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W. D. GAUTHIER
SHUNT CONTROL TO PREVENT ARCING IN AN ELECTROSTATIC
SPRAY COATING SYSTEM AND METHOD

3,083,121

2 Sheets-Sheet 1

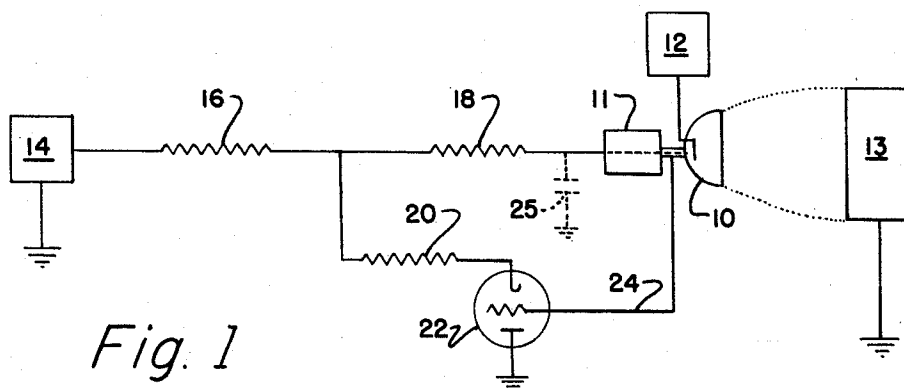


Fig. 1

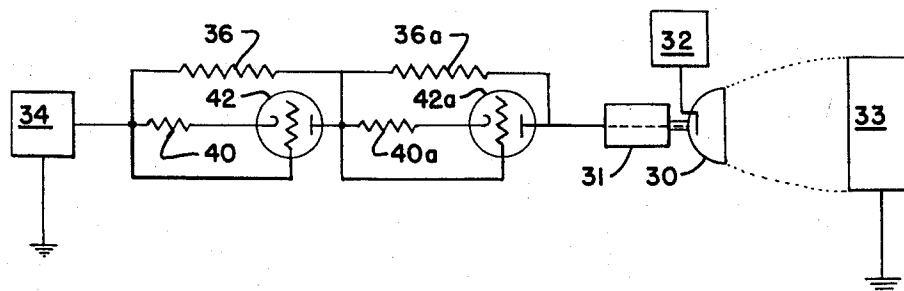


Fig. 2

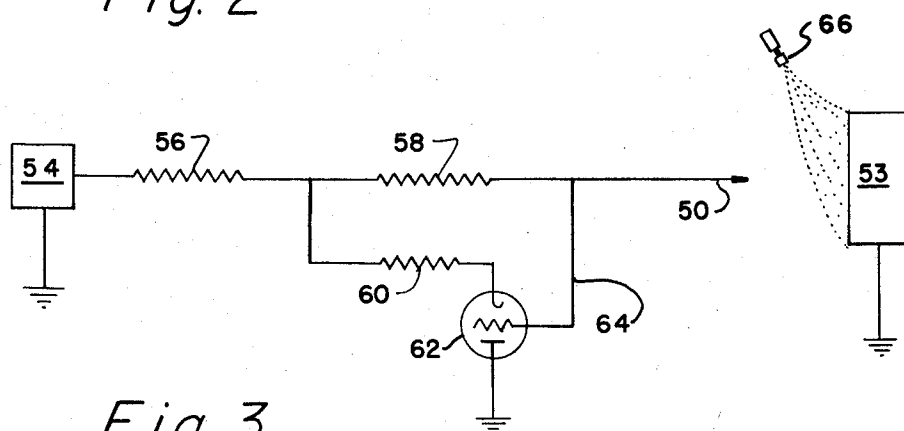


Fig. 3

INVENTOR.
WILLIAM D. GAUTHIER
BY *Harry E. Downer*
William D. Gauthier
Attorneys

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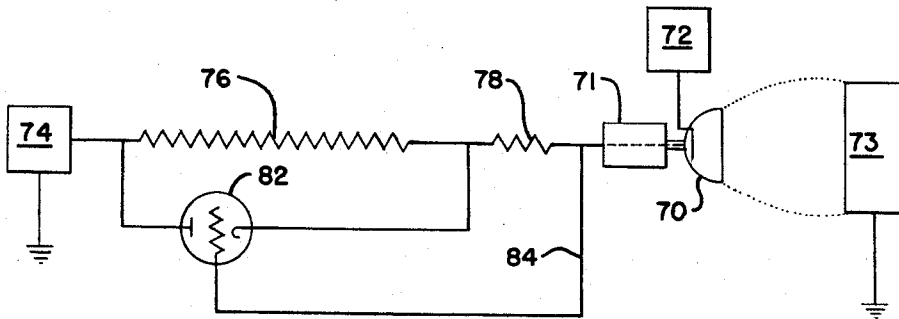


