United States Patent [19]

Masuda

[11] **3,841,264**

[45] **Oct. 15, 1974**

[54] **APPARATUS FOR APPLYING DUST PARTICLES BY CONTACT TYPE ELECTRIC FIELD CURTAIN**

[76] Inventor: **Senichi Masuda,** 40-10-605, 1-chome, Nishigahara, Kita-ku, Tokyo, Japan

[22] Filed: **Sept. 25, 1972**

[21] Appl. No.: **291,553**

[30] **Foreign Application Priority Data**

Sept. 29, 1971 Japan 46-76081

[52] **U.S. Cl.** **118/622,** 118/621, 118/629, 239/15

[51] **Int. Cl.** **B05c 5/02**

[58] **Field of Search** .... 118/620, 621, 622, 627, 118/629, 630; 117/93.4 R, 95, 96; 239/3, 15

[56] **References Cited**

UNITED STATES PATENTS

2,438,561	3/1948	Kearsley	118/622 X
2,600,129	6/1952	Richards	117/93.4
2,659,841	11/1953	Hampe	239/15
2,763,125	9/1956	Kaposch et al.	239/15
3,049,301	8/1962	Heuschkel	239/15
3,358,639	12/1967	Lopenski et al.	118/49.5
3,484,276	12/1969	Burggraaf et al.	117/95
3,503,823	3/1970	Richart et al.	118/620 X

Primary Examiner—W. C. Reynolds
Assistant Examiner—Leo Millstein

[57] **ABSTRACT**

An insulating or semiconductive tube defines a path along which powder flows from a source to an article to be coated therewith. Electrodes that extend circumferentially and are equispaced axially are embedded in the tube wall and are so connected with terminals of an a.c. source that there is a constantly varying potential difference between axially adjacent electrodes, to produce a field that tends to repel powder from the tube wall. A corona discharge electrode, fixed at the outlet end of the tube, is connected with one terminal of a high tension d.c. source. The other d.c. terminal is grounded to the article to be coated.

