, to move past the second electrode where the powder particles are utilized in some specific application.

In modern day electronics, it is commonly recognized that the transfer of electrons may be regulated and classified according to the energy of the electron which, of course, is proportional to the electron velocity. This concept is utilized in vacuum tube technology where the low velocity electrons are collected at the grid of the tube. The average speed at which an electron or ion passes through a given medium is referred to as the drift velocity, where the drift velocity can be defined by the following formula:

FORMULA 1

$$W = E_0 E_p a / 2\pi N$$

where

E_0 = charging field

E_p = collection field

a = particle radius

N = gas viscosity

The significant point to note in this formula is that the velocity of the electron as it passes through a medium is directly proportional to its radius or size.

Consequently, an important relationship is the size of a charged particle and the maximum acquired particle charge which may be referred to as the limiting or saturation charge for a given particle. Saturation charge can be represented by the following formula:

FORMULA 2

$$N_s e = 3 E_0 a^2$$

where

a^2 = surface area

E_0 = electric field

Similarly, it is important to note here that saturation charge is directly proportional to the surface area and that significant size differences between the particle being transferred could result in particle classification.

In view of the known behavior of electrons during transfer or travel, a number of experiments were conducted in order to decide whether powder particles would behave as electrons when subjected to transfer from a first electrode to a second electrode which was in the form of a stencil. More specifically, it was needed to determine whether the powder particles would pass through the apertures of the stencil electrode because of their charge or velocity and thereby react similarly to electrons under the same conditions. In conducting these experiments, the parameters of powder concentration, stencil electrode design and electrode spacing versus required transfer potential utilized in powder transfer, were investigated.

In conducting the experiments, the powder height of 0.03 inch was used between two copper electrodes where the particle size (mesh size) of the powders being transferred was between 40 and 100 and the substrate onto which the powder was to be directed was made of cellulose acetate butyrate.

In the first test, the distance between the charging electrode and the stencil electrode was one-eighth inch and a transfer potential of 1,100 volts was imposed between the electrodes. In the second test, the distance between the charging electrode and the stencil electrode was one-fourth inch and a transfer potential of 2,500 volts was impressed. In reviewing the results of the two tests, it was determined that in transferring powder particles in the environment outlined above, the particles do, in fact, react as electrons which, when exposed to the proper transfer potential, develop sufficient energy or velocity to maintain a momentum such that when they are propelled against the force of gravity from the charging electrode, the particles have sufficient momentum to travel through the apertures of the stencil electrode and beyond the stencil electrode based on the concept of inertia. As a result of

this, it is clearly seen that many practical applications can be utilized by not limiting the path of the transfer particles to an area defined between the electrodes.

It was noted, in conducting the above-outlined experiments that when the transfer potential is too high, the powder particles due to their excess velocity have a tendency to ricochet off the substrate surface which may be arranged beyond the stencil electrode. Alternately, high velocity particles traveling through the stencil electrode may dislodge previously deposited powder particles thereby causing poor quality printed images or coatings. It was additionally noted that, while the smallest aperture in a stencil electrode is dependent upon the particle size of the powder being transferred, the pattern created by printing through larger sized apertures is affected by the electric field pattern surrounding the aperture. Further testing has shown that either a positive or a negative polarity can be used on the first or charging electrode to initiate powder transfer between the two electrodes.

In view of the above-determined fact that charged powder particles can react as electrons when concerned with particle transfer, numerous variations of particle transfer devices can be utilized other than in the application of electrostatic printing. An important feature of this invention is that the path of the particles being transferred is not defined to an area between the two electrodes which create the electric field. In that the momentum of the particles allow them to travel to and beyond the second electrode, the transferred particles may be used not only for electrostatic printing but in other devices such as particle classification and in particle transfer or pumping arrangements wherein a series of particles are transferred successively from one point to another.

In the field of electrostatic printing, the present invention has the obvious advantage, over prior art devices, of allowing the production of a relatively compact printing apparatus capable of rapidly printing or coating a plurality of individual objects or a continuous substrate where the object or substrate travel above and adjacent to the second electrode, rather than between the two electrodes. In addition the articles being coated do not form part of the electric circuit as in many prior art devices.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view in perspective of the present invention utilized in electrostatic printing apparatus;

FIG. 2 is a schematic view of the invention utilized in another embodiment of an electrostatic printing apparatus;

FIG. 3 is a front plan view of the interior of an embodiment of the present device utilized for pumping or transferring charged particles;

FIG. 4 is a side view of FIG. 3;

FIG. 5 is a top view of FIG. 3;

