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(71) Applicant : **NORDSON CORPORATION**
28601 Clemens Road
Westlake Ohio 44145-1148 (US)

(72) Inventor : **Matsunaga, Masahumi**
4-1-55-201 Shimoda-cho, Kohoku-ku
Yokohama City, Kanagawa Pref. (JP)

Inventor : **Kohama, Takashi**
2-5-25 Kaminoge, Setagaya-Ku
Tokyo (JP)

Inventor : **Takayanagi, Akito**
2-4-2 Minamidai, Nakano-ku
Tokyo (JP)

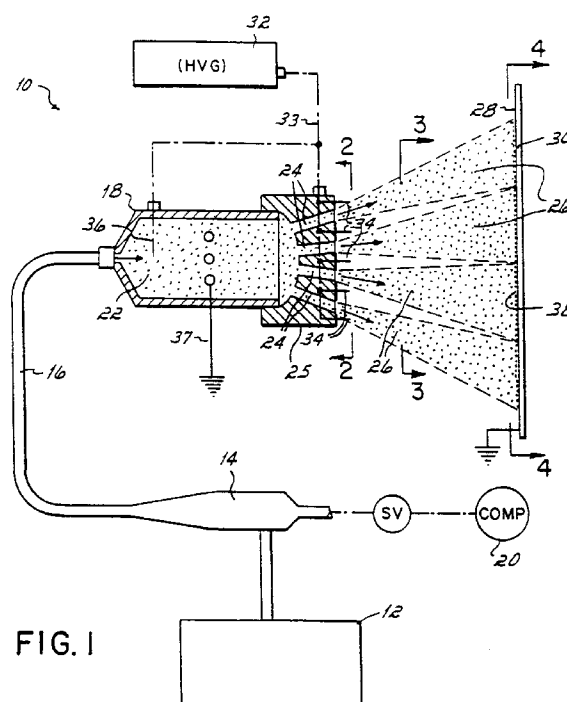
Inventor : **Inou, Ryo**
4-11-18 Matsubara, Setagaya-Ku
Tokyo (JP)

Inventor : **Yabuuchi, Isao, Sunheim Idogaya**
No. 101
108 Idogaya Naka-machi, Minami-ku
Yokohama City, Kanagawa Pref. (JP)

(74) Representative : **Allen, Oliver John Richard et al**
Lloyd Wise, Tregear & Co. Norman House
105-109 Strand
London, WC2R 0AE (GB)

(54) **Improvements in and relating to electrostatic powder coating.**

(57) An electrostatic powder coating gun splits a pressurized gas-powder mixture into a plurality of separate electrostatically charged spray streams (26) to achieve a high degree of directionality and reduce deflection. The powder particles in the mixture may be electrostatically charged while inside one or more chambers (22) in the gun (18), either by an applied DC electrostatic field or by friction. The flow paths traversed by the spray streams (26) may be arranged and/or oriented so as to advantageously powder coat a particular surface configuration, such as the inside of a container. Alternatively, electrostatic charging of powder particles may occur via a plurality of electrodes (34) located external to the gun, with at least one external electrode associated with each spray stream (26). To further reduce deflection, the mixture may be sprayed from the gun in a pulsed manner. Additionally, the electrostatic fields created by the external electrodes (34) may be pulsed between an "off" and "on" condition during spraying.



This invention relates to electrostatic powder coating, particularly, to electrostatic powder coating utilising a plurality of spray streams.

According to conventional powder coating methods and apparatus, a pressurized mixture of gas and powder particles is electrostatically charged and ejected or sprayed outwardly from a gun in the direction of an object to be coated. The particles entrained in the gas-powder mixture may be charged while inside the gun via an applied electrostatic field or by frictional charging, i.e. triboelectric, or outside the gun via an electrostatic field produced by an external electrode. During electrostatic powder coating, the charged powder particles in the mixture repel one another as they travel toward the object to be coated. During flight, the lower electrical potential of the object to be coated electrostatically attracts the particles.

To achieve uniformity in coating with a conventional coating gun, it is common to locate a trumpet-shaped deflector in front of the nozzle of the gun. The deflector diffuses or spreads the flow path of the pressurized mixture so that the powder will cover a broader surface area. While this method works reasonably well in rough coating an object, it suffers from several limitations. Primarily, due to the relatively broad cross-sectional area, the sprayed mixture produces a thick air cushion. This air cushion obstructs the flow of following particles and causes a substantial number of the subsequently sprayed particles to rebound away from the coating surface. As a result, powder coating by this method takes additional time to ensure complete coating and significant amounts of powder are lost due to rebounding.

Conventional powder coating methods and apparatus also suffer from limitations in coating uneven or irregular surfaces, such as the inside surface of a cylindrical container or a metallic pipe. When using an external electrode to establish an electrostatic field between the gun and the object, the strongest lines of electrostatic force will be located along a direct line of sight path to the nearest portions of the object, and electrostatic lines of force directed toward the recessed portions will be significantly weaker. For instance, with respect to a container, the lines of electrostatic force will be strongest between the gun and the top of the inside surface of the container and weakest between the gun and the bottom of the container.

When powder coating an object or work piece with multiple projections and/or hollows, i.e. an uneven surface, the charged particles initially take the path of the strongest electrostatic field lines. Thereafter, the particles tend to continue along this same path, eventually accumulating on discrete areas of the object which are nearest the gun, or on projections which are closer to the gun than surrounding areas. As a result, the object is not uniformly coated. More specifically, workpieces or objects with projections

and/or hollows are coated very unevenly. In many cases, it is common that the tops or edges of the projections will be coated heavily, the bottoms of hollows will be coated thinly and the corners of hollows will hardly be coated at all. The tendency of the particles to accumulate in discrete areas rather than uniformly over the entire surface is referred to as the Faraday cage effect.

Another problem associated with powder coating relates to insufficient charging of the powder particles mixture when frictional charging is used. To increase the charging rate when using frictional charging, it is necessary to increase the contact area of the mixture. However, this results in a longer and more complex flow path. As a result, if one wishes to change colors, it takes a longer time to change over to a different color powder.

With an electrostatic field produced by an external electrode, charging efficiency may sometimes be increased by increasing the field strength. However, this may increase the adverse effects produced by the Faraday cage effect. Additionally, particles having a higher charge retain their charge after deposition, thereby repulsing subsequent particles and inhibiting the application of a second coating.

Another problem associated with powder coating relates to changes in the volume of powder particles sprayed per unit time. Typically, the amount of powder sprayed per unit time is changed by increasing or decreasing pump pressure. However, pressure variations produce changes in ejection speed from the spray gun, which may result in different coating phenomena, such as soft landing or continuous jet stream collision. In soft landing, coating is affected via electrostatic attraction and coating weight increases where further coating is unnecessary, due to the Faraday cage effect. Places where further coating is necessary are insufficiently coated. With jet stream collision, rebounding is so violent that even deposited powder particles may be blown off the object.

Another limitation of conventional powder coating methods and apparatus relates to coating relatively small objects. If a lower pressure is used, i.e. 1.5 Kg/cm² or lower, to accommodate the lower required volume, the spray pattern becomes unstable, resulting in uneven coating.

A method of electrostatic powder coating in accordance with the invention comprises the steps of spraying a pressurized mixture of gas and powder particles outwardly from a spray gun characterised in that the mixture is sprayed in a plurality of separate spray streams, the particles entrained in the mixture being electrostatically charged within an internal chamber of the gun, thereby producing a plurality of electrostatically charged spray streams.

Such an arrangement improves the uniformity in the powder coating of uneven, or irregularly shaped objects, such as, for example, the inside surface of a

container, and also reduces the amount of deflection or rebounding which occurs during powder coating.

In accordance with a second aspect of the invention, a method of electrostatic powder coating comprises the steps of spraying a pressurized mixture of gas and powder particles outwardly from a gun in a series of pulses; electrostatically charging the particles entrained in the mixture during the spraying step via an electrostatic field established by an electrode operatively connected to a DC power supply; characterised in that the electrostatic field is pulsed during the spraying step.

With such an arrangement, a higher efficiency in the charging of particles entrained in a gas-powder mixture used in electrostatic powder coating is achieved without adversely affecting the application of subsequent coatings, furthermore the adverse coating results produced by the Faraday cage effect, particularly when utilizing a powder coating apparatus equipped with an external electrode, are minimised.

In accordance with a further aspect of the invention, a method of electrostatic powder coating comprises spraying a pressurized mixture of gas and powder particles outwardly from a spray gun towards the surface to be coated, and electrostatically charging the particles, characterised in that the mixture is sprayed in pulses.

With such an arrangement the efficiency of powder coating relatively small objects or with relatively small volumes is improved.

Apparatus in accordance with the invention comprises a gun having at least one internal chamber, the chamber having at least two openings to atmosphere; means for introducing a pressurized mixture of gas and powder particles into the chamber and spraying the mixture outwardly from the gun through the openings to produce two or more separate spray streams and means for electrostatically charging the particles entrained in the mixture by means of at least one electrode which produces an electrostatic field when operatively connected to a power supply.

Methods and apparatus in accordance with the invention split a pressurized mixture of gas and powder particles into a plurality of separate spray streams. Splitting the mixture into a plurality of fine spray streams reduces rebounding effects and enables an operator to powder coat relatively large or small surface areas with multiple flow paths arranged in a selectable pattern which is dictated by the shape of the object to be coated.

Particles entrained within the multiple spray streams may be electrostatically charged by multiple external electrodes, with at least one external electrode associated with each of the spray streams. The use of multiple fine spray streams in conjunction with multiple external electrodes provides efficient charging of powder particles in the separate spray streams with minimum air cushion.

In accordance with a further feature of the invention, the gas-powder mixture is sprayed from the gun in a pulsed manner. Pulsing the powder particles from the gun produces more precise control over the amount of powder sprayed per unit time and actively "air cushions" and facilitates coating with relatively smaller volumes.

The DC electrical power supplied to the external electrodes to produce the electrostatic fields for charging particles may be pulsed between an "off" and an "on" condition during spraying to periodically pulse the electrostatic fields established between the external electrodes and the object to be coated. Pulsing of the electrostatic fields reduces the Faraday cage effect because when the field is "off", particles will flow unimpeded by the field along flight paths produced by aerodynamic forces only. This produces more uniform coating of areas such as container bottoms and recesses of irregular surfaces.

Pulsing the electrostatic field may be carried out in conjunction with pulsing of the powder flow. Additionally, these two features may be further combined with the use of multiple spray streams and multiple external electrodes.

The methods and apparatus of this invention are particularly suitable for powder coating the inside surfaces of containers. More particularly, the combination of multiple spray streams and powder charging inside the gun reduces the Faraday cage effect and allows uniform coating of the inside of a can. The invention further contemplates a number of additional features related to electrostatic charging of particles inside the gun, such as utilization of multiple charging chambers, either connected in series or in parallel.

This invention is particularly useful in powder coating the inside surfaces of containers and for this purpose the combination of multiple spray streams aid multiple external electrodes, along with pulsing of the electrostatic fields established by the electrodes is preferred. Additionally, pulsing the powder spray stream or multiple spray streams is also preferred. When coating the inside surface of a container, pulsing the electrostatic field may be carried out in combination with pulsing the powder ejections, and these two features may be further combined with the use of multiple spray streams and external electrodes.