5 Claims, 9 Drawing Figures

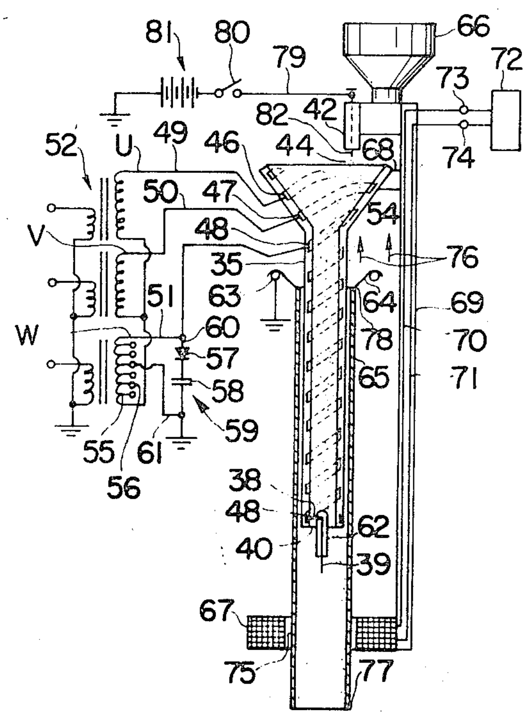


FIG. 1

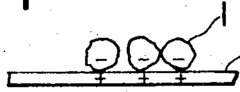


FIG. 2

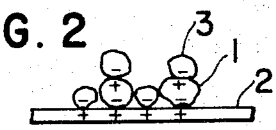


FIG. 3

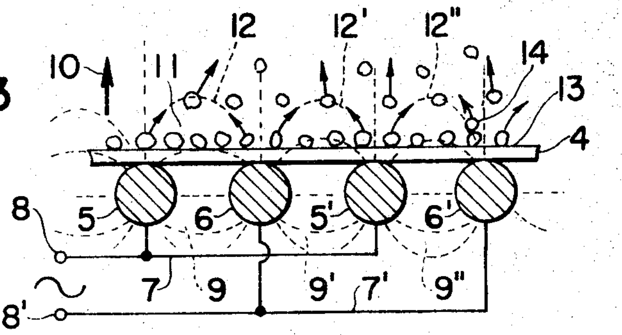


FIG. 4

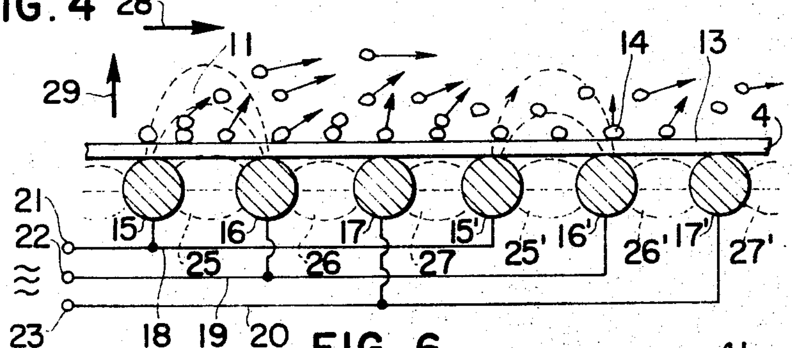


FIG. 5

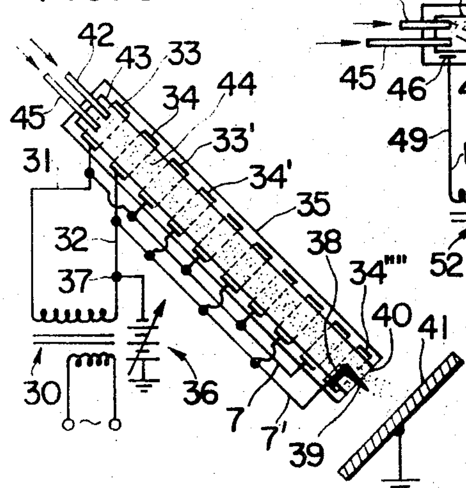


FIG. 6

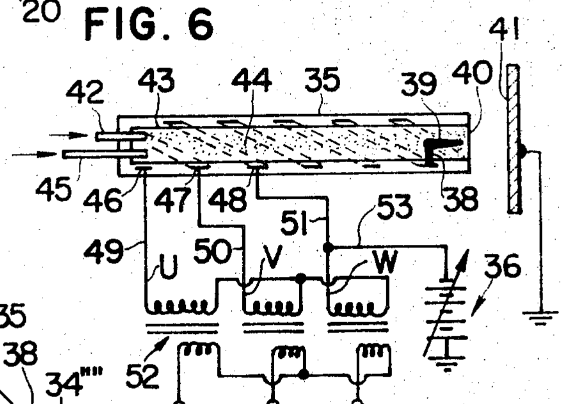


FIG. 7

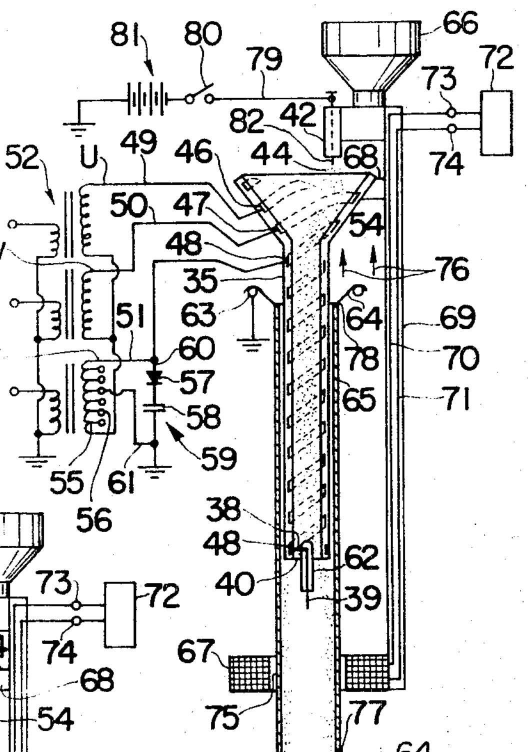


FIG. 8

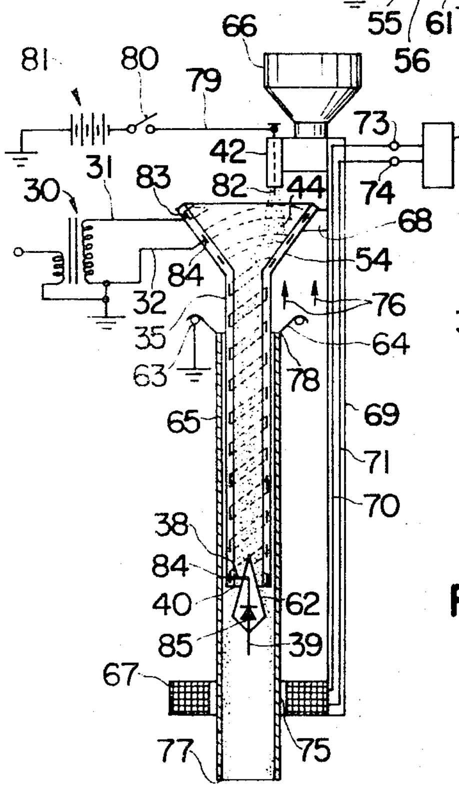
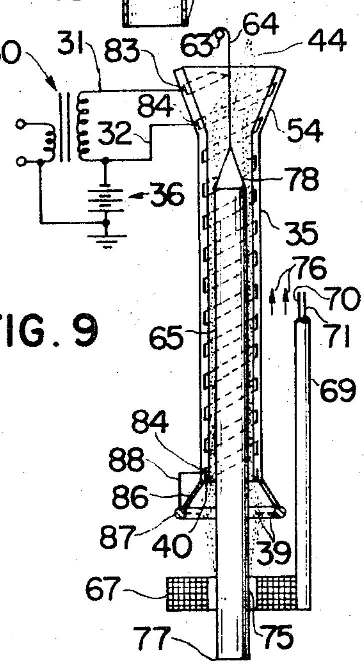


FIG. 9



APPARATUS FOR APPLYING DUST PARTICLES BY CONTACT TYPE ELECTRIC FIELD CURTAIN

This invention relates to a means for coating articles with substantially dry powder particles, which particles can be subsequently converted to a film-like or paint-like coating on the article by heating or otherwise processing the article to fuse the particles; and the invention is more particularly concerned with a means for so accomplishing such coating as to effect very accurate application of powder to the article to be coated.

The technique of coating or painting with substantially dry powder has heretofore been practiced with the use of a gun having a body made of insulating material and having an electrode at its outlet end for producing a d.c. corona discharge. The article to be painted was electrically grounded to one terminal of a d.c. source, the electrode was connected with the other terminal. Powder particles were carried through the gun body in a gas stream, and in passing the electrode they were strongly charged with ions and were thus electrostatically attracted to the grounded article.

This prior technique had the disadvantage that the gas stream which propelled the powder particles to the corona discharge zone necessarily emerged from the gun with the particles and continued to influence their direction of motion. As a result, there was a substantial amount of scattering of the particles, so that it was necessary to practice the technique in a booth equipped with a suction hood and preferably also with apparatus for collecting and recovering powder particles. For the same reason, it