Fig. 4

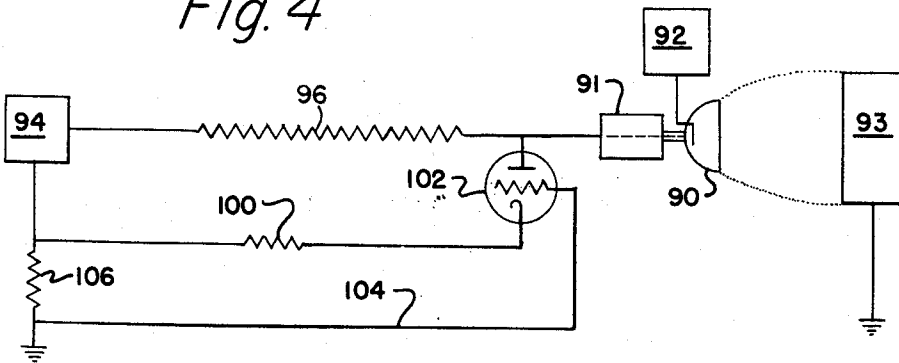


Fig. 5

INVENTOR.

WILLIAM D. GAUTHIER

BY

Harry E. Dawson
William D. Gauthier
Attorneys

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3,083,121

SHUNT CONTROL TO PREVENT ARCING IN AN ELECTROSTATIC SPRAY COATING SYSTEM AND METHOD

William D. Gauthier, Indianapolis, Ind., assignor to Ransburg Electro-Coating Corp., a corporation of Indiana

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My invention has to do with improvements in systems for the spray coating of articles of manufacture in an electrostatic field, and particularly with the control of voltages and currents in such systems.

This application is a continuation-in-part of my application Serial No. 651,377, filed April 8, 1957, now abandoned.

Systems utilizing highly charged electrode means and electrostatic fields having high potentials, as of the order of 40 to 100 kilovolts and more, with sufficient currents to carry out highly efficient electrostatic spray coating operations, have been known and used commercially. One form of such systems operated to control the field gradients in desired manner during variations in field electrode spacings, preferably by the use of impedances and the reduction of the effective capacity so that the systems were incapable of undesirable sparking, fire hazard or shock to personnel. Reference may be made to Juvinal et al., Serial No. 785,754 filed January 8, 1959, a continuation-in-part of Juvinal et al., Serial No. 572,752, filed March 20, 1956, and now abandoned, for further information regarding such systems. The specific system used commercially utilized control impedances of essentially constant value, whereas my invention provides an impedance of variable value, responsive to current flow, as the desired control means for an electrostatic spray coating system.

Practical embodiments of my invention may take different forms. In one form, the automatically variable impedance, which preferably is an electron-discharge controllable amplifying device having an anode, cathode, and control element, is connected in parallel with the depositing field, and the control device is so constructed that upon an increase in field-current the impedance of the variable-impedance element will be decreased to increase the current drain through a fixed resistance and thus reduce the voltage applied to the charged electrode. In another form my invention may take, the variable impedance element is connected in series with the field between the charged electrode and the voltage source, and the arrangement is such that an increase in field current will be accompanied by an increase in the value of the variable impedance, increasing the voltage drop across it and again reducing the voltage applied to the charged electrode.

An object of my invention is to provide improved electrostatic spray coating apparatus.

Another object is to provide an electrostatic spray coating system in which the average potential gradient of the depositing field is maintained within desired values despite varying distances between the charging electrode and the nearest grounded object.

A further object of the invention is an electrostatic spray coating system incapable of sparking or other dangerous disruptive electrical discharge regardless of the proximity of grounded objects to the charging electrode.

Another object of the invention is to provide means for discharging extremely rapidly the inherent capacitance of an electrostatic spray coating system.

Means for accomplishing the above stated and related objects of my invention will now be described in detail,

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with reference to the accompanying drawings in which:

FIG. 1 is a circuit diagram of apparatus for spray coating embodying a form of my invention;

FIG. 2 is a circuit diagram of apparatus showing another form of the invention;

FIG. 3 is a circuit diagram of another embodiment of the invention;

FIG. 4 is a circuit diagram of yet another embodiment of the invention; and

FIG. 5 is a circuit diagram of still another embodiment of the invention.