Embodiments in accordance with the invention may utilize a multi-hole nozzle or a multi-tube spray hole assembly to split the pressurized gas-powder mixture into a plurality of fine spray streams. If a multi-hole nozzle is used, the nozzle connects to a forward, open end of the gun, and the holes of the multi-hole nozzle define the openings for the internal chamber of the spray gun through which the powder is sprayed. If a multi-tube spray hole assembly is used, a manifold of the assembly connects to the forward end of the gun. The manifold holds multiple tubes in place at the forward end of the gun, in fluid communication with

the chamber. Opposite ends of the tubes are held in a desired arrangement by a holder. With the multi-tube spray hole assembly, the tubes define the chamber openings.

With either the multi-hole nozzle or the multi-tube spray hole assembly, the chamber openings may be arranged in any desired pattern. The arrangement of the chamber openings determines the flow paths that the multiple spray streams will traverse when ejected from the gun. The openings may be aligned linearly, arranged around the circumference of a circle, or arranged in multiple, parallel rows, preferably with each row being staggered with respect to the adjacent rows. The openings may also be tilted, or angled, to produce an angled flow path.

Depending upon the shape and the size of the object to be coated, the chamber openings may be arranged so as to direct the flow paths in a desired manner. This feature is preferred when powder coating objects with multiple hollows, such as radiation fins, transformers or radiators. With objects of this type, it is usually preferable to use six to twenty-four separate spray streams. In most instances, it is also preferable for the inner diameters of the chamber openings, i.e. the tubes of multi-tube spray hole assembly or the holes of the multi-hole nozzle, be in the range of about 2-8 mm. When using multiple chamber openings, it is preferable that the chamber openings be spaced apart about 80-800 mm. The assembly tubes and the nozzle may be of plastic, such as fluororesins; nylon or polypropylene, depending on the polarity of the charging or the coefficient of friction.

One particular arrangement of the chamber openings which provides benefits in coating irregular surfaces involves arranging the chamber openings around the circumference of a circle and orienting the chamber openings obliquely with respect to the circle. With such an arrangement, if the chamber openings are directed outwardly, multiple spiralling streams are produced which are particularly suitable for coating the inside surfaces of a container or pipe. Alternatively, the chamber openings may be directed inwardly, toward a center axis through the circle, to provide circularly arranged flow paths which initially will converge to a point and then diverge outwardly. Depending upon the distance between the end of the gun and the object to be coated, this arrangement can be used to coat either large or small surface areas.

With any of these arrangements of the chamber openings, the pressurized gas-powder mixture may be electrostatically charged inside the gun, outside the gun by one or more external electrodes, or by a combination of internal and external charging. The particular commercial application for the invention will determine the most suitable manner of charging powder particles entrained in the mixture.

When one or more external electrodes are used to charge powder particles, it is sometimes desirable

to pulse the electrostatic field produced by each electrode between an "on" and an "off" condition. This pulsing of electrostatic field may be achieved by a pulse controller which provides selectable interruption of the electrical connection between each external electrode and a DC power supply. Pulsing the electrostatic field reduces the Faraday cage effect when external electrodes are used. Pulsing of the electrostatic field is disclosed in applicant's Japanese Kokai Publication No. 01 [1989] 11,669 published January 17, 1989.

The spray of powder particles from the gun may be pulsed. Pulsing of the powder particles may be achieved by using a powder pulse controller connected to the ejector to eject the mixture from the gun according to a desired waveform.

By cycling between "on" and "off" condition at a desired pressure, usually a uniform pressure, the powder particles are sprayed out of the end of the gun in consecutive pulses, and the air cushion is reduced. Pulsing of the powder particles reduces deflection or rebounding off the object to be coated. Because pulsing enables a uniform pressure to be maintained during spraying, the controller enables the duration and amplitude of the pulses to be carefully controlled and the amount of powder particles sprayed per unit time will remain relatively uniform, even when coating small objects or with relatively smaller volumes. Pulsing of powder is disclosed in applicant's Japanese Kokai Publication No. 62[1987] 11,574, published January 20, 1987.

The holes of the multi-hole nozzle or the tubes of the multi-tube spray hole assembly may be further equipped with a small-scale nozzle which has either multiple smaller holes or a single elongated slit. A small-scale nozzle of this type provides further separation of the mixture into even finer spray streams.

Depending upon the type of powder particles used, and the size, shape and composition of the object to be coated, the above-described features may be used in various combinations to achieve uniform powder coating.

The invention will now be described by way of example only and with reference to the drawings, in which:

Fig. 1 is a schematic which depicts, in longitudinal cross-section, an embodiment of electrostatic powder spray coating apparatus in accordance with the invention.

Fig. 2 is a transverse view taken along lines 2-2 of Fig. 1.

Fig. 3 and Fig. 4 are transverse cross-sectional views taken along lines 3-3 and lines 4-4 of Fig. 1, respectively, which depict four separate spray streams of gas-powder mixture as they progress toward an article to be coated.

Fig. 5 is a schematic which depicts, in longitudinal cross-section, a second embodiment of electrostatic

powder spray coating apparatus in accordance with the invention.

Fig. 6 is a transverse cross-sectional view taken along lines 6-6 of Fig. 5, which depicts a coating pattern produced by the four spray streams of gas-powder mixture shown in Fig. 5.

Fig. 7 is a transverse view, similar to Fig. 2, which depicts a third embodiment of an electrostatic powder spray coating apparatus in accordance with the invention, wherein the apparatus is equipped with a multi-hole nozzle having a central electrode and holes arranged on a circumference of a circle.

Figs. 8, 9 and 10 depict the spray pattern produced by the nozzle depicted in Fig. 7 at progressively further distances from the nozzle, as the spray streams progress toward an article to be coated.

Fig. 11 is a longitudinal schematic view, similar to Fig. 5, which depicts a fourth embodiment of an electrostatic powder spray coating apparatus in accordance with the invention, wherein the apparatus includes a multi-tube spray hole assembly.

Fig. 12 is a transverse view taken along lines 12-12 of Fig. 11.

Figs. 13 and 14 are transverse cross sectional views taken along lines 13-13 and 14-14 of Fig. 11, respectively, which depict a plurality of spray streams of a gas-powder mixture produced by the multi-tube assembly depicted in Fig. 11, as the spray streams progress toward an object to be coated.

Fig. 15 is an enlarged, transverse schematic view which depicts a further embodiment of a powder spray coating apparatus in accordance with the invention, wherein a wire is used to create an electrostatic particle charging field.

Fig. 16 is an enlarged, transverse view, similar to Fig. 15, which depicts a variation of the embodiment shown in Fig. 15 in that the wire is insulated along its length except for a plurality of spaced, uncovered regions.

Fig. 17 is an enlarged, transverse view, similar to Figs. 15 and 16, which depicts another variation of the embodiment shown in Fig. 15 in that the wire has angled slits which expose a plurality of spaced, uncovered regions which face toward the product being coated.

Fig. 18 is a transverse view taken along lines 18-18 of Fig. 17.

Fig. 19 is a longitudinal schematic view, similar to Fig. 11, which depicts a fifth embodiment in accordance with the invention, another variation of the multi-tube assembly.

Fig. 20 is a transverse cross-sectional view taken along lines 20-20 of Fig. 19, which depicts two spray patterns formed by the multi-tube assembly shown in Fig. 19.

Fig. 21 is a longitudinal schematic, similar to Figs. 11 and 19, which depicts a sixth embodiment in accordance with the invention, yet another variation of the

multi-tube assembly.

Fig. 22 is a transverse view taken along lines 22-22 of Fig. 21.

Fig. 23 depicts a spray pattern formed by the multi-tube assembly shown in Figs. 21 and 22.

Fig. 24 is a perspective view which depicts one application of the invention wherein the tubes of the multi-tube assembly are aligned linearly.

Fig. 25 is an elevational, or side, view of the Fig. 24 application taken in the direction indicated by arrow 25 in Fig. 24.

Fig. 25a depicts two graphs which illustrate another aspect of the invention, pulsing the electrostatic field during the spraying of powder particles.

Fig. 27 is a longitudinal schematic which depicts a seventh embodiment in accordance with the invention, still another variation of a multi-hole nozzle, wherein the multi-hole nozzle has spray holes arranged on the circumference of a circle, formed obliquely and directed outwardly with respect to the center line of the circle.

Fig. 27 is a transverse view taken along lines 27-27 of Fig. 26.

Fig. 18 depicts, in perspective view, a powder spray flow and deposition pattern produced by the nozzle shown in Figs. 26 and 27.

Fig. 29 is a longitudinal cross-sectional schematic which depicts another application of the invention, namely the spray coating of the inside surface of a can using the nozzle depicted in Figs. 26 and 27.

Fig. 30 is a transverse cross-sectional view taken along lines 30-30 of Fig. 29.

Fig. 31 depicts, in perspective view, a spray flow and deposition pattern formed when the multi-hole nozzle depicted in Figs. 26 and 27 is varied so that the spray holes are still oriented circumferentially and formed obliquely, but directed inwardly with respect to the center line of the circle.

Fig. 32 depicts the spray pattern produced by the multi-hole nozzle shown in Fig. 31 with the view taken along line 32-32 in Fig. 31.

Fig. 33 is an enlarged, longitudinal schematic view which depicts an eighth embodiment in accordance with the invention, still another variation of the multi-tube assembly, wherein the tubes are arranged on the circumference of a circle, formed obliquely and directed inwardly with respect to the center line of the circle.

Fig. 34 is a transverse view taken along lines 34-34 of Fig. 33.

Fig. 35 is a perspective view of a small-scale, multi-hole nozzle that may be attached to a spray hole of either the multi-hole nozzle or the multi-tube assembly.

Fig. 36 is a perspective view of a small-scale, slit nozzle that may be attached to a spray hole of the multi-hole nozzle or the multi-tube assembly.

Fig. 37 depicts an electrostatic powder spray

coating apparatus in accordance with the invention, wherein the apparatus is equipped with a pulse generator for pulsing the flow of the gas-particle mixture from the gun.

Fig. 38 depicts pulse waveforms which may be used to control the operation of the electrostatic powder spray coating apparatus depicted in Fig. 37.

Fig. 39 is a longitudinal cross-sectional schematic which depicts an electrostatic powder spray coating apparatus in accordance with the invention, wherein particles entrained in the gas-particle mixture are electrostatically charged inside the chamber of the gun.

Fig. 40 is a longitudinal cross-sectional schematic, similar to Fig. 39, which depicts another variation of electrostatic powder spray coating apparatus according to the invention, wherein particles are electrostatically charged inside the gun.

Fig. 41 is a longitudinal cross-sectional schematic which depicts an electrostatic powder spray coating apparatus in accordance with the invention wherein the apparatus includes two chambers connected in series.

Fig. 42 is a longitudinal cross-sectional schematic, similar to Fig. 41, which depicts variation of the embodiment shown in Fig. 41.