was practically impossible to apply the powder to only a small, precisely selected zone of the article to be painted. Thus a design, character or pattern could not be depicted on the article without masking it, nor was it feasible to use this prior technique for painting the interior of a small tube or of an article having a small cavity.

The present invention, by contrast, has as its general object to provide a means for painting an article with a substantially dry powder that is subsequently fused on the surface of the article, whereby the powder can be very accurately applied to selected surface portions of the article without scattering.

Thus it is a general object of this invention to provide a means for dry powder painting that not only causes powdered color material to be applied with such accuracy as to enable the technique to be used for delineating desired figures, patterns and designs but also enables such application to be made with unprecedented economy owing to avoidance of any waste of the powder material being applied and elimination of the need for a special booth in which the process is performed.

More specifically it is an object of this invention to provide a means for applying substantially dry powder material to an article without the need for carrying the material in a moving stream of gas, but whereby the powder particles are instead moved directly to the site to which they are to be applied by means of an electric field.

In general the objects of the invention are achieved by a means which constitutes a specialized and novel application of principles disclosed in my copending application, Ser. No. 151,789, filed June 10, 1971.

With these observations and objectives in mind, the manner in which the invention achieves its purpose will

be appreciated from the following description and the accompanying drawings, which exemplify the invention, it being understood that changes may be made in the precise method of practicing the invention and in the specific apparatus disclosed herein without departing from the essentials of the invention set forth in the appended claims.