FIG. 6 is a schematic sectional view of another embodiment of the present invention used in particle classification;

FIG. 7 is a sectional view taken along line 7—7 of FIG. 6;

FIG. 8 is a side view of another embodiment of the present invention used in an electrostatic printing device;

FIG. 9 is a longitudinal section of FIG. 8;

FIGS. 10, and 11 are top views of other embodiments of the charging electrode of the subject invention;

FIG. 12 is a front plan view of FIG. 10, and

FIG. 13 is a front plan view of the charging electrode and powder particles in place.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The embodiments shown in FIG. 1 of the invention are utilized in an electrostatic printing device comprising a supply hopper 10 which delivers powder particles 12 by means of gravity onto a conveying tray 14 which delivers the particles 12 from the mouth or exit 16 of the feed hopper to the first or charging electrode 18. The charging electrode 18 is mounted on or connected directly to the tray 14 and is arranged directly below the stencil electrode 20 which may be permanently or

movably mounted above the charging electrode on tracks or rails 22 or 24. The stencil electrode 20 includes apertures 21 in a desired pattern of indicia or the like, through which the transferred particles travel. The container 26 or other article to be coated is positioned adjacent to and immediately above the stencil electrode 20 when in proper position to be printed. The container 26 may be mounted on a conveyor means or the like (not shown) which moves it and a plurality of like objects into printing position over the stencil electrode. Electrical source, generally indicated at 28, impresses a potential between the electrodes 18 and 20.

In operation, dry powder or like particles of the type which may travel in an electric field are stored in feed hopper 10. These particles may be conductive or precharged, nonconductive particles as pointed out above. The particles stored in hopper 10 are directed onto tray 14 through the mouth 16 of hopper 10 by means of gravity. The particles 12 delivered to the tray flow towards the lower or charging electrode 18 as generally represented by the arrow. As the particles reach electrode 18, they are propelled by means of the electric field created between electrode 18 and electrode 20, against gravity and towards the stencil electrode 20. Due to the mass of the particles and to the potential between the electrodes, each particle contains sufficient momentum to carry a portion of the particles through the apertures 21 in the stencil electrode 20 and onto the desired surface of the container 26 or other article to be coated.

As explained previously, the particles used in this embodiment may be either conductive particles or precharged, nonconductive particles, the only stipulation being that the particles are of the type capable of traveling in an electric field established between two electrodes created by a potential difference across the electrodes. It should be further pointed out that stencil electrode 20 may be permanently mounted above charging electrode 18 so as to provide the desired pattern which determines the pattern of particles applied to the surface of the container or article 26 which is being coated. Alternately, the stencil electrode 20 may be movably mounted above the bottom, or charging, electrode 18 such that a plurality of articles or different portions of a continuous substrate may be coated with alternate patterns conforming to associated substrate which flows along with the container as shown generally by arrow 32 in FIG. 1.

FIG. 2 shows an additional embodiment utilizing the invention in an electrostatic printing device where the indicia or desired pattern is created on the substrate to be coated by first creating a latent electrostatic image thereon. In operation, a substrate or article 34 is first transferred to an area adjacent to and immediately above stencil electrode 38, having apertures 40, which form the desired pattern or indicia defining the latent electrostatic image to be placed on the substrate 34. Charging electrode 44 is mounted a spaced, predetermined distance immediately below stencil electrode 38 and an electric field is established between the electrodes 38 and 44 by means of electric source generally indicated at 46. As the substrate 34 is positioned over the stencil electrode 38 and the electric field between electrodes 38 and 44 is established, a latent electrostatic image is produced on the substrate 34 by the impact of charged, conductive particles 42 onto the desired surface of the nonconductive substrate 34. The forming of the latent electrostatic image 48 will be described more thoroughly later. The substrate 34 having a latent electrostatic image 48 placed thereon is next positioned adjacent to a source of positively charged, nonconductive powder particles 50 which may be toner or the like. The nonconductive toner particles 50 may be precharged by a positive corona, generally indicated at 52, and delivered by a tray or conveying means 54 to an area where the positively charged toner particles 50 are attracted to the oppositely charged areas defining the latent electrostatic image 48 on precharged substrate 44. Thereby the desired image or pattern to be printed on the substrate 34 is developed and is fully visible after application of the toner particles 50.