In FIG. 1 an atomizing head or bell is designated as 10. Preferably this head is constructed of an insulating material such as nylon and coated with a composition of predetermined controlled resistivity. It is rotated about its central axis by suitable motor means 11, preferably connected to the bell by an insulating shaft, and is connected to a controlled source 12 of liquid coating material such as paint or the like, so that the liquid material fed to the head is spread by centrifugal force into a thin film on a surface of the rotating head for atomization therefrom into the electrostatic field. The details of suitable rotating means 11 and the liquid supply means 12 for the atomizing head 10 are known to the art and form no part of my invention. It is also known that the effective capacity of the atomizing head and its electrically associated elements such as the rotating means should preferably be kept at a low value. By use of a form of my invention, however, the effective capacity of the head may be higher than that heretofore used commercially.

In coating operations, the atomizing head 10 is positioned in spaced relation from an article to be coated shown as 13, which is grounded as shown. An electrostatic field of high potential gradient is established between the head 10 and the article 13 through a circuit embodying my invention. A voltage source 14, designed to develop voltages preferably of the order of 100 kilovolts or more (and at least 40 kilovolts) and currents up to a few milliamperes, is grounded and its high voltage terminal (in this particular case the negative terminal) is connected to a first resistance 16, which may be built into the power pack itself if desired.

A second resistance 18 is connected in series between first resistance 16 and the atomizing head 10. Thereby a complete circuit is established from voltage source 14, through resistance 16 and resistance 18 to head 10, preferably without connection to the motor, and thence across the electrostatic field to the grounded article 13.

From a point between the resistances 16 and 18 a circuit to ground is provided through a third resistance 20 and a variable impedance element shown as a triode 22, which circuit provides a path to ground which, in effect, is in parallel to the path to ground through resistance 18 and head 10. In the drawing, and in the explanation which follows, it is assumed that the "hot" terminal of the voltage source 14 is of negative polarity, and hence the anode of the triode 22 is connected to ground and the cathode to the ungrounded terminal of the voltage source through the resistances 20 and 16. To control the effective impedance of the element 22, its control grid is connected through a line 24 to a point between the head 10 and the resistance 18.

The circuit illustrated in FIG. 1 operates in the following manner: Assuming that the element 22 is conducting only a relatively small amount of current by virtue of the bias applied to its grid and the self-bias developed across resistance 20, such small current results in only a small voltage drop across resistance 16. Current from the voltage source 14 will flow through the resistances 16 and 18 to the head 10 and thence through the field, or across the air gap between the head and

the grounded articles 13. If the head approaches the article the resistance of the air gap will decrease, increasing the current and thereby increasing the voltage drop across the series-connected resistances 16 and 18 to lower the potential of the head 10. At the same time, the increase in voltage drop across the resistance 18 will alter the bias on the grid of triode 22 to increase its conduction. When that condition exists, the voltage drop across the resistance 16 will be further increased, since such resistance carries both the current flowing through the head 10 and the current flowing to ground through the triode 22. The thus augmented voltage drop across the resistance 16 effects a further drop in the potential of the head 10.

As will be obvious, the relative values of the resistances 18 and 20 determine the effect on grid voltages of changes in the current flowing to the head. An increase in the value of the resistance 18 augments the effect on grid voltage of changes in current to the head. The resistance 20, by affecting the current flowing in the aforesaid parallel circuit, affects the voltage drop across the resistance 16 and also, by affecting the voltage of the cathode of the element 22, affects the bias on the control element of the triode. In this latter function, an increase in the value of the resistance 20 tends to offset an increase in the value of the resistance 18.

Suitable values for the resistances 16, 18 and 20 will depend to an extent on characteristics of the triode 22. A value of the order of 50 megohms for the resistance 16, of the order of 10 megohms for the resistance 18 and of the order of one megohm for the resistance 20 will be suitable for certain tube characteristics.

In the above explanation it has been assumed that all current from the "hot" terminal of the voltage source flows to ground over the conductive paths illustrated in the drawing. Actually, of course, at the voltages used in practice there will be some leakage of current over other paths; but if the conductors, the motor 11, and other conductive parts are properly sheathed with polyethylene or other suitable high voltage insulating material, any such leakage will be effectively immaterial. Where atomization is to be effected electrostatically the current reaching the head, in the system shown in FIG. 1, must be that required to effect such atomization. With a voltage source providing an output voltage of 100 kv., with the resistance values set forth above, and with a twelve-inch spacing between the head and the article, the space current across the field will be in the neighborhood of thirty microamperes. Except for negligible leakage, this current will comprise all of the current flowing through resistance 18 and a portion of the current flowing through resistance 16 from the power supply 14. At the same time tube 22, by virtue of its grid characteristic curve and the values of resistances 18 and 20 heretofore specified, would for example have a space current of 150 microamperes. This current would also pass through the resistance 16 resulting in a total current of about 180 microamperes under the assumed conditions and a voltage drop of about 9 kv. across resistance 16. Under the conditions mentioned there would be about one-third of a kilovolt additional drop across the resistance 18, so that the voltage at the atomizing edge of the bell 10 would thus be about 90 kv., approximately optimum for electrostatic atomization at a 12" spacing.