The accompanying drawings illustrate several complete examples of embodiments of the invention constructed according to the best modes so far devised for the practical application of the principles thereof, and in which:

FIGS. 1–4 are more or less schematic drawings explaining the principles of the present invention; and

Each of FIGS. 5–9 is a more or less diagrammatic view of powder coating apparatus according to the present invention, each figure depicting a different embodiment thereof, and mechanical portions of the apparatus being in each case shown in longitudinal section.

Referring now more particularly to the accompanying drawings, FIG. 1 illustrates that when a dust or powder particle **1** is in contact with an electrically charged solid body **2**, the dust particles in contact with the body take on a charge opposite to that of the body. Thus, regardless of whether the solid body is a conductor, semiconductor or insulator, if the body is charged positively, as shown, the particles in contact with it acquire a negative charge and are attracted to it, and the body serves as an exciter.

However, as shown by FIG. 2, the contact electrification of fine particles takes place not only as between the particles and a solid body, but also as between particles when they are close together, since they tend to impress charges upon one another just as the solid body impresses charges upon them. Thus there is a difference in the surface charge conditions of the several particles in a closely spaced group of them, even though all particles are composed of the same material.

FIG. 3 shows a group of electrodes **5, 6, 5′, 6′** (which are illustrated as cylindrical and rod-like, for purposes of example), arranged parallel to one another and at equispaced intervals and in proximity to a sheet-like exciter **4** which is a nonconductor or a semiconductor. The alternate electrodes **5** and **5′** are connected with one terminal **8** of a single-phase alternating current source, and the intermediate electrodes **6, 6′** are connected with the other terminal **8′** of that source. Thus, as between any adjacent pair of electrodes there exists a constantly varying voltage difference and consequently a varying and alternating electric field.

Individual particles which contact the front surface **13** of the exciter **4** (that is, its surface remote from the electrodes) are charged by the exciter; but because of the constantly varying charge on the exciter, soon after such contact they are repelled from the exciter into the space **11** in front of it. The repulsion force upon the particles, which is denoted by the arrow **10**, is produced irrespective of the sign of the charge on the particles.

In the space **11** the particles are in a constantly changing field which is produced by the a.c. charge on the electrodes and which is denoted by the arcuate lines of force **12, 12′, 12″**. That field subjects the particles to electrodynamic forces which tend to move them along the lines **12, 12′, 12″**. The particles are of course still subject to the repulsion force denoted by arrow **10**, and they are additionally subjected to centrifugal force due to the curvature of the paths in which they tend to move. The individual particles are thus maintained in a state of rather intense motion or perturbation at a small distance in front of the exciter **4**, but because their individual motions are oscillatory when the electrodes are charged with a single-phase a.c., the group of particles, collectively, has no net motion. The apparatus just described can therefore be characterized as a generator of a standing wave electric field curtain, of contact type.

Where the exciter **4** is an insulator or semiconductor, it is a prerequisite to generation of a field comprising lines of force **12** that penetrate the space in front of the exciter that the relaxation time be sufficiency larger than the period T of the alternating voltage, where relaxation time is defined as the product of the resistivity and the dielectric constant. The a.c. frequency is preferably the commercial 50 or 60 H_z, but can be any arbitrarily selected frequency within the range of about 5–500 H_z.

Where the same general arrangement of electrodes and exciter is employed, but with a three-phase current applied to the electrodes, the curtain of particles can be made to migrate in a predetermined direction transverse to the electrodes and along the exciter. FIG. **4** illustrates such an apparatus wherein the electrodes are arranged behind the exciter **4** in groups of three electrodes, namely, **15, 16, 17** and **15', 16', 17'**, but all adjacent electrodes are, again, equispaced from one another. By means of conductors **18, 19** and **20** the several electrodes are connected with the terminals **21, 22, 23** of a three-phase a.c. source, the first electrode **15, 15'** of each triad being connected with terminal **21**, the second electrode **16, 16'** with terminal **22** and the third electrode **17, 17'** with terminal **23**.

The resultant electric field, as designated by the lines **25, 26, 27** and **25', 26', 27'** between the several pairs of adjacent electrodes is in the nature of a wave that travels transversely to the electrodes in the direction designated by the arrow **28**. Thus the charged particles in the space **11** in front of the exciter **4** are subjected to a repulsion force denoted by the arrow **29**, centrifugal forces due to the curvatures of the paths in which they tend to move, and electrodynamic forces which urge them along curved paths that follow the field force lines. Because of the travelling wave effect of the electric field, the particles collectively have a net motion in the direction of the arrow **29**, and the apparatus can thus be said to generate a travelling wave electric field curtain of the contact type.