Fig. 1 shows an electrostatic powder spray coating apparatus 10 in accordance with the invention. The apparatus 10 includes a power supply hopper 12 where powder particles are mixed with air to entrain the particles therein. An ejector, or pump, 14 transports the gas-powder mixture from the tank 12 through a transfer tube 16 and into a gun body 18. An air compressor 20 drives the pump 14 and maintains a sufficiently high pressure to entrain powder particles suspended in air from the hopper 12. At the gun body 18, the mixture exits tube 16 and flows into a chamber 22. From the chamber 22, the mixture exits a plurality of chamber openings, designated generally by reference numeral 24, formed within a multi-hole nozzle 25 at a forward end of the gun 18.

During operation, the gas-powder mixture is sprayed out of the chamber 22 via the chamber openings 24 to create a plurality of distinct, fine spray streams which traverse flow paths, designated generally by reference numeral 26, while they progress toward a surface 28 of an article 30 to be coated.

During spray coating, particles entrained within the gas-powder mixture are electrostatically charged so that they will be attracted to the lower electrostatic potential of the surface 28, indicated on Fig. 1 as a ground potential. Fig. 1 shows a high voltage generator 32 which supplies a DC voltage for producing one or more electrostatic fields for electrostatically charging the particles in the gas-powder mixture. An electrically conductive cable 33 connects voltage source 32 to a plurality of electrodes, designated generally by reference numeral 34, which project outwardly from a

forward end of the gun 18. Each of the electrodes is associated with a respective chamber opening 24 so as to maximize the electrostatic charging of particles in the gas-powder mixture which traverse the respective flow path 26.

In embodiments in accordance with the invention which utilize one or more external electrodes, it is desired that the electrodes be associated in their electric circuits with a resistance (not shown) in the range of about 10^5 - 10^9 ohms, thereby to prevent sparking when the gun 18 is close to the object 30 to be coated. In one preferred embodiment, the external electrodes are made of silicon carbide and have a resistivity of about $10^6 \Omega \text{ cm}$.

If desired, to further increase the efficiency of electrostatically charging particles entrained in the gas-powder mixture, the cable 33 may also supply a high voltage to a DC electrode 36 located inside the chamber 22 of the gun 18. In cooperation with an internal ground terminal 37, the electrode 36 sets up an electrostatic field inside the gun 18 to produce charged ions which electrostatically charge particles entrained within the gas-powder mixture during flow through chamber 22. Because of the relatively high pressure and flow rate of the gas-powder mixture while in the chamber 22, most of the charged particles entrained therein move past the grounded terminal 37 and are sprayed out of the nozzle 25, although some charged particles may be attracted to and deposited onto the grounded terminal 37.

Fig. 2 shows a transverse, cross-sectional view of a front or spraying end of the nozzle 25. According to this embodiment, the multi-hole nozzle 25 includes chamber openings 24a, 24b, 24c, and 24d which produce spray streams that traverse flow paths 26a, 26b, 26c and 26d, respectively, and which are electrostatically charged by external electrodes 34a, 34b, 34c, 34d, and 34e. Thus, in this embodiment, each flow path 26 generated by a respective chamber opening 24 extends between a pair of the external electrodes 34. This maximizes the number of particles in the gas-powder mixture which are electrostatically charged during spraying.

Fig. 3 shows, in cross-sectional view, the distinct flow paths 26a, 26b, 26c and 26d traversed by spray streams formed by chamber openings 24a, 24b, 24c and 24d, respectively, while enroute toward surface 28.

Fig. 4 shows a composite spray pattern 38 which is formed on the surface 28 by the four separate spray streams depicted in Fig. 3. As shown by Fig. 4, the flow paths 26 traversed by the separate flow streams become enlarged and merge together while enroute toward surface 28. The final spray pattern 38 produced on surface 28 will depend upon the distance between the front end of the gun 18 and surface 28.

Fig. 5 shows a second embodiment in accordance with the invention, which is a variation of the

electrostatic powder spray coating apparatus 10 depicted in Fig. 1. According to this variation, the multi-hole nozzle 25 is replaced by a multi-hole nozzle 125 which has tapered, or converging, chamber openings 124. These chamber openings 124 produce four distinct, but relatively close spray streams which traverse flow paths 126 to produce a spray pattern 138, as shown in Fig. 6, which is narrower and denser than the spray pattern 38 depicted in Fig. 4.

Fig. 7 depicts a third embodiment in accordance with the invention, which is another variation of the multi-hole nozzles 25, 125 used in the first two embodiments. More particularly, the apparatus 10 is equipped with a multi-hole nozzle 225 which has a plurality of chamber openings 224 arranged on the circumference of a circle. With this nozzle 225, a single external electrode 234 is located in the middle of the chamber openings 224.

Fig. 8 shows a plurality of circularly arranged spray streams produced by the multi-hole nozzle 225, shortly after ejection from the gun 18. Because the chamber openings 224 are arranged around a circle, the flow paths 226 traversed by the spray streams are also arranged in a circular pattern. Fig. 9 shows the same spray streams as those depicted in Fig. 8, but further away from the end of the gun 18. In Fig. 9, the spray streams have merged to form a single, annularly shaped flow path.

Fig. 10 depicts the same spray streams depicted in Fig. 8 and Fig. 9, but after deposition onto the surface 28. The deposited spray streams form a disc-shaped pattern 238. Compared to Fig. 9, Fig. 10 shows that the particles from the gas-powder mixture have flowed toward the center so as to eliminate the central opening shown in Figs. 8 and 9.

Fig. 11 shows a further embodiment in accordance with the invention, wherein the apparatus 10 is equipped with a multi-tube spray hole assembly 325 instead of the multi-hole nozzles 25, 125 and 225 depicted in Fig. 1, Fig. 5 and Fig. 7, respectively. The multi-tube spray hole assembly 325 includes a manifold 327 connected to the front end of the gun 18, a plurality of tubes 329 connected to the manifold 327 so as to be in fluid communication with the chamber 22 and a holder 331 which retains the forward ends of the tubes 329 in a predetermined arrangement. Like the holes in those embodiments of the invention which utilize a multi-hole nozzle, the tubes in the embodiments which utilize a multi-tube spray hole assembly define the chamber openings.

An electrically conductive cable 333 has a first end which connects to a DC voltage source (not shown), and a second end which connects to a plurality of external electrodes, designated generally 334. The electrodes 334 extend forwardly from the holder 331. Like the multi-hole nozzle 25 or 225, the multi-hole tube spray hole assembly 325 splits the gas-powder mixture into a plurality of fine spray streams

which traverse a plurality of flow paths 326 toward the surface 28. In this embodiment, there are six flow paths designated 326a, 326b, ...326f (see Fig. 13), and particles entrained within the spray streams traversing these flow paths are electrostatically charged by electrodes 334a, 334b, 334c.....334f, respectively. See Fig. 12.

Fig. 12 shows a front view of the holder 331, with the forward ends of the tubes 329 aligned linearly to locate the chamber openings 324a, 324b.....324f in a line.

Fig. 13 shows a cross-sectional view of the spray streams formed by multi-tube spray hole assembly 325, shortly after ejection. At this distance, the spray streams are separate and distinct and take the form of six linearly aligned discs. Fig. 14 shows the same spray streams sometime thereafter, at a distance where the spray streams have merged to form a single, elongated spray pattern 338.

Figs. 15, 16 and 17 show variations wherein the chamber openings 24 of a multi-hole nozzle or multi-tube nozzle are aligned linearly and electrostatic charging of particles entrained in the gas-powder mixture is achieved via single wire 42 which serves as the electrode. The wire 42 is parallel with the chamber openings 24, either directly in front of and aligned with the openings, or offset to one side. This single-wire electrode is equally suitable for either the multi-hole nozzle embodiments or the multi-tube spray hole assembly embodiments in accordance with the invention. The object to be coated (not shown) is placed on the other side of wire 42 from chamber openings 24.

Fig. 15 shows wire electrode 42 exposed along its entire length, with insulative covering 43 is removed at the ends of the wire 42 beyond the chamber openings 24. Alternatively, the insulative covering 43 may extend along the length of the wire 42, except for a plurality of spaced, selected regions 44 which correspond to the respective chamber openings 24, where the wire 42 is exposed.

Alternatively, as shown in Figs. 17 and Fig. 18, the insulative covering 43 is removed from a V-shaped region 47 at the bottom of wire 42 in Figs. 17 and 18, opposite the object being coated, to expose the bottom portion 44 thereof which serves as an electrode.

Fig. 19 shows a fifth embodiment in accordance with the invention, another multi-tube spray hole assembly 425. The multi-tube assembly 425 includes a manifold 427, which is identical to the manifold 327, a plurality of tubes 429 with first ends which communicate with the chamber 22 and opposite ends which define a plurality of chamber openings 424. These opposite ends of the tubes 429 are retained within a holder 431, which orients the chamber openings 424 in linear alignment, but in two distinct groups of three.

In use, the multi-tube spray hole assembly 425 produces two separate groups of spray streams, with

three spray streams included in each group. As a result, as shown in Fig. 20, the assembly 425 produces a spray pattern 438 which includes an upper region 438a formed by spray streams which traverse flow paths 426a, 426b, and 426c and a lower region 438b which is formed by the spray streams which traverse flow paths 426d, 426e, and 426f. A conductive cable 433 connects from a power supply (not shown) to a plurality of external electrodes 434 which extend forwardly from the holder 431. The cable 433 and the external electrodes 434 are identical to the cable 333 and the external electrodes 334 depicted in Fig. 11.

Fig. 21 shows a sixth embodiment in accordance with the invention, another multi-tube spray hole assembly 525. The multi-tube spray hole assembly 525 includes a manifold 527, a plurality of tubes 529 with first ends connected to the manifold 527 and second ends retained in a predetermined configuration in a holder 531. An electrically conductive cable 533 connected to a power supply (not shown) extends along holder 531 and connects to a plurality of external electrodes, designated generally 534, which extend forwardly from the holder 531.

As in the first, second, fourth and fifth embodiments, it is preferable in the sixth embodiment to have at least one external electrode 534 associated with each of the chamber openings 524. As shown in Fig. 22, the forward ends of the tubes 529 are oriented such that chamber openings 524a are aligned in a first row which is parallel to second row chamber openings 524b, with the openings of the first and second rows being staggered with respect to each other. Chamber openings 524c form a third row which is parallel to the first two rows and staggered with respect to the second row, but aligned with the first row.

Fig. 23 shows a spray pattern 538 formed by the multi-tube spray hole assembly 525, with three distinct coating lines 538a, 538b and 538c of coating which correspond to the first, second and third rows of chamber openings 524a, 524b and 524c, respectively.

Fig. 24 illustrates one application of the electrostatic spray coating apparatus 10 of the invention. Fig. 24 shows the multi-tube spray hole assembly 325 used to spray coat an object 50 which includes a bottom, horizontal member 51 and a plurality of parallel, vertical members 52 which define bottom parallel surfaces 53 and side walls 54, respectively. Because of the linear orientation of the front ends of the tubes 329 within the holder 331, the spray streams may be directed toward the object 50 so as to coat the side walls 54 and the bottom 53 of one slot at a time, as shown in both Figs. 24 and 25. If desired, the assembly 325 may be extended downwardly within the slots during spray coating.

Fig. 25 shows a pulse controller 339 connected to the cable 333 which supplies DC electrical power to the electrodes 334. The pulse controller 339 provides

switching to connect and disconnect DC power to the electrodes 334 according to a desired sequence. This pulses the electrostatic fields produced by the electrodes 334 between an "on" and an "off" condition.