If the article and head, undergo relative movement toward each other and the head-article spacing becomes only 5", for example, if there were no change in the head voltage the average potential gradient and space current to the article would go up to more than double their previous value. However, as the 5" spacing is approached, the increase in current flow from the atomizing edge tends to bias the grid of the tube 22 more positively, resulting in a heavier current draw through tube 22 and a correspondingly greater voltage drop across resistance 16. Again, if the values of resistors 18 and 20 have

been properly chosen in relation to a tube with a suitable grid characteristic curve, the additional draw through the tube at this reduced head-article spacing will be such as to drop the voltage to a much reduced head voltage at or near optimum for the reduced spacing. For example, an increase of 30 microamperes additional current through the resistance 18 (so that 60 microamperes in all are now flowing through it) would initially result in 300 volts additional positive bias on the grid of the tube 22. The additional space current flow through the tube, however, would increase the drop across resistance 20 (heretofore specified as having a value of $\frac{1}{10}$ that of the resistance 18), until the tube again stabilized at a space current flow therein satisfactory for the changed head-article spacing. In the case assumed this would, for example, be 620 microamperes. This higher current draw through the resistance 16, coupled with the 60 microamperes passing through the resistance 18 to the atomizing head, would result in approximately a 34 kv. drop across the 50 megohm resistance 16 and approximately a 35 kv. drop when the additional current through the resistance 18 is considered; and this will be seen to result in reducing the head-to-article voltage to a value of about 65 kv., substantially optimum for electrostatic atomization at a 5" spacing.

The foregoing examples have been given as though the head were of metal and had little or no resistance therein. Even if the head has a few megohms of distributed resistance, say about 5 megohms, this is relatively insignificant as compared with the combined values of the resistances 16 and 18 so that the actual atomizing edge voltages would still conform very closely to the figures given above.

It will also be understood that only a few microamperes of additional current flow from the atomizing head as the article and head still further approach each other can result in further markedly increased current drain by the tube 22; and it will be apparent that if the tube 22 drew two milliamperes there would be a 100 kv. drop across the resistance 16 and no voltage at the atomizing edge of the head. An exact no-voltage condition at the head edge can, of course, not be obtained since there would then be no current flow through the resistance 18 to provide grid bias; but the condition can be closely approached to the extent that the head edge voltage can be pulled down to a few kilovolts when the article and the edge get within about $\frac{1}{2}$ " of each other. The quantity of electricity stored in the capacity between the head and ground (indicated by the dotted line capacity representation 25), will drain off as the voltage of the head is dropped by virtue of increased space currents through the tube 22. Thus my invention reduces the importance of low effective capacity in the head; but nevertheless, as stated heretofore, I prefer to use a head with at least a few megohms of distributed resistance as measured between its apex and atomizing edge, in order to still further reduce any possible capacitive discharge effects.

Referring now to the circuit shown in FIG. 2, there is shown a further embodiment of my invention, wherein the variable-impedance element is in series rather than in parallel with the field. As shown, the impedance comprises two tubes which share the voltage drop in the system substantially equally rather than a single tube which may at times have substantially the entire voltage from the power pack developed across it. In describing this circuit, reference numerals 20 higher than used in FIG. 1 will be used on corresponding parts to reduce the necessity for a complete repetition of the description. A bell-like atomizing head 30 rotated by a motor 31 and supplied with paint or other suitable coating material from a source 32 is again adapted to electrostatically coat article 33. In this case the circuit completed between the grounded article and the atomizing head 30 and including the high voltage power supply source 34 is completed through the variable impedance, preferably a pair of

tubes 42 and 42a in series with each other and in parallel with high resistances 36 and 36a which may, for example, be of 500 megohms each. Cathode resistors 40 and 40a, which may be of 2 megohms each, are in series with the cathodes of the two tubes; and the grids of the tubes are connected to the left-hand ends of each of the cathode resistances (as viewed in the drawings) when the "hot" terminal of the power pack 34 is negative.