The present invention utilizes the above described principles and phenomena to effect controlled transport of particulate bodies such as powder particles, small floc particles and the like, by which such particles can be caused to form a coating on a desired portion of an article.

Certain requirements for such apparatus should be explained in more detail. As indicated above, where:

e = dielectric constant, and

p = resistivity,

then, for the production of an electric field that extends forwardly of the exciter **4**, into the space **11**, it is necessary that

$ep > T$,

where T is relaxation time. Where the frequency of the power source is 50 H_z and the specific dielectric constant $e_s = 5$,

$T/e = 4 \times 10^9$ ohms-cm.;

hence resistivity p must necessarily be somewhat larger than (as an approximation) 10^{11} ohms-cm. On the other hand, to cause the accumulated charge on the exciter itself to leak off in consequence of contacts, it is necessary to select the value of p as low as possible within the above explained limits, or else to let the exciter have an appropriate surface conductivity.

Experiments have shown that the electric field curtain of contact type is capable of exhibiting its action effectively with not only insulating and semiconducting particles but also with conducting particulate materials such as carbon black, metallic powder, etc.

It has also been determined that, in general, the action of the electric field curtain of contact type becomes stronger if both the particles and the exciter **4** are perfectly dry, or as nearly dry as possible. This is because the several factors governing the action of the field—magnitude of contact electrification, adhesive force between particles and exciter, tendency toward coagulation of the particles, moderate leakage of the accumulated charge from the surface of the exciter, etc.—are all governed very sensitively, but in a complicated manner, by the degree of moisture adsorbed on the surfaces of the particles and the exciter. Hence when too much adsorbed water is present, the magnitude of contact electrification decreases and at the same time adhesion between particles and the exciter increases. However, if the quantity of adsorbed moisture is too small, the leakage of the charge accumulated on the exciter surface may be hindered. Accordingly, the effect of the electric field curtain is enhanced by maintaining perfect dryness, or an appropriate degree of dryness, of the exciter, the powder particles, or both.

The electric field curtain effect can be enhanced in some circumstances by preliminary charging the powder particles by means of a corona discharge. It is also possible to increase the transportation effect with the use of a gas stream in cases where the gas stream does not interfere with other results desired. For example, the exciter can be provided with a front surface layer of porous material through which a gas stream can be sent, and the gas flowing forwardly out of it supplements the electrostatic repulsion force on the particles and thereby promotes the transportation effect.

In general, the present invention contemplates encircling a space that defines a particle passage with electrodes that generate an electric field in accordance with the above described principles, and utilizing that field in transporting particles along that passage and beyond it. The electric field thus confines the particles to a defined course and prevents them from diffusing. An electric field curtain of standing wave type can be used to confine the particles to the desired path while they are propelled along it by gravity, centrifugal force or the like; or an electric field curtain of travelling wave type can be used to effect transport of the particles by its electrodynamic propulsive force. The object to be coated can be brought into the interior of the passage space defined by the electrodes, or the defined passage can extend into the interior of an article having a cavity or bore. When appropriate, an air or gas stream can be used as a supplementary means for transportation of particles.

It will be understood that, to the extent necessary, the particles will be dried in any suitable manner, as by vacuum drying or streaming with a dry gas; and that the exciter is also dried, if necessary, as by heating it or streaming a dry gas across it.

FIGS. 5–9 are more or less diagrammatic showings of specific applications of the principles of the invention.

Referring first to FIG. 5, which exemplifies an embodiment of the invention that utilizes an electric field curtain of standing wave type, a group of substantially identical annular electrodes 33, 34, 33', 34' . . . are arranged concentrically with one another and embedded at equispaced axial intervals in the wall of a tube 35 of insulating material. The tube 35 which serves both as an exciter and as a guide or passage defining means for particles 44 to be fed through it, can be mounted in an upright position or, as here shown, can be substantially inclined to the horizontal. Alternate electrodes 33, 33' . . . are connected by a conductor 7 with one terminal 31 of a single phase a.c. source, here represented as the secondary of a step-up transformer 30. The other electrodes 34, 34' . . . are connected by a conductor 7' with the other conductor 32 of the a.c. source. Hence an electric field curtain of standing wave type is formed on the inner surface of the exciter tube 35.

