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J. D. ORNDOFF
CONTROL APPARATUS

2,650,329

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2 Sheets-Sheet 1

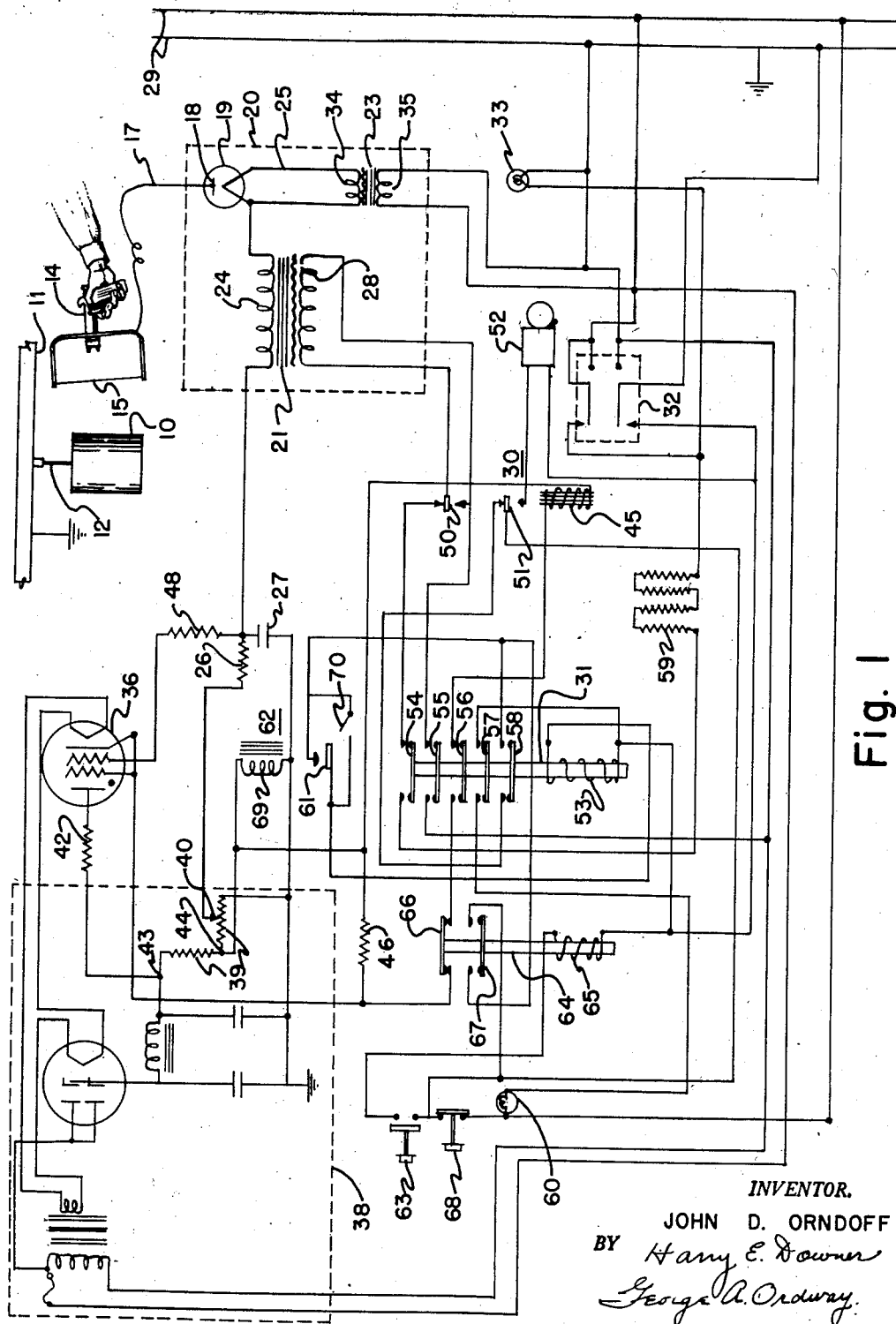


Fig. 1

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2 Sheets-Sheet 2

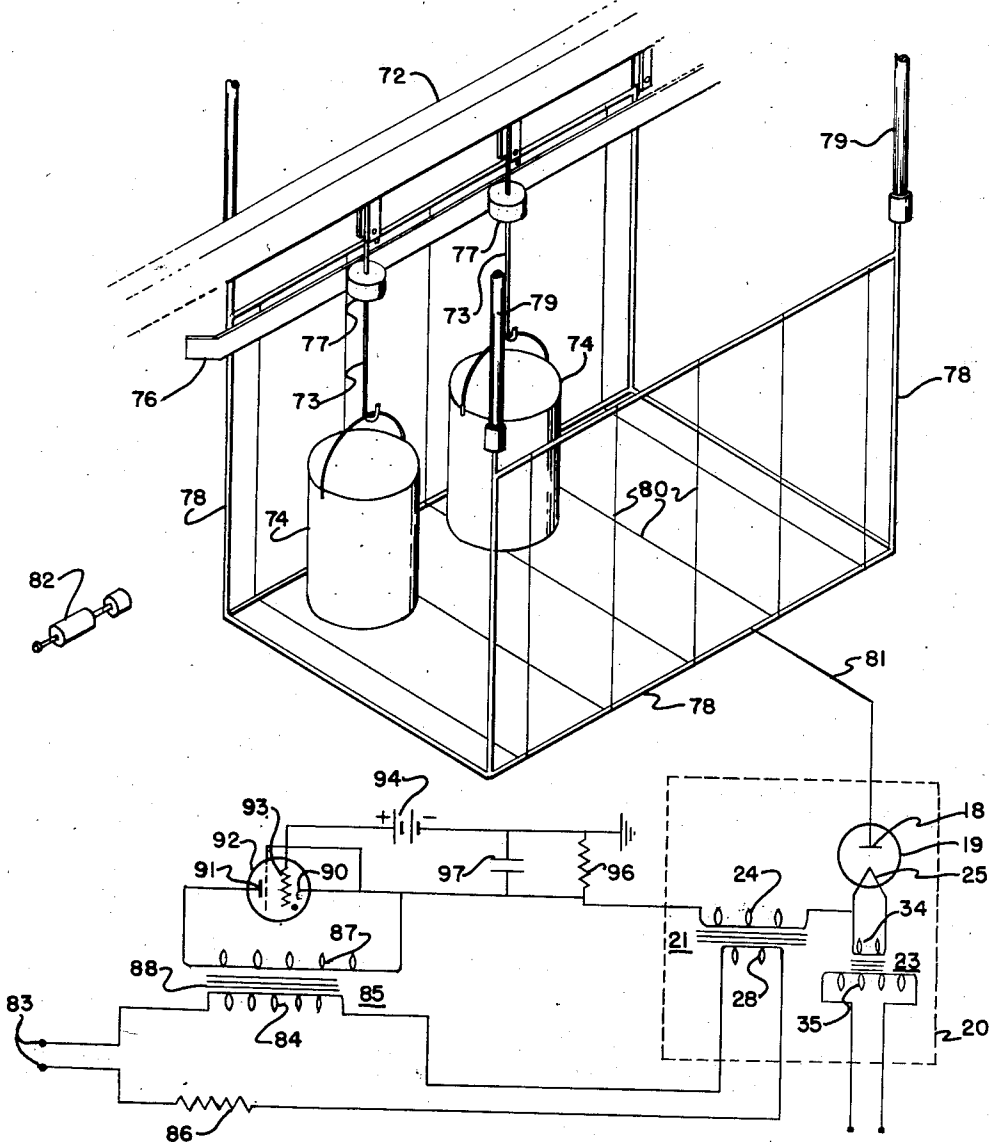
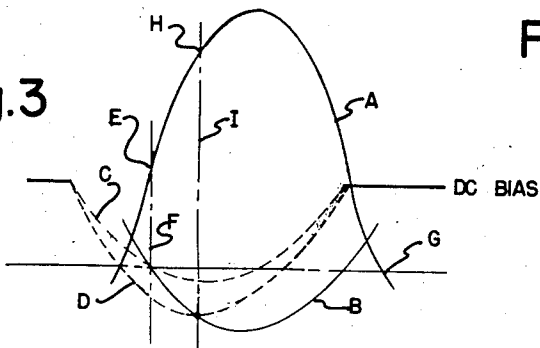


Fig. 2

Fig. 3



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CONTROL APPARATUS

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7 Claims. (Cl. 317—51)

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This invention relates to utilization of electrostatic fields and more particularly to novel apparatus which is adapted to control electrostatic fields.