In the system just described, it may be assumed that the characteristic curves of the tubes are such that approximately 20 or 25 microamperes flows through them when the head-article spacing is in the neighborhood of 10 or 12". The parallel path provided through the resistances 36 and 36a provides a small additional amount of current which may, for example, bring the total current flowing from the atomizing edge of the bell to the article in the neighborhood of 30 microamperes. Under these initial operating conditions, the tubes constitute initially low resistances in parallel with resistances 36 and 36a. On the other hand, as the distance between the atomizing head and the article is materially reduced, and the space current flow therefrom increases, increased current flow through the cathode resistances 40 and 40a biases the grids more negatively and increases the cathode-plate resistances of the tubes. As these resistances become higher the total effective resistance in the circuit also becomes higher, until eventually any further current flow takes place substantially entirely through the high resistances 36 and 36a. Since these provide very high resistance, not only is the voltage at the atomizing edge of the bell progressively decreased as the gap between it and the article decreases, but also the voltage regulation is such as to prevent an objectionable disruptive discharge, provided the head has a suitable distributed resistance sufficient to reduce capacity discharge effects satisfactorily (as 10 megohms when measured between the apex and atomizing edge of a 4" bell). A bell-head with the desired low effective capacity may have its body portion made of a material with good insulating characteristics, as nylon, and have at least one surface coated with a material providing a film which has predetermined very high electrical resistance, but sufficient slight conductivity to carry a current in the low microampere range to the atomizing edge. An alkyd resin, enamel-like coating material with finely divided carbon particles therein has proved very satisfactory for this resistive layer, having not only the necessary high electrode resistance, but also having high chemical resistance to the constituents of paint or other liquid coating material being used, and high mechanical resistance to abrasion by the coating material flowing thereover.

The circuit of FIG. 2 should preferably not be used with a very low resistance or large metal head. However, the circuit of FIG. 2 has the advantage of "failing safe" in the case of a majority of tube failures, which are normally failures of the filament or heater. In the event of such a failure rendering the tube completely non-conductive, all current must then flow through the relatively high resistance in parallel with it.

It is also to be understood that the system is effective with any type of paint charging electrode, insofar as safety conditions are concerned, and need not necessarily energize only the atomizers illustrated in the figures. The protective circuits may be used in conjunction with a paint charging electrode in the form of a wire electrode, for example, with paint or other suitable coating material being introduced into the field between such electrode and the article by an air gun or any other suitable spray device. Such a system is illustrated in FIG. 3 with reference numerals 40 higher than those used in FIG. 1 being used on corresponding parts to simplify the description. Resistance 56 may again be of 50 megohms, for example, and resistance 58 of 10 megohms, the voltage of the supply source being applied to the charging electrode 50 through these resistances. In this case the charg-

ing electrode may be a thin wire electrode as, for example, a wire 10 mils in diameter and 2 feet long; and paint is sprayed into the field between this charging electrode and the grounded article 53 from a suitable spray source, as a conventional air spray gun 66. The tube 62 has its grid connected between the resistance 58 and the charging electrode 50 by the lead 64, and its cathode connected to the other side of the resistance 58, between it and the resistance 56, through the cathode resistance 60, which may be of one megohm, and the plate of tube 62 is connected to ground. Operation of the circuit is analogous to that described in connection with the system of FIG. 1.

It is to be understood that while the circuits are shown in each of the three figures as separate from the voltage supply indicated by the box at the left of each figure, they can in commercial practice be incorporated within the cabinet of the power pack and combined with it. Moreover, while the actions of the circuits have been described in connection with initial voltage supplies assumed to be constant, such voltage supplies can also inherently effect some of the desired voltage drop within themselves, so that the control circuits illustrated would in such case not be required to effect the entire desired control for maintenance of optimum electrostatic atomizing voltages, or for safety.

It is also to be understood that it may be desirable to use additional grid bias batteries or other grid bias voltage sources to effect operation on a suitable portion of the grid characteristic curve; that the use of amplifiers in the grid circuit may be desirable to effect greater grid voltage changes in the control tube as a result of relatively small current changes from the charging electrode; and that the control tube itself may be replaced by any other form of variable current-controlling device.

The circuits heretofore illustrated and described have all been designed for a situation where the positive terminal of the power pack is connected to ground, and the negative terminal is connected to the field electrode which charges the spray particles. Somewhat different circuits are necessary when the spray charging electrode is connected to the positive terminal of the high voltage power supply, and circuit embodiments for such use are illustrated in FIGS. 4 and 5.