Powder particles 44 are introduced into the upper end of the tube 35 from a supply tube 42, and they flow by gravity to an article 41 to be coated, which is located at a short distance from the lower end of the tube and in line with it. In the course of its passage through the tube, each particle contacts the inner surface thereof only once or a few times, just sufficiently to pick up a charge that will insure its being repelled from the surface of the tube; hence, as with the exciter 4 in the previously described embodiments, the particles will mainly be spaced from the inner surface of the tubular exciter 35 as they fall through it, and they are thus confined to substantially axial flow through the tube.

From the annular electrode 34'''' nearest the outlet end of the tube an electrically conducting stay 38 projects radially into the tube 35 and supports a needle-shaped corona electrode 39 that is disposed substantially on the axis of the tube and projects axially outwardly from it. The negative side of a variable d.c. power source 36 is connected, as at 37, with the a.c. terminal 32, and through it with the electrode 34'''' and thus with the corona electrode 39. The positive side of the d.c. power source is grounded to the article 41 to be coated, so that a corona discharge takes place between the needle 39, as the cathode, and the article, as the anode. As powder particles pass out of the tube and through the zone in which the corona discharge is taking place, they receive an intense negative charge from the corona discharge, and hence they are attracted to the article 41.

FIG. 5 shows an air inlet 45 which opens to the interior of the tube 35 near its upper end, and through which a stream of air can be directed downwardly, in cases where it may be desired to supplement the propulsive force of gravity upon the powder particles.

FIG. 6 illustrates apparatus that utilizes the principle of the electric field curtain of travelling wave type. In this case the tubular powder guide 35 is disposed with its axis horizontal. Powder is introduced into it from a powder inlet 42 at one end, and an article 41 to be coated is located in axial alignment with the tube a short distance from its outlet end. Embedded in the wall of the tube 35 are three electrodes 46, 47, 48 which generate the electric field. They are foil strips that spiral around the tube and are spaced apart by equal and uniform distances all along it. These electrodes 46, 47, 48 are connected by means of conductors 49, 50 and 51, respectively, with the terminals U, V, W, respectively, of a three-phase a.c. source, here shown as a step-up transformer 52. A conducting stay 38 supports a substantially coaxial outwardly projecting corona discharge needle 39 near the outlet end of the tube 35 and connects that needle with the electrode 48. The electrode 48, in turn, through its connected conductor 51, is connected with the negative terminal of a variable power high voltage d.c. source 36, and the article 41 is connected with the positive terminal of that d.c. source. Hence there is again a corona discharge directed from the needle 39 to the grounded article 41.

The particles 44 that are introduced into the tube 35 from the powder inlet 42, after briefly contacting the interior surface of the tube to receive a charge therefrom, are propelled along the interior surface of the tube by the travelling wave effect of the electric field generated by the charged electrodes 46, 47, 48. They are mainly out of contact with the tube as they travel along it, owing to the above explained repulsion force. As they pass through the corona discharge, they receive an intense negative charge and are attracted to the positively charged article 41.

In this case the needle electrode can be adjusted both radially and axially, to provide for accurate guidance of the powder particles onto the article. An air inlet 45 can be provided, if desired, to assist in propelling the particles along the tube.

Instead of the needle-like corona discharge electrode 39, that electrode could obviously have some other shape; e.g., it can take the form of a cylindrical or annular conductor or a conducting membrane. The effect of the corona discharge can be augmented by providing several corona discharge needles projecting into the interior of the tube, for imparting charges to the particles. Likewise, the positive terminal of the high tension d.c. source could be connected with the corona discharge electrode, the article 41 then being connected with its negative terminal. In certain circumstances the corona discharge electrode can be eliminated, relying on the charge upon the particles due to contact electrification.

It will also be evident that the tube 35 need not have a circular cross section. Thus, at least its outlet end portion can be so shaped as to define a particular pattern or figure to be delineated on the article to be coated. In such cases it may be preferable to have the corona discharge electrode formed as a membrane or the like that extends around the inner surface of the tube at the outlet end thereof. By combining several devices of the type shown in FIG. 6, each operating with powder material of a different color, multicolored patterns can be very accurately coated onto articles to be painted. Powder application is further controllable by reason of the fact that flow of powder along the tube can be stopped by terminating energization of the field generating electrodes 46, 47, 48, or can be reversed by reversing their connections to the a.c. power terminals and thus changing phase direction. It will be further noted that with those electrodes in the form of foil strips, the tube 35 can be a flexible one if desired.