Electrostatic fields are utilized in many situations. For example, they are used in electrostatic coating processes and apparatus for promoting the deposition of paint or other coating material upon articles as illustrated in Harold P. Ransburg et al. Patent No. 2,247,963, in the electrostatic detearing processes and apparatus whereby excess paint or other finishing material is removed from coated articles as illustrated in Charles K. Gravley Patent No. 2,359,476, in processes and apparatus for removing dust particles from air or other gases and in processes and apparatus for depositing and/or orienting fibers, flock or abrasive particles on a suitable base.

The potential differences employed in the creation of electrostatic fields are in many cases not far below that which would be necessary to produce a sudden disruptive discharge or spark between the electrodes at their normal spacing, with the result that a minor change in the operating conditions may result in a sudden disruptive discharge. Among the factors which may cause sudden disruptive discharges are an accumulation of material on the electrodes, a reduction in the dielectric strength of the medium between the electrodes, a reduction in the spacing of electrodes, the approach of a grounded object to a charged electrode, and a surge of current in the primary of the high voltage source. In many situations, as in an atmosphere containing dust or vapors of volatile solvents, such a sudden disruptive discharge or spark might result in a fire or an explosion.

Heretofore, efforts have been exerted to increase the safety of apparatus utilizing electrostatic fields. Photoelectric switching devices have been employed to detect certain conditions that cause disruptive discharges. Also, I am aware that apparatus has been designed which operates in response to changes in current that flows in the electrostatic field for modifying conditions that cause disruptive discharges. An example of such apparatus is illustrated in application Serial No. 586,582 of Edwin M. Ransburg et al. now Patent No. 2,509,277. However, these previous devices have been either too sensitive or insensitive under certain conditions for practical operation or have possessed other limitations which have restricted their operation in certain respects from the point of adequate protection against the dangers from disruptive discharges.

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Therefore, it is an object of this invention to minimize dangerous current changes in field producing apparatus without effecting its operation due to normal current changes.

Another object of this invention is to provide apparatus for controlling an electrostatic field which is stable under substantially all conditions of operation.

Another object of this invention is to provide apparatus utilizing apparatus to which energy is not furnished when its control apparatus is inoperative for any reason.

Another object of this invention is to provide an apparatus having the above characteristics which will be simple in construction and durable in use and which, because it contains only standard components can be readily inspected, serviced and repaired in the field.

In accordance with the present invention there is provided a control system which includes a load circuit, a source of high potential for energizing the load circuit and means for controlling the source. The control means preferably includes a gas tube and a filtering circuit which may comprise a resistor-capacitor network. The filtering circuit is electrically connected between the load circuit and the gas tube to make the control means responsive to current changes in the load circuit of predetermined value.

In accordance with one feature of this invention the control means is connected to the voltage source by a switching apparatus which includes a manually operated means, a first relay means, a second relay means and a resistance means shunting the first and second relay means. The various means of the switching apparatus are connected in such a manner that upon the activation of the manual means, the switching apparatus reenergizes the load circuit and the control means is set for another operation.

In accordance with another feature of this invention, the control means and the switching apparatus are operatively associated with each other by an interlock relay which deenergizes the high voltage source upon the control means becoming inoperative.

For a better understanding of the invention, together with other and further objects thereof, reference is made to the following specification taken in connection with the accompanying drawing, and its scope will be pointed out in the appended claims.

In the drawing:

Fig. 1 is a detailed schematic circuit diagram

showing one form of the control apparatus as applied to hand electrostatic coating;

Fig. 2 is a detailed schematic circuit diagram showing another form of control apparatus as applied to a conveyORIZED electrostatic coating apparatus shown in perspective and;

Fig. 3 graphically illustrates the characteristics of the tube used in the control apparatus illustrated in Fig. 2.