Referring first to FIG. 4, reference numerals 60 higher than those used in the first description will be applied to the analogous parts. A high voltage power pack 74 has its negative terminal grounded and its positive terminal connected to resistance 76, which may, for example, have a resistance of the order of 2,000 megohms. An atomizing head or bell 70, preferably of low effective capacity as heretofore described, is rotated by a motor 71 and supplied with paint or other liquid coating material from a supply source 72. Resistance 76 is connected through a grid bias resistance 78, which may, for example, have a value of 1 megohm, to the head 70 which atomizes and charges the spray of coating material. The article 73 being painted is grounded, so that the atomizing head 70 and the article comprise the two electrodes of a high potential atomizing and depositing field, generally in the neighborhood of 80 or 90 kv.

In this case the tube 82 provides a circuit path in shunt with the high resistance 76, having its anode connected to the end of the resistance connected to the positive terminal of the power pack and its cathode connected to the other end of such resistance. A connection 84 leading from a point between the resistance 78 and the motor 71 to the grid of the tube 82 provides grid bias controlling the cathode-anode resistance of the tube. The characteristics of the tube would be so selected that at normal operating currents through the resistor 78, as the for example 30 microamperes, the cathode-anode resistance of the tube would be only a relatively few megohms, and substantially the entire voltage from the power pack would be applied to the atomizing head 70. Should the current through the resistance 78 rise, however, as by rea-

son of a lesser spacing between the article and atomizing head, the increased voltage drop across the resistance 78 makes the grid of tube 82 more negative with respect to its cathode, increasing its resistance and thus increasing the voltage drop and reducing the voltage applied to the atomizing head. When the space current leaving the atomizing head reaches a predetermined selected value as, for example, 80 or 90 microamperes, the tube characteristics should be such that the negative bias on the grid completely cuts off any conduction through the tube, raising its resistance substantially to infinity, and resulting in substantially all current flow to the head being through the high resistance 76. As will be immediately apparent, any further increases in space current flow from the atomizing head will result in large voltage drops across the resistance 76 and greatly reduced potential difference between the atomizing head 70 and the article 73.

In the circuit shown in FIG. 5, an atomizing head 90 is again adapted to be rotated by a motor 91 and to be supplied with a liquid coating material from a supply source 92 to coat a grounded article 93. A high voltage power pack has its positive terminal connected to a resistance 96, which may, for example, have a value of 50 megohms, the other end of this resistance being connected to the atomizing head 90. The negative terminal of the power pack is connected to ground through a resistance 106, which may, for example, have a value of 1 megohm. The grounded end of this resistance is connected to the grid of tube 102 through lead 104, and the other end of resistance 106 is connected to the cathode through resistance 100 which may also have a value of 1 megohm, the anode of the tube being connected to the end of resistance 96 farthest from the power pack. Since space current flow between the atomizing head 90 and the article 93 is returned through the ground connection to the power pack, it provides a voltage drop across resistance 106 which is proportional to the current flow, and which drives the grid more positive with respect to the cathode upon increases in space current flow. The characteristics of the tube are so selected that the tube is at or just barely above cut-off at a desired operating space current, as 30 microamperes. Increases in space current will cause increase in current flow through the tube and thus increased current flow through the resistance 96. For example, if the tube is conducting one milliampere at 60 microamperes of space current, there will be more than 50 kv. of voltage drop across the resistance 96 with a resultant very reduced voltage drop between the atomizing head and article.

The foregoing description of embodiments of my invention has been for the purposes of illustration and not by way of limitation of the invention. The invention is concerned broadly with the use of a current-controlling device, as a tube controlled by a grid or the like, for controlling voltages and current flows in an electrostatic spray coating system, as pointed out in the appended claims.

I claim:

1. Apparatus for electrostatically depositing liquid coating material on an article, comprising: a source of unidirectional high potential; a charging electrode electrically connected to said source; means for supporting the article to be coated; means connecting said article in circuit with said high potential source to establish an electrostatic field between said charging electrode and said article, the electrode-charging portion of said circuit including high resistance means through which at least a portion of the space current in said field flows; a source of liquid coating material; means for atomizing said liquid coating material into said electrostatic field, said charging electrode and said article being capable of relative movement during normal coating operation; a controllable variable impedance device connected to said high resistance means; and means for controlling the impedance of said device as a function of space current flow in said

electrostatic field for causing an amplified variation in current flow through said high resistance means, whereby variations in average potential gradient of said field during relative movement between said electrode and article are substantially reduced.