Fig. 25a illustrates one method of pulsing the electrostatic fields during spraying. With the spray gun continuously spraying, as shown by the upper waveform, the pulse controller 339 cycles the electrostatic field every 60 milliseconds, with the field turned "on" for 20 milliseconds and then "off" for 40 milliseconds. Pulsing of the electrostatic field is shown by the lower waveform.

It is to be understood that the relative durations of the "on" and "off" time, along with the duration of the entire cycle, may be varied according to any desired sequence. It is also to be understood that pulsing of the electrostatic field may be used in combination with the other powder coating features disclosed in this application, such as pulsing of the powder flow, to provide uniform coating of uneven surfaces, such as the inside surface of a container.

Fig. 26 shows another multi-hole nozzle 625, in accordance with the seventh embodiment of the invention. The multi-hole nozzle 625 would fit on the end of gun 18 in Fig. 1, for example, like nozzle 25, and includes a plurality of chamber openings 624 which are arranged on the circumference of a circle which is coaxial with the longitudinal axis of gun 18, with the openings 624 formed obliquely and directed outwardly with respect to a center axis 628 of the multi-hole nozzle 625. Fig. 27 more clearly shows the orientation and configuration of the chamber openings 624, along with an external electrode 634 aligned along axis 628, or the at the middle of the circle defined by the chamber openings 624.

Fig. 28 shows the multi-hole nozzle 625 in use, with a plurality of spray streams emanating from chamber openings 624 and traversing flow paths 626. The spray streams which emanate from multi-hole nozzle 625 form a spray pattern 638 which includes six distinct disc-shaped regions arranged around the circumference of a great circle.

Fig. 29 shows one application for which the apparatus 10 in accordance with the invention is well suited, particularly the seventh embodiment which utilizes the multi-hole nozzle 625 depicted in Figs. 26 and 27. This application involves powder spray coating of the interior surface of a hollow container 55. Because of the orientation of the chamber openings 624, the flow paths 626 of the spray stream are angled. When sprayed inside the container 55, or any other hollow, cylindrically shaped object, such as a pipe, the spray streams deflect off the inside surface 58 of the container 55 and continue along flow paths 626 which twist and descend, resulting in a reduced air cushion inside the can and producing more uniform coating of the inside surface 58. Fig. 29 and Fig. 30 include directional arrows 59 which show the twisting or spiral-

ling effect caused when the spray streams deflect off the inside surface 58 of the container 55 and progress toward the opposite or closed end thereof. Reduction of the air cushion inside the can which tends to prevent adequate powder coating material from entering the can, can be further achieved by pulsing the pump 14 of Fig. 1 as is discussed later in connection with Figs. 37 and 38. Moreover, reduction of the Faraday cage effect within container 55 will be achieved by pulsing the power supply for electrode 634 in a manner similar to that described with respect to Figs. 25 and 25a.

Fig. 31 depicts and eight embodiment in accordance with the invention, wherein a multi-hole nozzle 725 includes a plurality of chamber openings 724 which are arranged on the circumference of a circle and formed obliquely like those of multi-hole nozzle 625, but which are directed inwardly toward a center line through the circle. With this multi-hole nozzle 725, the flow paths 726 traversed by the spray streams converge toward the center line 737 and then diverge outwardly therefrom, as shown in Fig. 31.

Fig. 32 shows a spray pattern 738 formed by multi-hole nozzle 725. The spray pattern 738 includes six distinct regions arranged around the circumference of a great circle, with the regions being slightly oveled and elongated radially with respect to the circle. The pattern formed by the spray streams produced by multi-hole nozzle 725 is sometimes referred to as a Japanese hand drum. With this flow path 726 arrangement, by adjusting the distance between the end of the multi-hole nozzle 725 and an object to be coated, the surface area of coating can range from very small to very large.

Fig. 33 shows a ninth embodiment in accordance with the invention, a multi-tube spray hole assembly 825 which is designed to produce the same spray pattern as multi-hole nozzle 625. The multi-tube spray hole assembly 825 includes a manifold 827, a plurality of tubes 829 which extend from the manifold 827 and are retained by a holder 831 in a predetermined arrangement. As shown most clearly in Fig. 34, the chamber openings 824 formed by the tubes 829 are arranged on the circumference of a circle, oriented obliquely and directed inwardly with respect to the center line through the circle. If desired, a single electrode (not shown) may extend forwardly from holder 831

Fig. 35 depicts a small scale, multi-hole nozzle 60 which connects to one tube 29 of one of the multi-tube assemblies, Fig. 11 for example, so as to be in fluid communication with the respective chamber opening 324, for example. The small scale, multi-hole nozzle 60 includes a frustoconically shaped, outwardly flared passage 62 which terminates in a plurality of small scale holes 64 arranged around the circumference of a circle 65. The use of small scale holes 64 produces even smaller spray streams, thereby increasing control over the directivity of the spray streams used in

powder coating.

As shown in Fig. 36, a small scale, slit nozzle 70 may be attached to the forward end of a tube 29 of a multi-tube assembly, Fig. 11 for example, so as to be in fluid communication with the chamber opening 324, for example. The small scale, slit nozzle 70 includes an elongated diverging hollow portion 72 which terminates in an elongated slit 74.

While this small scale, multi-hole nozzle 60 and the small scale slit nozzle 70 are shown attached to the end of a tube 29 of a multi-tube assembly, they could also be applied to the embodiments in accordance with the invention which relate to a multi-hole nozzle 25.

Figs. 37 and 38 illustrate another aspect of the invention, that of spraying the gas-powder mixture from the gun 18 in a pulsing manner. According to this aspect of the invention, a pulse generator 76 is electrically connected via conductive lines 77 to a solenoid valve SV which controls air flow from a compressor 20 to powder pump 14 to cause the gas-powder mixture to flow from hopper 12 through the gun 18 and outwardly therefrom in a series of pulses. The operation of an electrostatic powder coating apparatus in a pulsing manner is described in Japanese Kokai No. 62 [1987] 11,574

Fig. 38 shows two example waveforms 78 and 79 which may be used to control pulsing of the spray streams outwardly from the gun 18. As indicated in the above-identified Japanese publication, by selecting the number of pulses per unit time, the amplitude of the pulses and the duration of the pulses, the amount of powder sprayed outwardly from the gun 18 may be readily adjusted and precisely controlled.

The pressure of the air pressure to pump 14 can be increased to assure constant ejection volume and rate per unit time. This assures better uniformity in coating. Moreover, pulsing the spray streams also facilitates spray coating where a thin coating thickness is desirable.

Figs. 39-42 show electrostatic charging of particles in the gas-powder mixture while inside the gun 18 of Fig. 1. Fig. 1 shows that internal charging may be used to supplement external charging via external electrodes 34. Alternatively, internal charging may be the sole means for electrostatically charging particles entrained in the gas-powder mixture. Internal charging is particularly advantageous in coating the inside surfaces of metal containers, where the use of external electrodes tends to produce a Faraday cage effect, as explained above.

Fig. 39 depicts an internal electrode 80 charged by a power supply (not shown) and grounded terminals 81 to produce an electrostatic field inside the gun 18. When electrostatically charging particles of the gas-powder mixture inside the gun, it is important to prevent adherence of the powder particles to either the electrode 80 or the grounded terminals 81. Fig. 39

shows compressed air inlet 82 which communicates with a conduit 83 via a port 84 in the gun. The conduit 83 surrounds electrode 80 and blows air around the electrode 80 to prevent charged particle accumulation thereon. Another air inlet 85 supplies pressurized air into a hollow annulus 86 which circumscribes the outside of the gun. Pressurized air from the annulus 86 flows radially inwardly into the gun via a plurality of ports 87 spaced around the circumference of the gun. Air flows directed radially inwardly from the ports 87 discourage the accumulation of charged particles on the ground terminals 81.

Fig. 40 shows an alternative structure for this same aspect of the invention. Inlet 85 is aligned with a single port 89 in the outer wall of the gun. The port 89 communicates with an annular hollow space 88 which circumscribes the gun along its internal surface. The annular hollow space 89 is formed by a tubular, conductive sinter 90 which is connected to an electrical ground (not shown). The porosity of the sinter 90 permits outflow into the gun of air supplied to the inlet 85, thereby discouraging particle accumulation thereon.

As indicated above, electrostatic charging inside the gun may be used alone or in conjunction with external charging. When used alone, it may be desirable to enhance or maximize the number of charged particles in the gas-powder mixture by using multiple charging chambers. For example, Fig. 41 shows an alternative embodiment of the invention which includes two charging chambers 22a and 22b connected in series with electrodes 80a and 80b and grounded terminals 81a and 81b located therein, respectively. A multi-hole nozzle 25 is located at the downstream end of the second chamber 22.

Alternatively, the multiple chambers 22 may be connected in parallel, so as to eliminate pressure loss necessitated by a series connection. The use of parallel connected chambers while not increasing the charge on the powder does provide an increase in the flow rate of powder sprayed from the gun.

Fig. 42 shows another variation of the invention involving multiple charging chambers. According to this embodiment, an upstream chamber 22a utilizes frictional charging, rather than an applied DC electrostatic field. Frictional or triboelectric charging occurs by routing the powder particles through a tortuously configured plastic or Teflon[®] conduit 92 which preferably contacts the inside surface of the chamber 22, which is in turn connected to a ground terminal 93. The powder particles become charged triboelectrically by multiple frictional contacts with the conduit 92. With this embodiment, it is important to make sure that the second charging chamber 22b charges powder with the same polarity as tribocharging chamber 22a.

Claims

1. A method of electrostatic powder coating comprising the steps of spraying a pressurized mixture of gas and powder particles outwardly from a spray gun characterised in that the mixture is sprayed in a plurality of separate spray streams, the particles entrained in the mixture being electrostatically charged within an internal chamber of the gun, thereby producing a plurality of electrostatically charged spray streams.
2. A method of electrostatic powder coating comprising the steps of spraying a pressurized mixture of gas and powder particles outwardly from a gun in a series of pulses; electrostatically charging the particles entrained in the mixture during the spraying step via an electrostatic field established by an electrode operatively connected to a DC power supply; characterised in that the electrostatic field is pulsed during the spraying step.
3. A method of electrostatic powder coating comprising spraying a pressurized mixture of gas and powder particles outwardly from a spray gun towards the surface to be coated, and electrostatically charging the particles, characterised in that the mixture is sprayed in pulses.
4. A method according to either claim 2 or 3 characterised in that the spraying step further comprises splitting the mixture into a plurality of separate spray streams which traverse a plurality of corresponding flow paths.
5. A method according to any preceding claim characterised in that the particles entrained in the mixture are charged by a plurality of electrodes located external to the gun.
6. An electrostatic powder coating apparatus comprising a gun having at least one internal chamber, the chamber having at least two openings to atmosphere; means for introducing a pressurized mixture of gas and powder particles into the chamber and spraying the mixture outwardly from the gun through the openings to produce two or more separate spray streams and means for electrostatically charging the particles entrained in the mixture by means of at least one electrode which produces an electrostatic field when operatively connected to a power supply.
7. Apparatus according to claim 6 characterised in that the charging means include at least two electrodes located external to the gun, one in or adjacent to each spray path.

8. Apparatus according to claim 6 or 7 characterised in that the openings are arranged around the circumference of a circle which is coaxial with the gun.