Referring now more particularly to Fig. 1, there is shown an article 10 supported from a conveyor 11 by a support 12. A manually manipulated spray gun 14 is placed in position to discharge paint on the article 10. Associated with the spray gun 14 is an electrode 15 positioned so that when charged it will charge the paint particles issuing from the spray gun and will also create an electrostatic field between itself and the article 10. The invention described herein is not limited to use with the coating apparatus just described. As mentioned before, detearing apparatus, orienting apparatus, gas cleaning apparatus or any other apparatus utilizing an electric field may be substituted for the coating apparatus described.

The electrode 15 is energized through a conductor 17, preferably of the flexible type as shown, which is connected to anode 18 of rectifier tube 19 of high voltage pack or supply 20. The voltage supply 20 also includes a high voltage transformer 21 and a filament transformer 23.

The apparatus as so far described is much the same as that more fully set forth and described in the co-pending application of H. P. Ransburg et al. Serial No. 596,870, filed May 31, 1945, now Patent No. 2,546,701.

One end of secondary 24 of the transformer 21 is connected to cathode 25 of the rectifier tube 19 and the other end of this secondary is connected to ground through a circuit comprising resistor 26 and capacitor 27. The purpose of this resistor-capacitor network will hereinafter become apparent. The circuit which includes secondary 24 may also be referred to as the output or load circuit of the high voltage supply 20. Primary 28 of the transformer 21 is connected to a suitable voltage from line 29 through contacts of control relay 30, switching relay 31, resistors 59, and timer 32. This circuit may be referred to as the input circuit of the high voltage supply 20. Pilot light 33 is associated with the timer 32 to inform an operator when the circuit through the timer is closed. Relays 30 and 31 will be described in greater detail hereafter.

Secondary 34 of the insulated transformer 23 is connected directly to the cathode 25, and primary 35 of the same transformer is connected to a power source by the line 29.

In the apparatus illustrated in Fig. 1, the operation of the high voltage supply 20 and the coating apparatus associated therewith is controlled by means responsive to the voltage across the resistor-capacitor circuit 26, 27, such voltage in turn being responsive to the current flowing between charged electrode 15 and the grounded article 10. The preferred means for effecting the desired control involves the use of a vacuum tube 36 shown as a tetrode of the gas-filled type. Associated with the gas tube is a power pack 38 including a potential divider 39 with adjustable tap 40. The potential divider 39 provides a suitable plate voltage and grid bias for the gas tube. The grid of this tube also is connected to the filtering circuit 26, 27 and thus it is also biased by the voltage drop across resistor 26. By biasing

the grid of gas tube 36, in this manner, its sensitivity to firing is reduced so that it will not respond to rapid transient variations in current in the electrostatic field between the article 10 and the electrode 15. However, the tube 36 will be sufficiently sensitive so that it will fire in response to prolonged current variations in the field, which may be caused by a foreign body or article 10 approaching too closely to the electrode 15. The plate circuit of the gas tube 36 includes protective resistor 42, that part of potential divider 39 between terminals 43 and 44, and resistor 46 between terminals 43 and 44, and contacts of relays 31 and 64. The grid circuit of the gas tube includes protective resistor 48, the resistor-capacitor network 26, 27, and the part of potential divider 39 between adjustable tap 40 and terminal 44.

The control relay 30 includes two sets of contacts 50 and 51. By means of contacts 50 relay 30 controls the power supply to transformer 21. By means of contacts 51 relay 30 controls signal 52 and the holding circuit of the switching relay 31. This relay comprises a coil 53 which, when energized, closes five sets of contacts, 54, 55, 56, 57 and 58. The contacts 54 and 55 control the circuit which supplies power to the transformer 21. This circuit includes the contacts 50, limiting resistor 59 and the timer 32. The contacts 56 control the plate circuit of the gas tube 36. The contacts 56 are included in that branch of the circuit connected across resistor 46 which includes coil 45 of relay 30, contacts 56 and contacts 66. The contacts 57 control a circuit which includes pilot light 60 which indicates whether switching relay 31 is open or closed. The contacts 58 control the holding circuit of relay 31. This holding circuit includes contacts 61 of interlock relay 62 (to be described in greater detail hereafter), the contacts 51, the timer 32 and a starting mechanism.