2. In an apparatus for electrostatically depositing liquid coating material on an article including a source of unidirectional high potential, a charging electrode electrically connected to said source, means for supporting the article to be coated, means connecting said article in circuit with said high potential source to establish an electrostatic field between said charging electrode and said article, the electrode-charging portion of said circuit including high resistance means, a source of liquid coating material, means for atomizing said liquid coating material into said electrostatic field, said charging electrode and said article being capable of relative movement during normal coating operation, a field potential regulator, comprising a tube having cathode and plate elements, one of these elements being connected to the end of said high resistance means which is connected to said charging electrode, and a control grid; and means for varying the cathode-grid bias of said tube as a function of space current flow in said electrostatic field for causing an amplified variation in current flow through said high resistance means, whereby variations in average potential gradient of said field during relative movement between said electrode and article are minimized and an objectionable discharge of electrical energy is avoided upon close approach of said electrode to another object

3. Apparatus of the character claimed in claim 1, wherein said charging electrode has low effective capacity.

4. In an apparatus for electrostatically depositing liquid coating material on an article including, a source of unidirectional high potential, a charging electrode electrically connected to said source, grounded means for supporting the article to be coated, means connecting said article in circuit with said high potential source to establish an electrostatic field between said charging electrode and said article, the electrode-charging portion of said circuit including high resistance means, a source of liquid coating material, and means for atomizing said liquid coating material into said electrostatic field, said charging electrode and said article being capable of relative movement during normal coating operation, a field potential regulator, comprising: a tube having cathode and plate elements, one of these elements being connected to the end of said high resistance means which is connected to said charging electrode and the other of these elements being connected to ground, and a control grid; and means for varying the cathode-grid bias of said tube as a function of space current flow in said electrostatic field for causing an amplified variation in current flow through said high resistance means, whereby variations in average potential gradient of said field during relative movement between said electrode and article are minimized and an objectionable discharge of electrical energy is avoided upon close approach of said electrode to another object.

5. In an apparatus for electrostatically depositing liquid coating material on an article including a source of unidirectional high potential, a charging electrode electrically connected to said source, means for supporting the article to be coated, means connecting said article in circuit with said high potential source to establish an electrostatic field between said charging electrode and said article, the electrode-charging portion of said circuit including high resistance means, a source of liquid coating material, and means for atomizing said liquid coating material into said electrostatic field, said charging electrode and said article being capable of relative movement during normal coating operation, a field potential regulator, comprising: a tube having cathode and plate elements connected to opposite ends of said high resistance means, and a control grid; and means for varying the cathode-grid bias of said tube as a function of space cur-

rent flow in said electrostatic field for causing an amplified variation in current flow through said high resistance means, whereby variations in average potential gradient of said field during relative movement between said electrode and article are minimized and an objectionable discharge of electrical energy is avoided upon close approach of said electrode to another object.

6. Apparatus of the character claimed in claim 5, wherein there are a plurality of high resistances in series in said circuit, each such resistance having a tube in shunt therewith, and the sum of the values of said resistances comprising at least several megohms per kilovolt of said high potential source when said charging electrode is sufficiently near another object that a disruptive discharge might occur.

7. Apparatus for electrostatically spray coating articles, comprising charging electrode means, means for maintaining an article to be coated at ground potential and spaced from said charging electrode means, voltage supply means connected in a circuit with said charging electrode means and capable of providing a high unidirectional potential difference of at least 40,000 volts and at least several thousand volts per inch average gradient between said charging electrode means and the article portion closest thereto during normal coating conditions to create an electrostatic depositing field, a vacuum tube, the circuit between said voltage supply means and said charging electrode means including a resistance and a connection to said tube, said tube having cathode and plate elements and a grid, one of said elements of said tube being connected to said resistance and the grid of said tube controlling the flow of current in said tube to control the voltage between said charging electrode means and said article; and means for projecting a spray of liquid coating material particles into the depositing field for charging and deposition of the spray particles on the article while still in liquid state.

8. Apparatus for electrostatically depositing liquid coating material on an article, comprising a source capable of providing a unidirectional high potential of at least 40,000 volts, a charging electrode electrically connected to said source, means for supporting the article to be coated in spaced relation to the charging electrode, means connecting said article in circuit with said high potential source to establish an electrostatic field between said charging electrode and said article, a source of liquid coating material, means for atomizing said liquid coating material into said electrostatic field, said charging electrode and said article being capable of relative movement which varies the length of the air gap therebetween during coating operation, said means connecting said current source to said charging electrode including a first resistance and a second resistance in series, said second resistance having a lower resistance value than that of said first resistance, a third resistance of still lower value having one end connected between said first and second resistance, a tube having a cathode connected to the other end of said third resistance, a plate connected to ground and a control grid connected to said charging electrode to minimize variations in the average potential gradient of said electrostatic field that would otherwise occur as a result of variations in the length of the air gap, whereby at all air gap lengths objectionable discharge of electrical energy of a character to initiate a fire or a shock to the operator is avoided.