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9. Apparatus according to claim 6,7 or 8 characterised in that means are provided causing the mixture to be sprayed outwardly from the gun in pulses.

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10. Apparatus according to any of Claims 6 to 9 characterised in that means are provided for pulsing the electrostatic fields during spraying.

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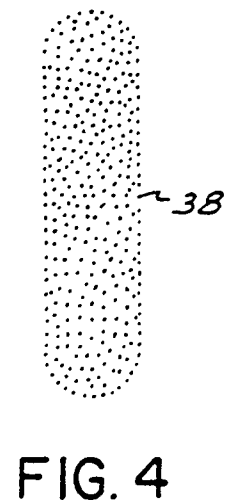
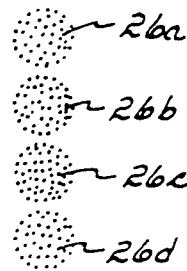
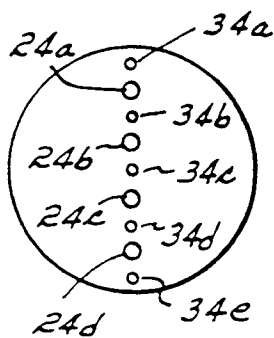
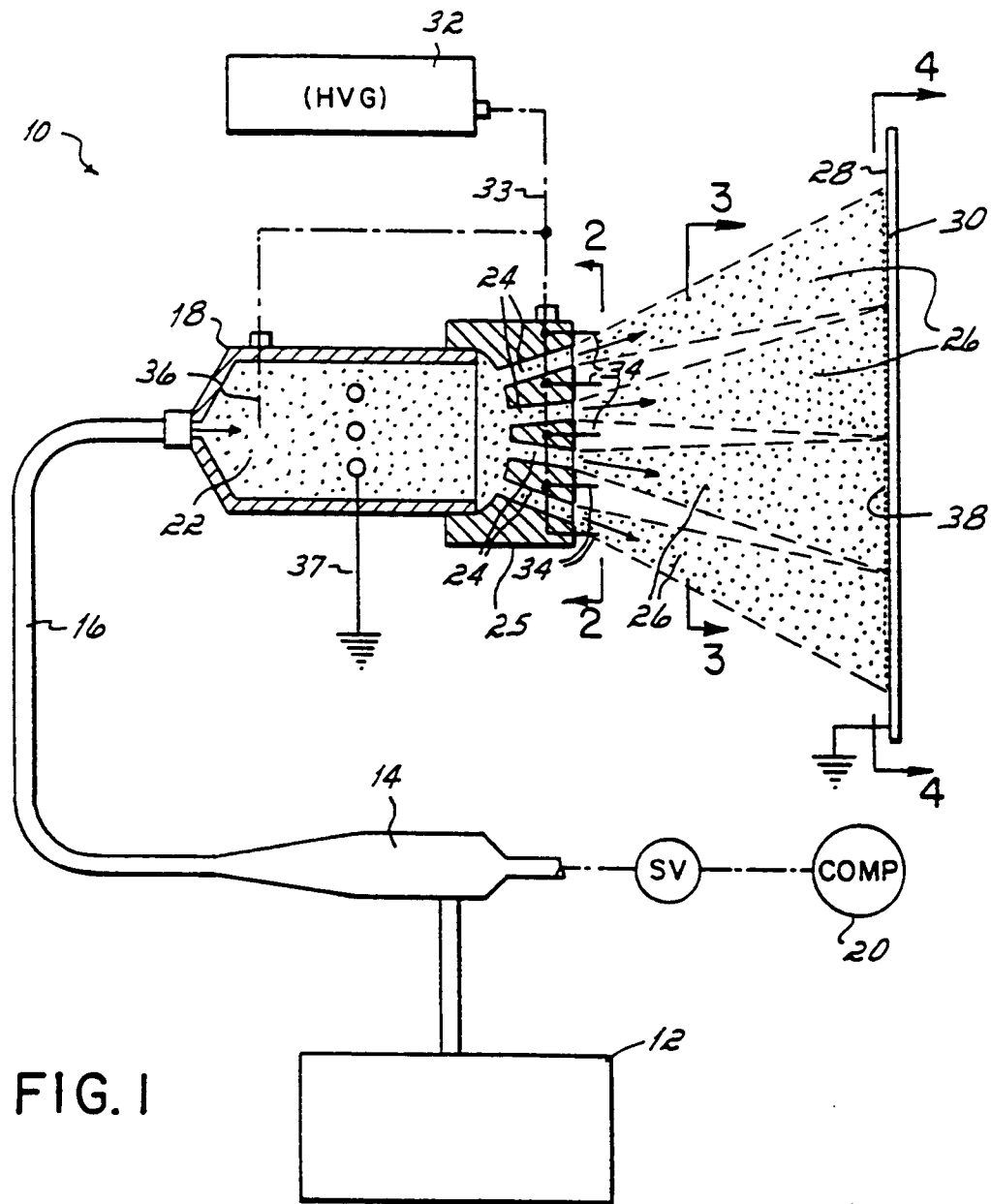
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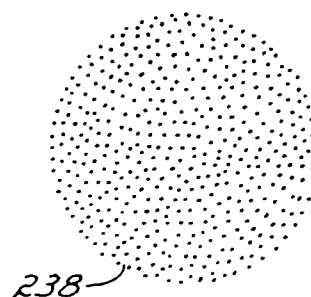
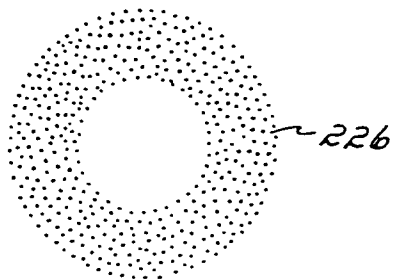
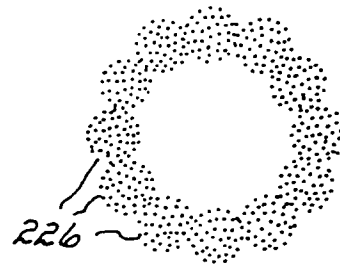
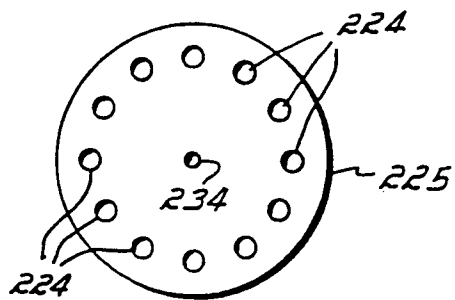
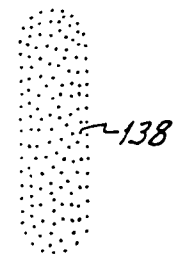
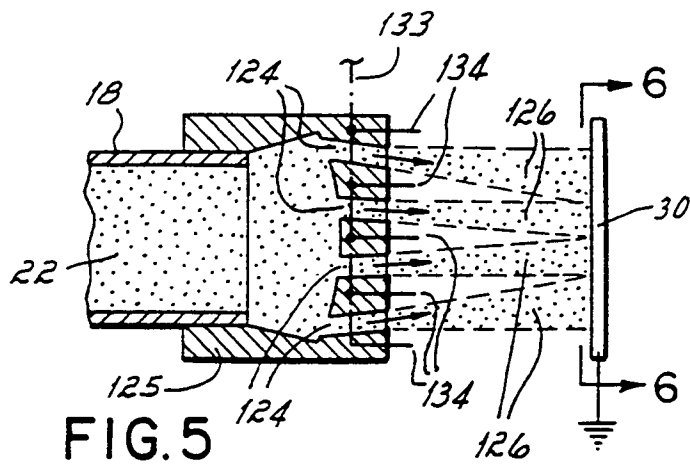
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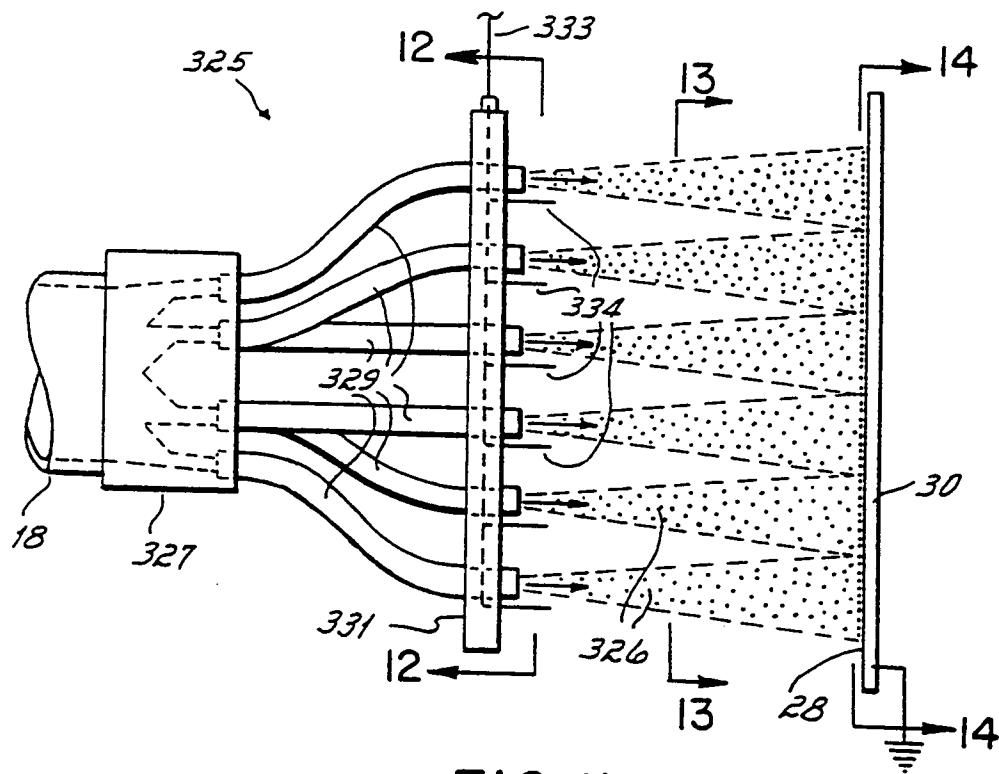