The starting mechanism includes a manually operated, normally open, switch 63 and operating relay 64. The relay 64 comprises coil 65 and pairs of contacts 66 and 67. When coil 65 is energized, contacts 66 are opened and contacts 67 are closed. The contacts 66 are in series with contacts 55 of starting relay 31 and coil 45 of the control relay 30. This series combination is shunted by the resistor 46 as previously explained. As a result of this arrangement, during the time that switch 63 is closed the coil 45 of relay 30 is disconnected from the plate circuit by the opening of contacts 66. At such time the plate circuit remains closed through resistor 46 and thus the plate voltage is never completely removed from the gas tube 36. This avoids energizing the relay 30 during starting and restarting operations. The contacts 67 are in the circuit that includes coils 53 and 65. By means of these contacts and switch 63, it is possible to energize relay 31 manually.

Manually operated switch 68 is provided in the holding circuit of relay 31 in order that the contacts of this relay may be manually controlled if this is desired for any reason.

Interlock relay 62 comprising coil 69 and the contacts 61 is provided between the plate circuit of gas tube 36 and the holding circuit of the switching relay 31. The coil 69 is shunted across a part of the potential divider 39, and the contacts 61 are positioned in the holding circuit of the switching relay 31 as previously described. The purpose of the interlock relay is to prevent supplying power to the high voltage transformer

21 when the control apparatus is inoperative because of burned out tubes, defects in the circuits of the control means, etc.

Manually operated lock switch 70, which is connected across contacts 61, is provided for the purpose of permitting the operation of the coating apparatus shown in Fig. 1 without the control apparatus just described. This is a key switch designed to be used only by responsible persons who are in possession of the key and is used only in emergency.

The parts of the apparatus illustrated in Fig. 1 are shown in the positions they occupy when the apparatus is completely inoperative.

Upon the application of a suitable source of potential to the line 29, the rectifier tube 19 is lighted and the power pack 38 and the timer 32 are energized. With the power pack 38 energized, the gas tube 36 is lighted and plate voltage is applied to tube 36 by means of that part of the plate circuit which includes the protective resistor 42, that part of potential divider 39 between 43 and 44 and resistor 46. The voltage from the power pack 38 also energizes coil 69 to close contacts 61 in the holding circuit of switching relay 31. The power pack 38 also applies a suitable biasing potential to the grid of the gas tube 36, the magnitude of which potential is determined by the position of adjustable tap 40 on the potential divider 39. After the timer 32 has been energized a predetermined time, usually about 45 seconds, a switch therein closes the circuits passing through it.

When the timer is in a closed position, switch 63 is actuated to energize coil 65, opening contact 66 and closing contact 67. This in turn energizes coil 53 and closes all of the contacts of relay 31. With all of the contacts of relay 31 closed, the following condition exists: (1) pilot light 60 is lighted (2) transformer 21 is energized (3) current is established through combination 26, 27 and (4) gas tube 36 has its grid biased. It is to be noted that during the starting operation, contacts 66 of relay 64 are open. As has been previously explained, under this condition the plate circuit consists of the plate of tube 36, protective resistor 42, that part of potential divider 39 between 43 and 44, resistor 46 and the cathode of tube 36. Since resistor 46 is of relatively high resistance, it will not permit tube 36 to be fired by surges that may result from the starting operation. This resistor also functions to insure that a voltage will be applied to the plate of the tube 36 during the time the tube 36 is not discharging. Upon release of the button of the switch 63, coil 65 is deenergized, which results in closing contacts 66 and opening contacts 67, and coil 53 remains energized by means of the circuit passing through contacts 58 to keep contacts 55 in a closed position. The closing of contacts 55 and 56 closes a circuit connected across the resistor 46 which connects the coil 45 of relay 30 into the plate circuit.