The forming of the latent electrostatic image occurs when the conductive particles 42 having, for example, a negative polarity, selectively bombard the defined areas on the positively charged substrate corresponding to apertures 40 in stencil electrode 38 thereby resulting in a change in the preselected polarity in the defined areas of the substrate surface. The latent image is created in that there is no permanent transfer of conductive particles 42 onto substrate 34. Elimination of adhesion between particles 42 and substrate 34 is accomplished by increasing the momentum of the particles to a degree where the particles ricochet off the substrate. Increased momentum is accomplished through the use of either large mesh particles (60 mesh) or high particle velocity of smaller particles created through higher potential between the electrodes. It should be noted that the use of larger particles assures charge transfer as evidenced in Formula 2, cited above, wherein it was established that the charge carried by a conductive particle is directly proportional to its surface area.

FIGS. 8 and 9 show yet another embodiment of the present invention utilized in an electrostatic printing device wherein a stencil is used to define the pattern of coating applied to the substrate or article to be coated but is made of a nonconductive material and is not an electrode which defines the electric field giving force to the particles being transferred. The device comprises a housing, generally indicated at 56, having sidewall 58 and end wall 60. The base of the housing comprises a bottom or charging electrode 62 to which a plurality of either conductive particles or precharged, nonconductive particles 64 are delivered into a receptacle portion 65 of the charging electrode. A second electrode 66, in the form of an elongated conducting rod or the like is mounted at 61 within the end walls 60 positioned above the charging electrode 62. A stencil 68 which may be made of nonconductive material is mounted as part of the housing immediately above the elongated electrode 66. An article to be coated 70 is arranged adjacent to and above the aperture 72 in stencil 68, where the pattern of the coating to be placed on substrate 70 is defined by the aperture 72 in stencil 68.

In operation, the particles 64 are delivered to the electrode 62 by any appropriate means and an electric field is established between electrodes 62 and 66 so as to propel particles 64 towards electrode 66. When a potential difference is established between the two electrodes, there is an avalanche of powder propelled towards elongated electrode 66. Due to inertia and the momentum of the particles established because of their size and the potential, the particles are permitted to bypass electrode 66 and be propelled through aperture 72 onto the surface of substrate 70.

The versatility of the present invention is quite evident from the fact that the path of particle transfer is not limited to between the two electrodes establishing the electric field as in prior art devices. Consequently, after the particles being transferred pass beyond the second electrode, as explained above, the particles may be utilized for a number of useful applications.

In FIGS. 6 and 7, the present invention is utilized in a particle classification device which classifies or separates particles according to size and conveys or transfers the classified particles to separate utilization or storage areas. The device in FIGS. 6 and 7 comprises a storage and feed hopper 74 for storing and delivering by gravity a supply of various sized conductive and precharged nonconductive particles 76. The hopper 74 is mounted above and adjacent to conveying plate 78 which serves as the base portion of the housing 79. The plate 78 is caused to reciprocate or vibrate by means of motor 80 directly linked to supporting arms 82 which are in turn supported on base 84. A plurality of charging electrodes 86 are connected to the conveying plate 78 and are mounted a spaced, predetermined distance immediately below a plurality of individually associated stencil type electrodes 88. The stencil electrodes 88 comprise a plurality of apertures 90 which are progressively larger in each successive electrode so as to allow the passage therethrough of only appropriately sized

particles. Elongated conduits 92 are mounted immediately above each of the stencil electrodes 90 and a conveying fluid, such as air, travels within these conduits to direct the particles traveling beyond the stencil electrodes. A receiving hopper 94 is arranged at the end of the conveying plate 78 to receive excess or larger sized particles.

In operation, the various sized particles 76 are delivered by gravity from hopper 74 out of mouth 75 onto the conveying tray 78. Vibration of the plate is caused by connecting arms 82 which also are linked to a reciprocating motor or the like 80. Due to the vibration in plate 78, the particles 76 travel to the successively arranged pairs of charged and stencil electrodes 86 and 88, respectively. The apertures 90 in each of the successively arranged stencil electrodes are progressively larger so that the smaller particles will be withdrawn first from the conveying flow on tray 78. As the flow of particles reach each of the charging electrodes 86, the particles are propelled against the force of gravity up to stencil electrode 88 and through apertures 90 into the path of conveying fluid 93. Only the particles which are smaller than the apertures 90 of any given stencil electrode are allowed to pass therethrough and the remaining larger particles are deflected from the screen or stencil electrode 88 back onto the conveying tray 78. These deflective particles pass to the next successive pair of charging and stencil electrodes where the particles are again propelled towards the stencil electrode which has larger apertures to accommodate the next largest particle size. The particles pass through successive pairs of electrodes until the very largest particles are delivered from the end of the conveyor into a collection hopper 94.