FIG. II

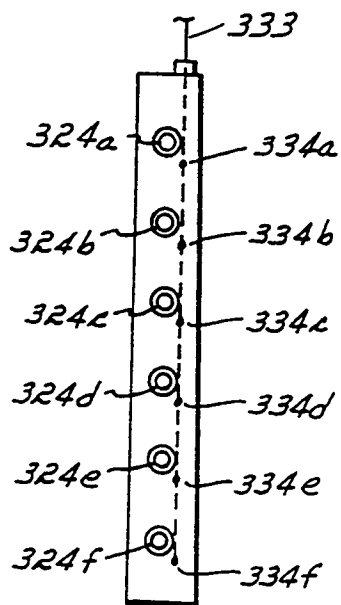


FIG. 12

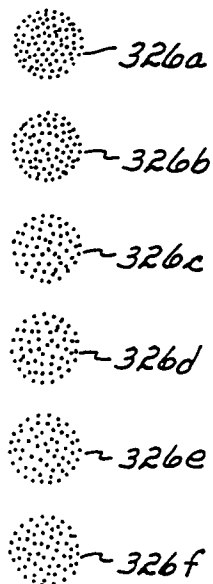


FIG. 13

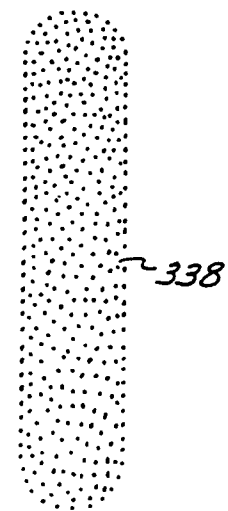


FIG. 14

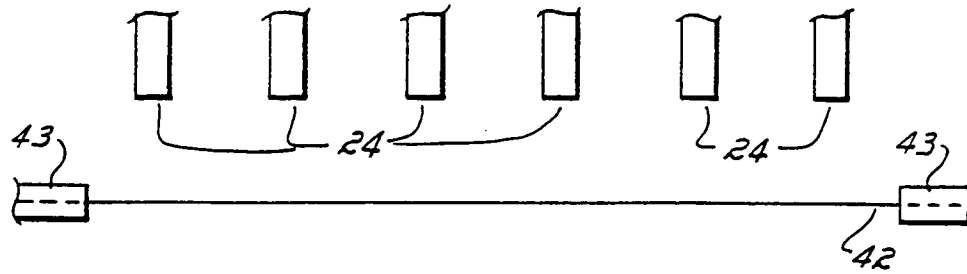


FIG. 15

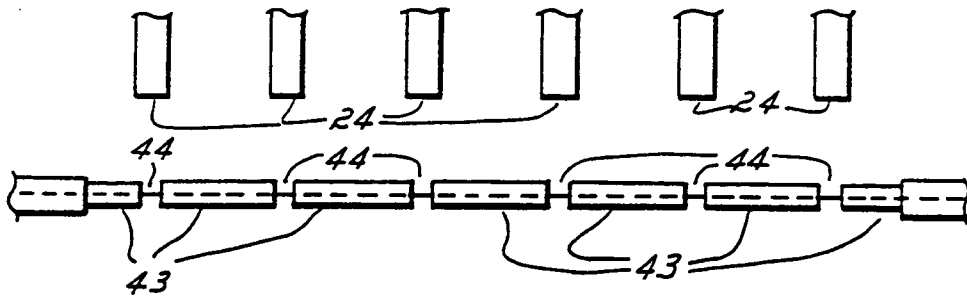


FIG. 16

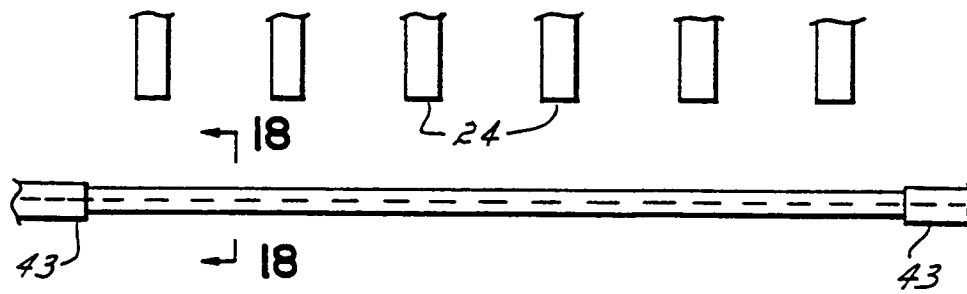


FIG. 17

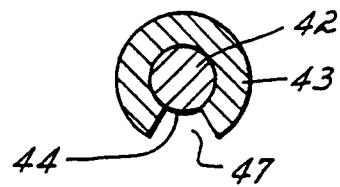
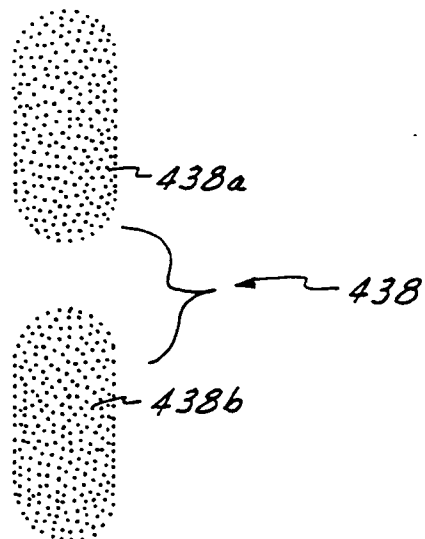
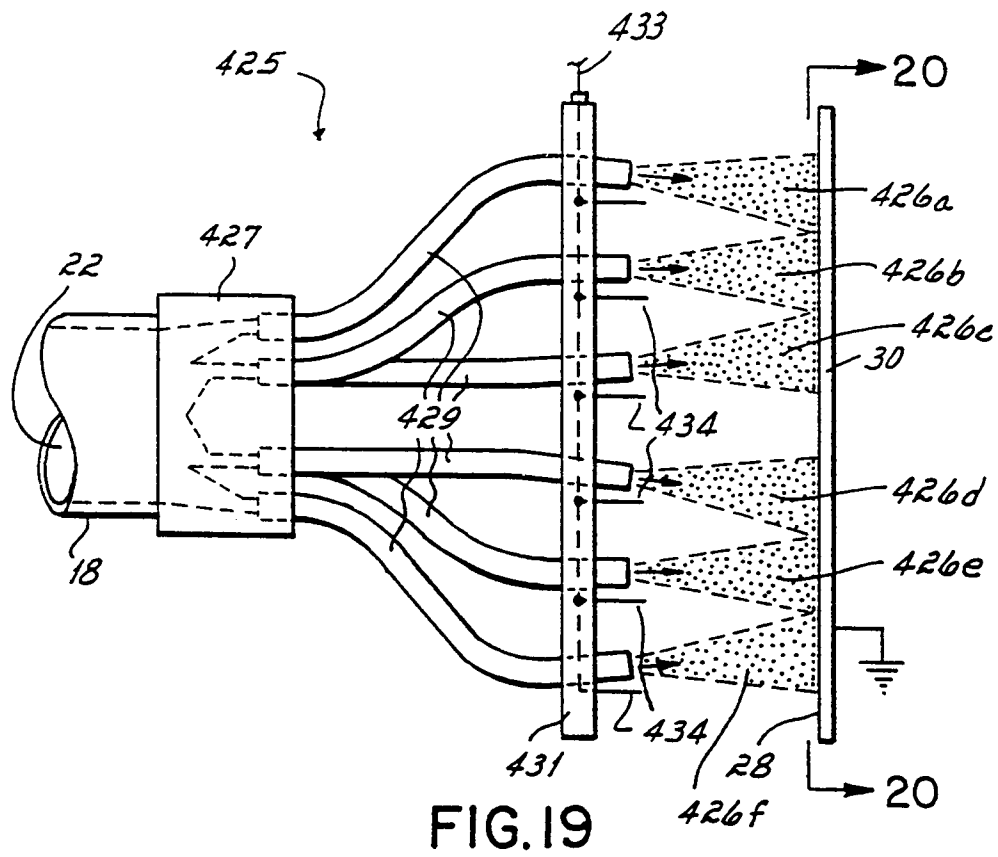
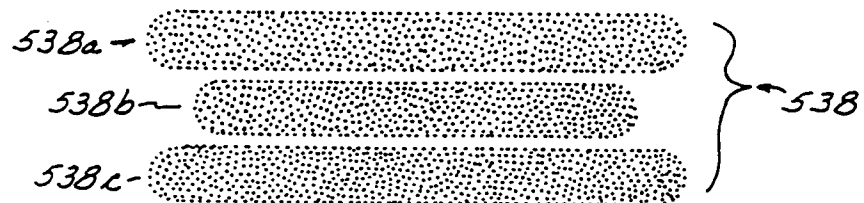
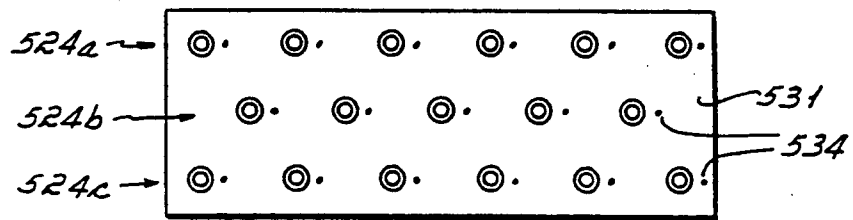
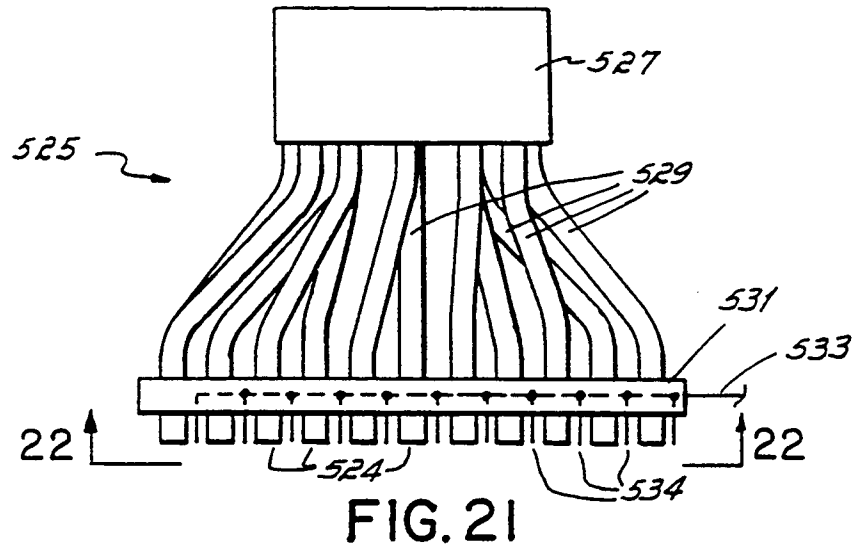