9. In the method of electrostatically spray coating articles in an electrostatic field created by a unidirectional high potential between a charging electrode and another electrode comprising at least one of the articles and wherein relative movement between the electrodes results in appreciable variation in the gap spacing therebetween during normal coating operation, and wherein electrostatically charged coating material particles in the field are electrostatically deposited on the article, the steps of providing a controllable variable impedance device operatively connected to said charging electrode circuit to

control the impedance of the electrode circuit, and controlling said device in response to changes in space current across said gap to automatically continuously change the voltage between the electrodes to materially minimize variations in the average field gradient which would otherwise accompany such changes in spacing.

10. In the method of electrostatically spray coating articles in an electrostatic field created by a unidirectional high potential between a charging electrode and another electrode comprising at least one of the articles and wherein relative movement between the electrodes results in appreciable variation in the gap spacing therebetween during normal coating operation, and wherein electrostatically charged coating material particles in the field are electrostatically deposited on the article, the steps of providing a high resistance in series with said charging electrode, and a tube connected to said resistance and having its cathode-grid control voltage changed by and as a function of changes in space current across said gap to cause amplified variations in voltage drop across said resistance resulting in minimization in the variations in the average field gradient which would otherwise accompany such changes in spacing, while maintaining the energy level of a discharge from the charging electrode below that which would be provided by a metal sphere of a radius of about three centimeters in the same electrostatic system.

11. In an apparatus for electrostatically depositing liquid coating material on an article, a source of unidirectional high potential, a charging electrode electrically connected to said source, grounded means for supporting the article to be coated, means connecting said article in circuit with said high potential source to establish an electrostatic field between said charging electrode and said article, the electrode-charging portion of said circuit including high resistance means connected to one terminal of the high potential source, a source of liquid coating material, and means for atomizing said liquid coating material into said electrostatic field, said charging electrode and said article being capable of relative movement during normal coating operation, field potential regulating means, comprising a tube having cathode and plate elements, one of these elements being connected to the end of said high resistance means which is connected to said charging electrode and the other of these elements being connected to the other terminal of the high potential source, and a control grid; and means for varying the cathode-grid bias of said tube as a function of space current flow in said electrostatic field for causing an amplified variation in current flow through said high resistance, whereby variations in average potential gradient of said field during relative movement between said electrode and article are minimized and any discharge of electrical energy is also minimized upon close approach of said electrode to another object.

12. Apparatus of the character claimed in claim 11, wherein the means for varying the cathode-grid bias of said tube comprises a resistance connected between ground and said other terminal of the high potential source.

13. Apparatus for electrostatically depositing liquid coating material on an article, comprising, a source of unidirectional high potential; a charging electrode electrically connected to said source; means for supporting the article to be coated; means connecting said article in circuit with said high potential source to establish an electrostatic field between said charging electrode and said article, the electrode-charging portion of said circuit including high resistance means; a source of liquid coating material; means for atomizing said liquid coating material into said electrostatic field, said charging electrode and said article being capable of relative movement during normal coating operation; a tube having cathode and plate elements connected to opposite ends of said high resistance means, and a control grid; and

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means for varying the cathode-grid bias of said tube as a function of space current flow in said electrostatic field for causing a variation in current flow through said high resistance means, whereby variations in average potential gradient of said field during relative movement between said electrode and article are minimized and any discharge of electrical energy is also minimized upon close approach of said electrode to another object.

14. Apparatus of the character claimed in claim 13, wherein the high resistance means in said circuit has a tube in shunt therewith, the value of said resistance comprises at least several megohms per kilovolt of said high potential source when said charging electrode is sufficiently near another object that a disruptive discharge might occur, and said tube is rendered less conducting upon near approach to the object.

15. An apparatus for electrostatically depositing coating material on an article, comprising a high voltage uni-

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directional current source for establishing an electrostatic field between a charging electrode and the article to be coated, a variable impedance associated with the current path from the source to the article, and means responsive to space current flow in said field for automatically varying the value of said impedance to reduce variation in the average potential gradient of said field, in the event of relative movement between said electrode and the article.

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