Fig 7 shows the flow of conveying fluid 93 directing various particles away from a stencil electrode 88 as they pass through appropriately sized apertures 90. The arrows generally represented at 77 represent the particles being deflected back onto the conveying tray 78 where they are passed onto the next pair of charging and stencil electrodes.

FIG. 3, 4 and 5 represent yet another embodiment of the present invention which is directed to a pumping device utilized to transfer particles to a plurality of spaced, successively arranged electrodes of opposite polarity. The pumping device includes a support base 94 on which is mounted a base or charging electrode 96. The base electrode 96 is connected to a voltage source (not shown) by means of conductor 98 extending through the base 94. A pair of parallel arms or stands 100 are used to support, in successive, stacked, spaced relationship, a plurality of elongated conductors 102, 104 which form the collecting electrodes in the pumping device. The positively charged elongated electrodes 102 are alternately arranged in stacked relationship with negatively charged, elongated electrodes 104. Consequently, it is seen that each elongated electrode has an adjacent elongated electrode of opposite polarity both above and below it. Each of the elongated electrodes 102, 104 may be in the form of aperture grids such that a portion of the powder particles pass through and beyond the grid electrode.

In operation, an electric field is established by imposing potential difference between the electrodes thereby creating the lines of force which the particles follow. As the particles near the first positively charged, elongated electrode 102 its momentum allows it to pass in close proximity but beyond the first electrode such that the charge or polarity of the particle is changed, causing a repulsion between the particle and the first electrode. Through a combination of the repulsive force and the momentum of the particle, it is transferred to the second negatively charged electrode 104 where similarly, by means of its momentum, the particle passes in close proximity to and beyond the electrode 104 where the polarity of the particle is again changed. This process continues, allowing the particles to travel from electrode to electrode and thereby be pumped or transferred to a desired height or location.

FIGS. 10, 11, 12 and 13 represent an additional feature of the present invention directed to another embodiment of the charging or base electrode. In the foregoing description of the

present invention, the charging or base electrode has been a solid plate. However, it has been found that a modification of the solid plate charging electrode is better suited to some applications of the present invention.

FIGS. 10 through 13 disclose a charging electrode generally indicated as 107 and including a solid baseplate 108 having a plurality of fine conductive wires 110 mounted in various configurations such that positions of the conductive wires are arranged on the upper surface of the plate 108 and in spaced positions relative to one another. The wire may be of various sizes and material dependent upon the specific application in which the present embodiment is used. The wire used during experimentation has been 0.005 inch in diameter and made from tungsten, nichrome or copper material. This charging electrode is made from a plurality of fine wires 110 used to transfer particles 112 of nonconductive material such as zirconia alumina, soda glass, borate glass, etc. The use of the multiwire charging electrode 107 allows the elimination of the precharging of the nonconductive particles as described with reference to the apparatus of FIG. 2.

Tests have shown that the means of transfer of these nonconductive materials may be ionic conduction, ion bombardment, surface conduction, due to surface contaminants, or a combination of any of these. An example of this combination effect is shown when nonconductive particles 112, 114 are placed on a multiwire charging electrode 107. The nonconductive particles 112 in contact with the wire 110 transfer immediately where the nonconductive particles 114 laying between the two wires 110 are transferred only after a short interval of time has lapsed. This time is estimated to be between 0.001 to 0.1 of a second.

In view of the above-described inventions, applied to the outlined embodiments, the present invention is fully defined in the following claims.

I claim:

1. A separating apparatus for transferring both conductive and nonconductive powder particles of the type which are capable of movement in an electric field, the apparatus comprising a plurality of apertured screen electrodes, each having different size mesh apertures;

a plurality of basic electrodes, each mounted a spaced, predetermined distance below a screen electrode;

means for applying a predetermined transfer potential between said electrodes thereby establishing an electric field between each pair of electrodes;

conveying means connected to and including the plurality of base electrodes including a conveying plate attached to the plurality of base electrodes;

means supplying the powder particles to the conveying means;

vibration means connected to said conveying plate wherein the conveying plate is reciprocated causing travel of the particles to successive electrode pairs; and

means for conveying a carrier fluid immediately above each screen electrode, including a channel means having an input on one side of a screen electrode and an output on the other side to direct gas transversely across one side of the screen electrode with a minimum of disturbance of the particle travel between the screen electrode and the base electrode, whereby various size particles are delivered to the conveying means and enter the electric field of an electrode pair and are projected toward said screen electrodes, the particles compatible to the particle screen aperture passing through the appropriate screen electrode due to their momentum and being conveyed from the screen electrode by the carrier fluid, larger particles being blocked and passed along the conveying means to the next electrode pair.

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