FIG. 18





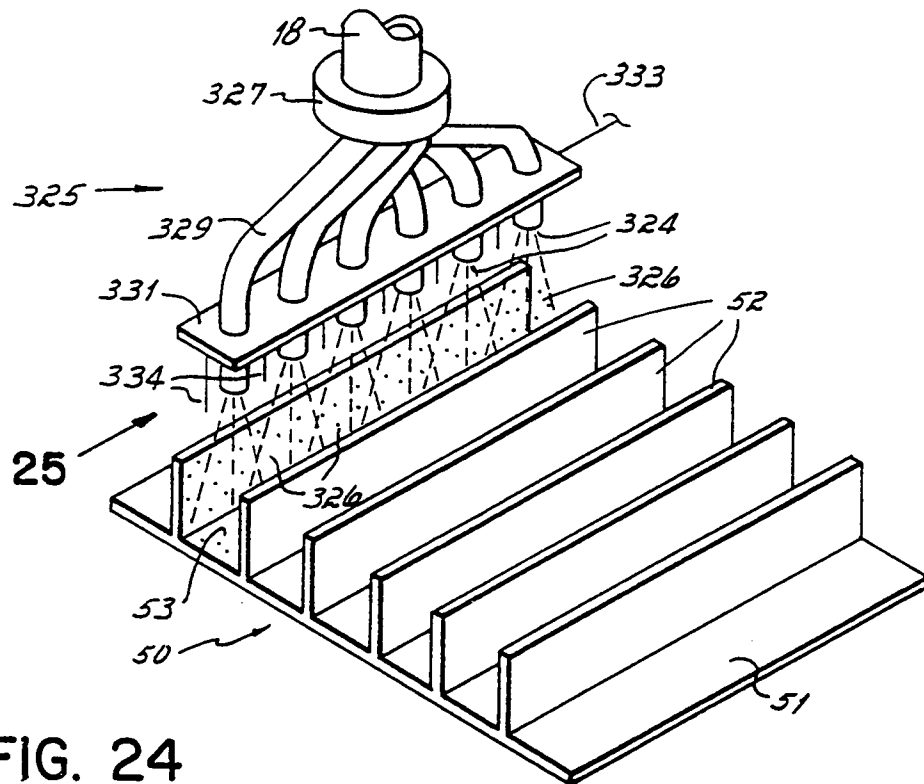


FIG. 24

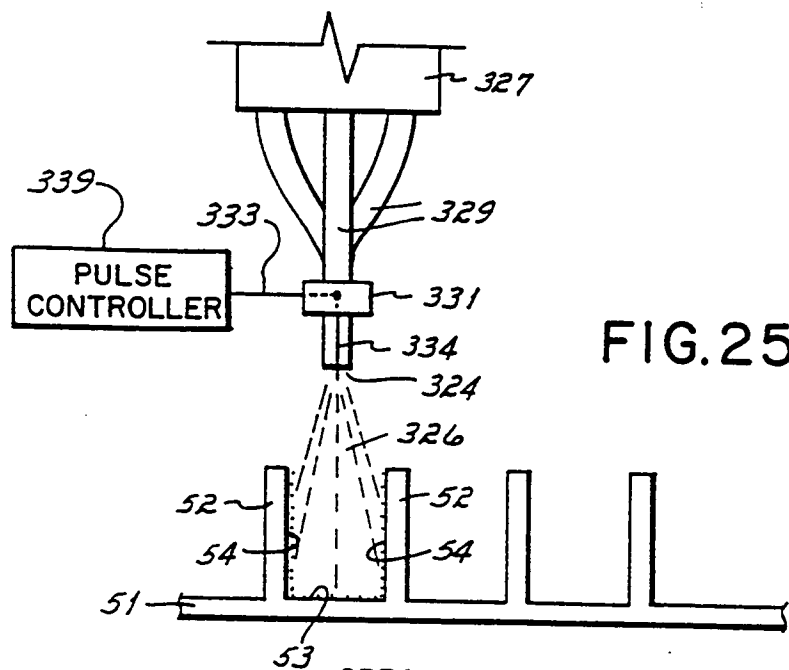
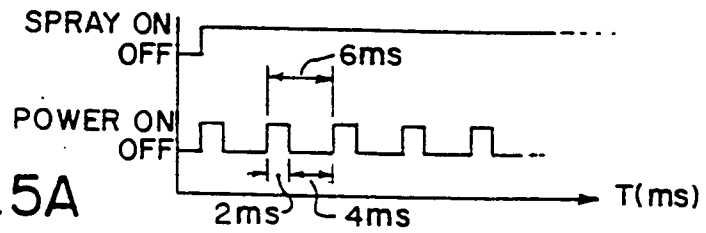