FIG. 7 illustrates apparatus embodying the principles of this invention by which powder can be coated onto the interior surface of a tube or pipe 65. The apparatus again comprises a tubular body 35 which serves as both an exciter and a particle guide, and which has three spirally arranged foil strip electrodes 46, 47, 48 embedded in its wall. The electrodes are respectively connected, by means of conductors 49, 50, 51, with the terminals U, V, W of a three-phase a.c. source comprising a transformer 52.

The transformer secondary winding 55 that comprises terminal W has a number of selectable taps 56, and across one of these and the terminal W are connected a rectifier 57 and a condenser 58, in series, to provide a d.c. power source. The voltage across that d.c. source is of course dependent upon the particular tap 56 to which connection is made. Through a conductor 60 the negative side of this d.c. power source is connected with the conductor 51, to thus connect the electrode 48 with the negative d.c. terminal as well as with terminal W of the a.c. source. The electrode 48 is in turn connected with a needle-like corona discharge electrode 39 that projects coaxially outwardly from the discharge end of the tubular exciter 35. An insulating sheath 62 surrounds all but the projecting outer end portion of the corona electrode.

In this case the tubular body 35 is upright, and it is formed at its top with a funnel-like inlet portion 54 in which continuations of the electrodes 46, 47, 48 are also embedded.

A pipe or other hollow article 65 to be coated, grounded to the positive terminal of the d.c. source, is supported, as by means of straps 64, in concentric surrounding relation to the tube 35 and in a manner that provides for relative axial motion between the article and the tube 35. From a supply vessel 66 above the funnel-like inlet of the tube 35 powder particles are fed downward thereinto through an inlet duct 42, and after making contact with the inner surface of the funnel-like portion and thus receiving a charge, the particles are transported down the tube 35, propelled by both gravity and the travelling wave of the a.c. field. The particles move very smoothly and continuously, even without the use of a supplemental gas stream and even though the tube 35 may have an inside diameter as small as 10–15 mm.

Near the lower end of the tube 35 the particles receive an intense negative charge, owing to the action of the corona discharge means, and are attracted to the inner surface of the grounded article to be coated. Hence if the article 65 is moved steadily downwardly relative to the apparatus comprising the tube 35, the article will receive a very smooth and uniform coating on its interior surface.

An induction heating coil 67 can be spaced below the outlet end of the tube 35, in surrounding relation to the article 65. It is connected in fixed relation to the funnel-like inlet portion of the tube 35 by means of an arm 68 projecting laterally from the tube and an upright 70 which is secured to that arm and also to the supply vessel 66 and the induction heating coil. By means of conductors 70 and 71 the induction heating coil is connected with the terminals 73 and 74 of a high frequency current source 72. As the article to be coated is moved downwardly relative to the coating apparatus comprising the tube 35, the coil 67 causes the deposited powder to be fused very shortly after its application, and in this manner a very uniform film or coat of paint can be applied to the entire interior surface of the article. It will be understood that instead of the induction heating coil, other expedients could be used for heating the article, such as infra-red lamps, electron beams, electric heaters or gas burners.

As shown in FIG. 7, a slender, rod-like corona discharge electrode 82 extends through the inlet duct 42 for powder material. The rod 82 is connected, through a conductor 79 and a switch 80, with one terminal of a high voltage d.c. source 81, the other terminal thereof being grounded; hence when the switch 80 is closed, the rod 82 produces a corona discharge by which the particles are preliminarily charged before they enter the inlet portion of the tube 35. Such corona discharge accelerates the downward transportation of particles along the tube 35.

The apparatus of FIG. 8 is similar to that of FIG. 7 in most respects, as is evident from like reference characters designating like parts in those two figures. In the FIG. 8 apparatus, however, there are only two spiral electrodes 83, 84 embedded in the wall of the tube 35, and they are connected to the terminals 31, 32 of a single phase a.c. source illustrated as a step-up transformer 30. In this case, therefore, a contact electric field curtain of standing wave type is generated, and the particles move down the tube 35 solely under the influence of gravity, their smooth descent being assured by the fact that they are mainly out of contact with the surface of that tube. The corona discharge needle 39 is similar to that in the FIG. 7 embodiment, except that in FIG. 8 the rectifier 85, which is connected in series between the corona elctrode and the spiral electrode 83, is located within the insulating sheath 62 that surrounds the corona electrode.