Upon the energization of transformer 21, energy is furnished for establishing an electrostatic field between the article 10 and the electrode 15 to permit the practice of electrostatic coating. The current flowing in the electrostatic field between the grounded article 10 and the charged electrode 15 passes through the capacitor-resistor network 26, 27 and creates across this network a drop in potential directly proportional to the magnitude of such current. The grid voltage impressed on the gas tube 36 will be the algebraic sum of the voltage drop across the capaci-

tor-resistor network 26, 27 and the voltage between the terminal 44 and the tap 40 of potential divider 39. The connections are such that a negative bias will be imposed on the grid of the tube 36 by the voltage across the terminal 44 and the tap 40, and the potential across the resistor-capacitor network 26, 27 is algebraically added to this negative biasing potential which reduces the negative value of the bias or makes it positive. The components which create the potentials used for biasing the grid of tube 36 are of such characteristics that no plate current will flow through the gas tube 36 while the coating apparatus is operating under normal conditions. However, as soon as an abnormal condition occurs, for example, when the article 10 approaches too close to the electrode 15, the biasing condition of tube 36 will be changed sufficiently to fire it. Accordingly, as long as the electrode 15 is maintained at a safe distance from the article 10, the negative bias imposed on the grid of the gas tube 36 will remain above that necessary for current to flow in the plate circuit, relay 30 will remain deenergized, and the operation of the transformer 21 will continue. However, as explained, should the electrode 15 approach an article 10 too closely, or should other conditions arise as a result of which the current in the electrostatic field is increased from its normal value toward a value which it will have just before a spark occurs, the voltage drop across the network 26, 27 will increase sufficiently and decrease the negative grid bias imposed on the gas tube 36 to a point such that the gas tube becomes conductive. When this occurs, current in the plate circuit energizes the relay 30 which deenergizes the relay 31, sounds the signal 52 and deenergizes transformer 21. The deenergization of transformer 21 reduces to zero the potential difference between the article 10 and the electrode 15 to remove all dangers of sparking.

When the transformer 21 is deenergized in the manner just described, the operator will correct the causative conditions and restart the apparatus by closing the switch 63 as previously described.

In the modification of the invention shown in Fig. 2, there is shown a conveyORIZED coating apparatus associated with a control system embodying different features from the one illustrated in Fig. 1. The coating apparatus comprises a channel member 72 adapted to enclose a conveyor chain (not shown) from which are suspended a plurality of supports 73 which are adapted to carry articles 74, for example, such as the illustrated buckets. Suitable means may also be provided for rotating the articles to be coated which preferably comprise a shoe 76 and rollers 77. An electrode frame 78 which is supported from suitable insulators 79 is located in a coating zone through which articles 74 are moved. Fine ionizing wires 80 are conductively supported on the frame 78 and are electrically connected by a conductor 81 to a high voltage supply. The same voltage supply is here illustrated that is shown in Fig. 1; like numbers are applied to the same parts; its description will not be repeated. A material issuing means which may be in the form of a spray gun 82 is provided for spraying coating material into the coating zone. The coating apparatus thus far described may be more easily understood by reference to the more detailed description of a similar coating apparatus in the application of Harold P. Ransburg et al., Serial No. 575,956, now Patent No. 2,463,422.

The control system shown in Fig. 2 is associated with the high voltage supply 20 and the power supply circuit for this high voltage supply. The power supply circuit for the voltage supply 20 includes terminals 83 which are adapted to be connected to a commercial power supply. This circuit also includes the primary 84 of control transformer 85, the primary 28 of high voltage transformer 21 and limiting resistor 36. The transformer 85 also includes secondary 87 and iron core 88. The characteristics of the iron core 88 are such that it remains unsaturated regardless of the value of the current that flows in secondary 87 and the effective reactance in primary 84 is generally inversely proportional to the current flow in secondary 87. Secondary 87 is connected between cathode 90 and anode 91 of gas tube 92. The grid 93 of the gas tube 92 is biased by a constant source of potential, such as battery 94. The secondary 24 of high voltage transformer 21 is connected to ground through a network comprising resistor 95 and capacitor 97. This network is connected to the grid 93 in such a manner that the voltage across resistor 95 opposes the biasing voltage supplied by the battery 94 so that the grid 93 is biased by a pulsating potential, the instantaneous value of which is the algebraic sum of the voltage produced by the battery 94 and the potential drop across the capacitor-resistor network 95, 97. The capacitor-resistor network is connected into the control circuit in such a manner that at minimum current conditions in the field between articles 74 and electrode 78, 80, the gas tube 92 fires for a maximum period of time, and under maximum current conditions in the field, the gas tube 92 fires for a minimum period of time.