FIG. 25

FIG. 25A



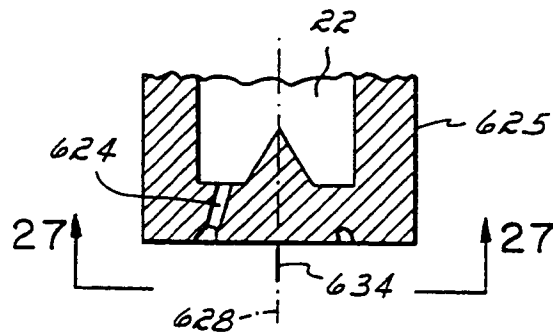


FIG. 26

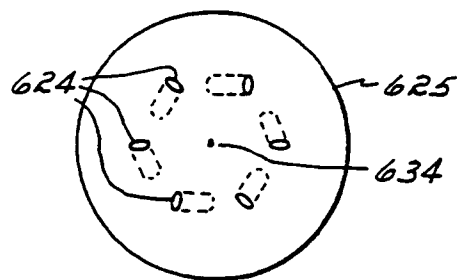


FIG. 27

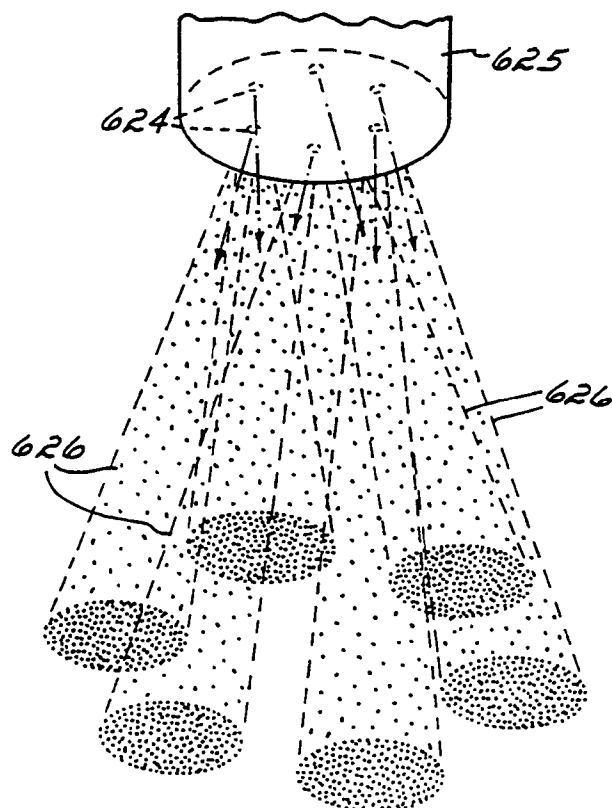


FIG. 28

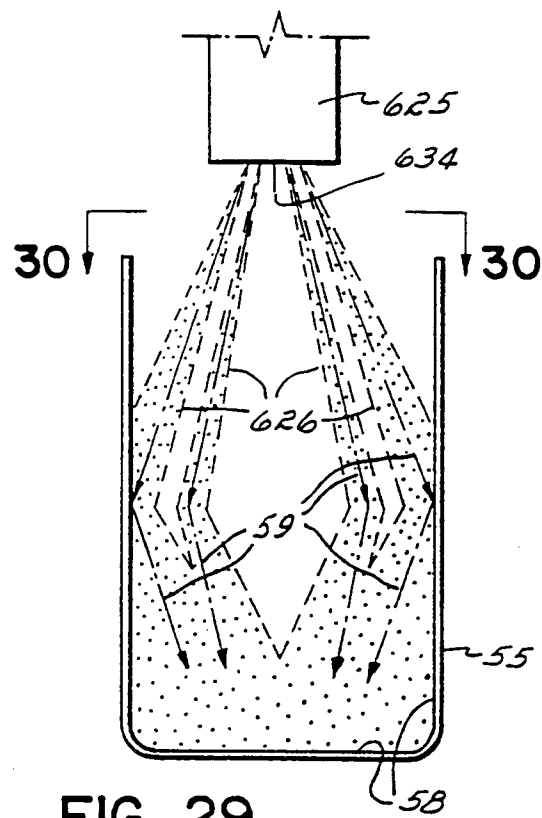


FIG. 29

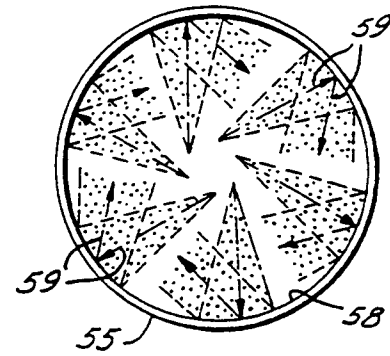


FIG. 30

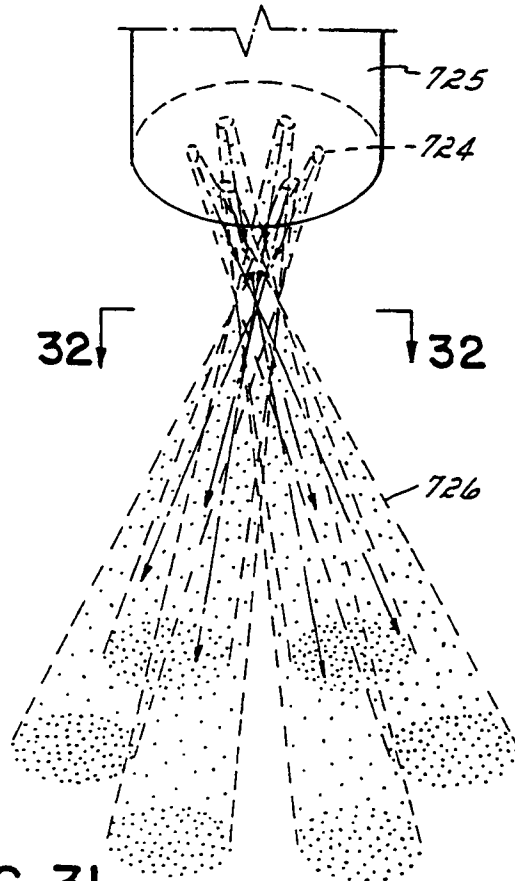


FIG. 31

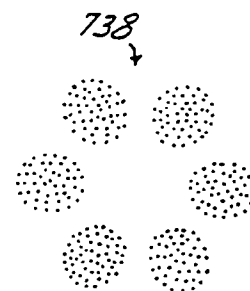


FIG. 32

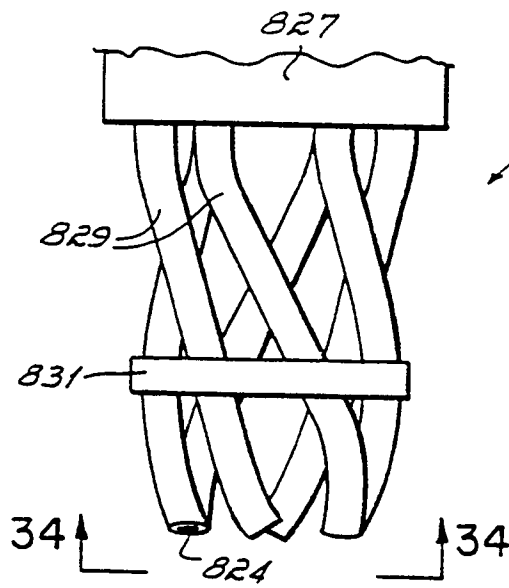


FIG. 33

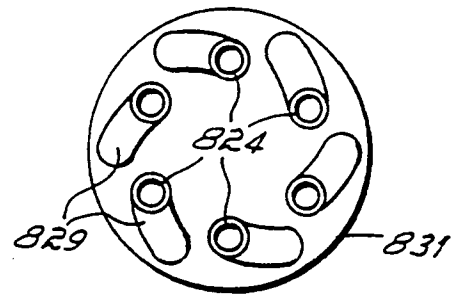


FIG. 34

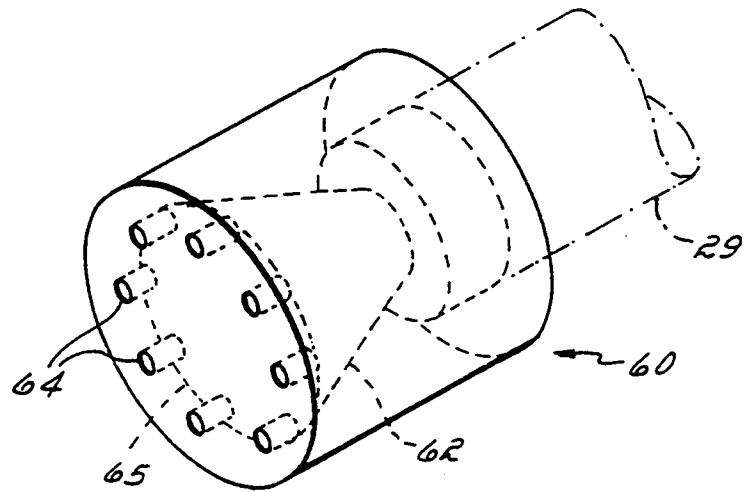


FIG. 35

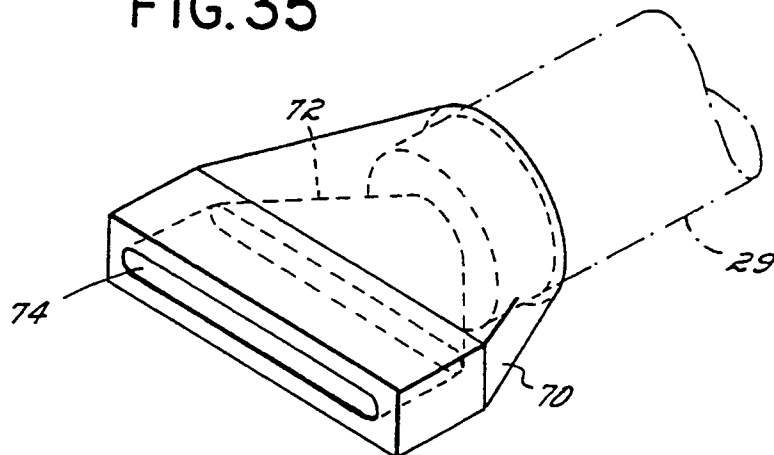


FIG. 36

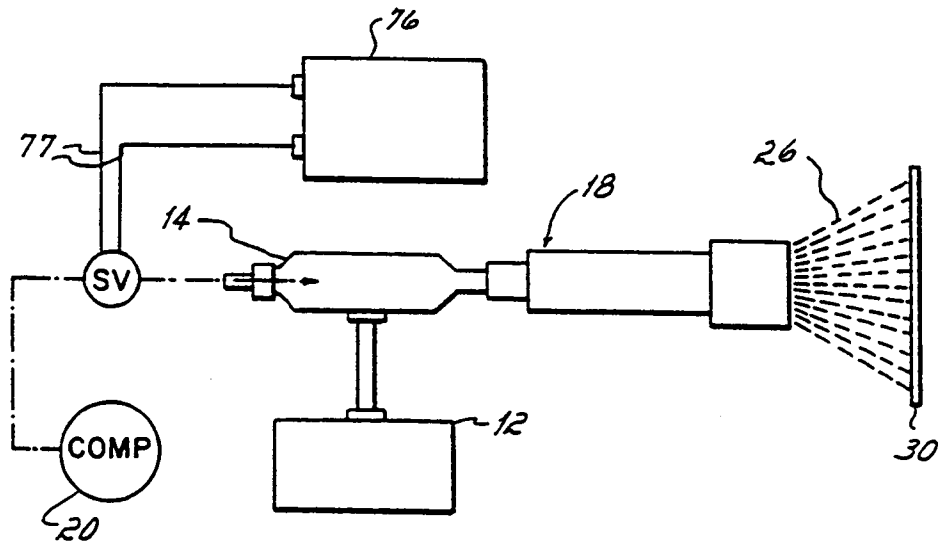


FIG. 37

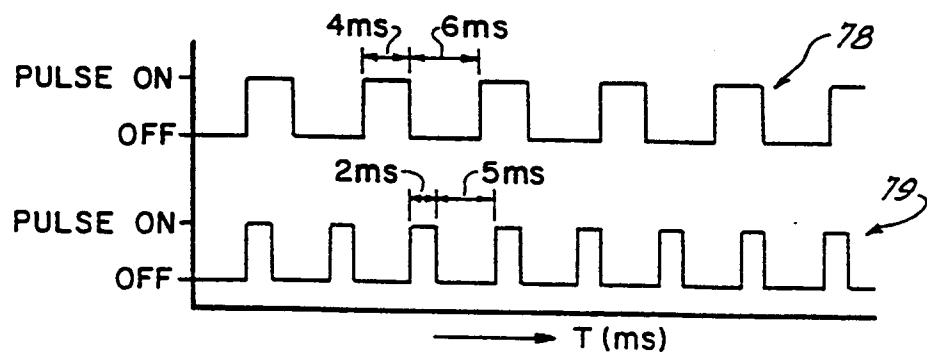


FIG. 38

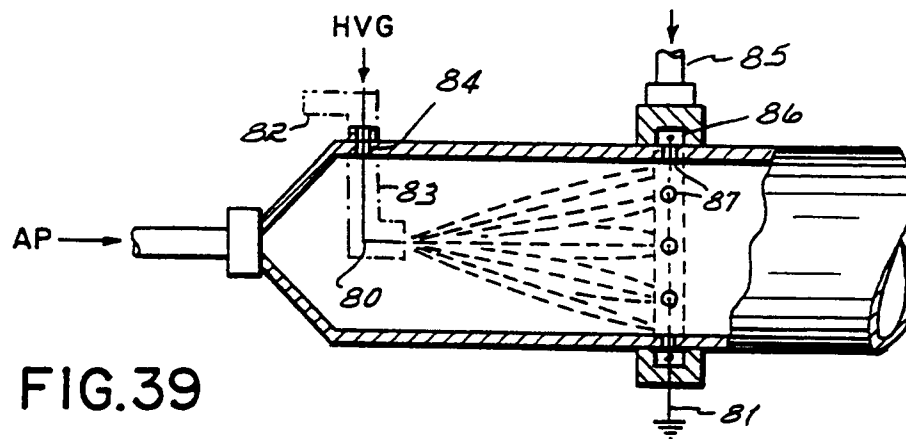


FIG. 39

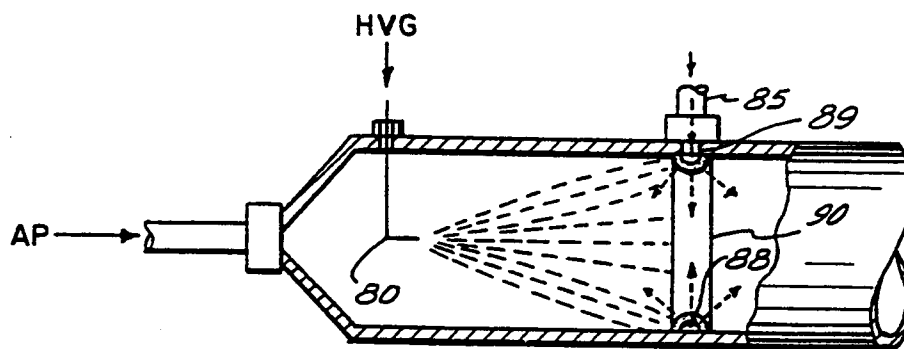


FIG. 40

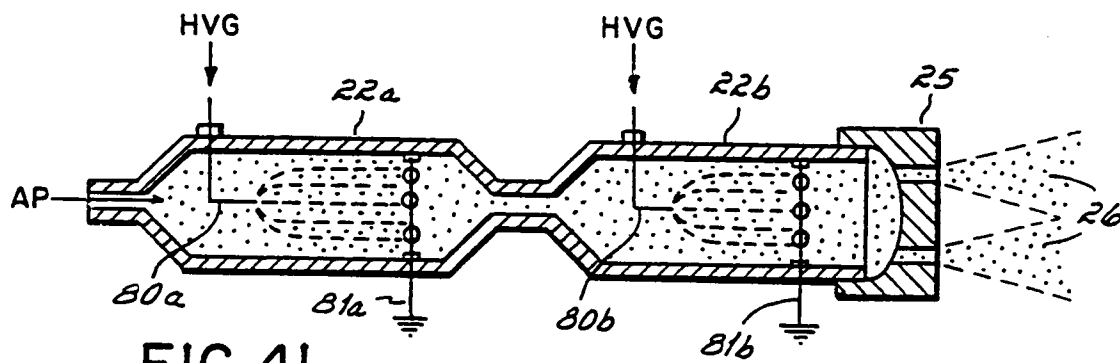


FIG. 41

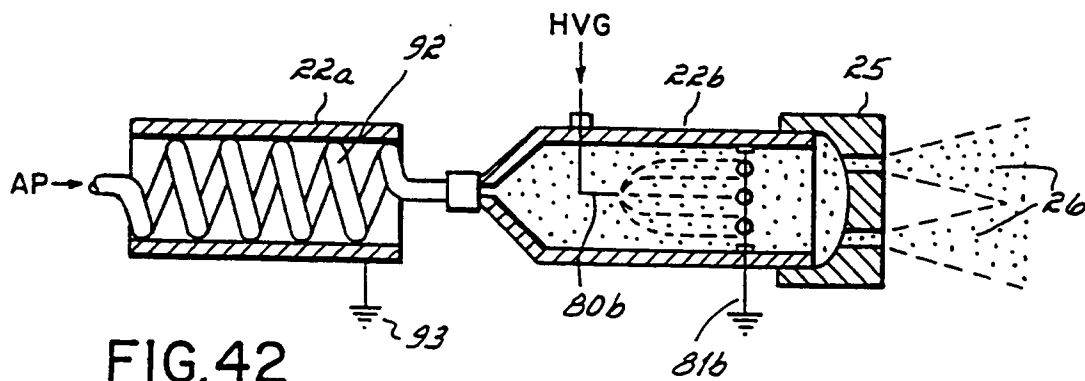


FIG. 42



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 30 4931

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	US-A-3 767 116 (CLAUSEN ET AL) * claim 1 *	1, 6, 8	B05B5/03 B05B5/047 B05B5/10 B05B7/14
Y	---	4, 9, 10	
X	DE-A-2 734 174 (SIEMENS AG) * the whole document *	2, 3	
Y	---	4, 9, 10	
X	DE-A-3 330 665 (WEITMANN & KONDAD GMBH & CO KG) * page 10, line 3 - line 19 * * page 11, line 14 - line 19 * * figures 2, 4, 5 *	6, 7, 10	
A	---	1, 4, 5	
X	GB-A-1 142 527 (AEROCOAT S.A.) * the whole document *	1, 6	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			B05B
Place of search THE HAGUE		Date of completion of the search 04 AUGUST 1992	Examiner JUGUET J. M.
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application I : document cited for other reasons & : member of the same patent family, corresponding document	

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