FIG. 9 illustrates apparatus by which a uniform coating of powder material can be applied to the exterior surface of an elongated cylindrical article 65, such as a pipe, tube or rod. The guide and exciter tube 35 in this case concentrically surrounds the article to be coated and of course has an inside diameter somewhat larger than the outside diameter of the article. As in the FIG. 8 embodiment, two spiral electrodes 83, 84 are embedded in the wall of the tube 35 and are connected with a single phase a.c. source 30 to generate an electric field curtain of standing wave type. The tube 35 and the article 65 are oriented with their axes vertical, the article being suspended in a manner that provides for moving it steadily downward through the tube. By way of a conductor 32, a high tension d.c. source 36 has its negative terminal connected with the spiral electrode 84, and through it with a corona discharge electrode that comprises a conductive ring 87, held concentric with the tube 35 on a bell mouth support 86 at the bottom of that tube, and a plurality of needle-like corona discharge electrodes 39 which project radially inwardly from that ring. The article 65 is of course grounded to the positive terminal of the d.c. source.

As in the FIG. 8 embodiment, powder particles introduced into the top of the tube 35 move downwardly along it by gravity, receive an intensive charge in the zone of the corona discharge needles 39, and are thereby attracted to the article, settling on it in a smooth uniform coating; and the coating can then be fused, as by heat produced by a high frequency induction coil **67**, to provide a smooth coat of film or paint on the article.

From the foregoing description taken with the accompanying drawings it will be apparent that this invention provides a very novel method and means for accomplishing very accurate coating of an article with a powdered material that can be fused into a film after its deposition, and that by means of the invention such precision can be achieved in the coating process that the interior surfaces of small cavities and bores can be evenly coated and designs and patterns can be delineated without the need for masking. It will also be apparent that the invention eliminates the need for spray booth and powder recovery equipment by reason of the coating accuracy that it insures, and thus facilitates the coating process and reduces its cost.

Those skilled in the art will appreciate that the invention can be embodied in forms other than as herein disclosed for purposes of illustration.

The invention is defined by the following claims:

1. Apparatus by which finely divided particulate material from a source thereof can be coated onto a cylindrical surface of an elongated workpiece, said apparatus comprising:

A. an elongated tubular guide element of electrical insulation material having a cylindrical surface which can oppose said surface of the workpiece all around the same so that said guide element can be disposed in telescoping relationship to the workpiece, said surface of the guide element having a diameter such that said opposing surfaces are radially spaced apart when the guide element and the workpiece are concentric to one another;

B. means for holding the tubular guide element and the workpiece in concentric telescoped relationship to one another and for effecting relative axial motion between the guide element and the workpiece;

C. means for introducing finely divided particular material from said source thereof into the interior of the tubular guide element from one end thereof;

D. a plurality of electrodes extending circumferentially around the tubular guide element and arranged in axially spaced relation to one another; and

E. conductor means connecting each electrode with only one terminal of an alternating voltage source, axially adjacent electrodes being connected with different terminals so that a varying potential difference exists between each pair of axially adjacent electrodes to produce an electric field that controls the motion of said material in the direction lengthwise of the guide element.

2. The apparatus of claim **1**, wherein said guide element is receivable within the interior of a tubular workpiece that is to have its inner surface coated, further characterized by:

F. a corona discharge electrode exposed near the other end of the tubular guide element;

G. means connecting said corona discharge element with one terminal of a high voltage d.c. source; and

H. means for connecting the workpiece with the other terminal of said d.c. source.

3. The aPparatus of claim **1**, wherein said tubular guide element has its inside diameter large enough to receive a workpiece therein for coating of an exterior surface of the workpiece.

4. The apparatus of claim **1**, further characterized by:

F. an inductance heating coil adapted to surround the workpiece supported in concentric relation to the tubular guide element and in fixedly spaced relation to said other end thereof, said inductance heating coil being connectable with a source of high frequency alternating current.

5. The apparatus of claim **1**, further characterized by:

D. said electrodes being embedded in the wall of the tubular guide element and being arranged spirally around and along the tube with axially adjacent electrodes spaced apart by substantially uniform distances all along their lengths.

* * * * *