The operation of the apparatus shown in Fig. 2 will be explained in connection with Fig. 3 which shows the characteristic curves of gas tube 92 during a portion of one cycle. In this diagram curve A represents the plate potential of the gas tube which is alternating where a 60-cycle alternating current is applied to terminals 83. Curve B represents the critical grid potential. Curve C represents the grid potential during minimum current conditions in the field between the article 74 and the electrode 78, 80. Curve D represents the grid potential during the abnormally high current conditions in the field between the article 74 and the electrode 78, 80.

When the apparatus illustrated in Fig. 2 is in normal operating condition, the current in the electrostatic field between the article 74 and the electrode 78, 80 is of minimum value and the grid potential applied to grid 93 is illustrated by curve C. As long as this grid potential remains below the value of the critical grid potential illustrated by curve B, gas tube 92 will not fire. However, as soon as the grid potential exceeds the critical grid potential, the tube will fire. From observing Fig. 3 it will be readily seen that the firing of gas tube 92 will occur when curve C intersects curve B at which time the plate voltage has reached a value E which is obtained by drawing a perpendicular F through the intersection of curves B and C. The tube continues to fire until the plate voltage again reaches zero which occurs at G. The current produced during each cycle under this normal condition passes through the secondary 87. This produces a maximum current in the secondary 87 and results in a maximum potential delivered to the electrode 78, 80.

When an abnormal condition occurs during the operation of the apparatus illustrated in Fig. 2,

for example, when one of the articles 74 approaches too closely to the electrode 78, 80, there is an increase in the current in the electrostatic field which results in a grid potential applied to the grid 93 illustrated by curve D. As long as this grid potential remains below the value of the critical grid potential illustrated by curve B, gas tube 92 will not fire. However, as soon as the grid potential exceeds the critical grid potential, the tube will fire. Again observing Fig. 3, it will be readily seen that the firing of gas tube 92 will occur when curve D intersects curve B at which time the plate voltage has reached a value H which is obtained by drawing a perpendicular I through the intersection of curves B and D. The tube continues to fire until the plate voltage again reaches zero which occurs at G. The current produced during each cycle under this abnormal condition is substantially less than under the previously described normal condition. When this lesser current flows through the secondary 87, it produces a smaller voltage drop across secondary 28 which results in the application of a smaller voltage to electrode 78, 80.

Thus it is seen that by this control apparatus, the voltage applied to the electrode 78, 80 is automatically maintained low enough at all times to prevent sparks in the coating apparatus.

What is claimed is:

1. In combination, an electric load having a supply circuit including a first switch operable to deenergize said load, an electron discharge device having a cathode, anode, and control element, an anode circuit for said device including a source of anode voltage and a second switch connected in said anode circuit between said anode and said cathode, another circuit for applying to said control element a potential proportional to current flowing in said supply circuit, means responsive to current flowing in said anode circuit for opening both said switches when current in said supply circuit reaches a predetermined value, and a resistance in parallel with said second switch for maintaining a minimum predetermined potential between said cathode and said anode when said second switch is open.

2. The invention set forth in claim 1 with the addition of switch-closing means operative to close said first and second switches, said means being adapted to maintain the circuit including said second switch open for a predetermined interval of time after said first and second switches are closed.

3. The invention set forth in claim 1 with the addition of interlocking means energized by said source of anode voltage and being operable to open said first and second switches independently of said current responsive means upon deenergization of said source of anode voltage.

4. The invention set forth in claim 1 with the addition that said two switches are normally open sets of contacts of an electromagnetic switching device having also a third set of normally open contacts and a winding operative when energized to close all said sets of contacts; said current responsive means comprising a holding circuit including said winding, said third set of contacts, and normally closed contacts of a relay, said relay having a winding connected in said anode circuit and energizable by current of a predetermined maximum value to open its contacts; switching mechanism having a first set of normally closed contacts in series with said second switch in said anode circuit, said switch-

ing mechanism also having a second set of normally open contacts, said switching mechanism being operable temporarily to open its first set of contacts and simultaneously close its second set of contacts; and an energizing circuit including the second set of switching mechanism contacts and the winding of said electromagnetic switching device.

5. The invention set forth in claim 4 with the addition that said switching mechanism is electromagnetic and has a winding energizable to open its first set of contacts and close its second set of contacts, and a manually operable switch biased to open position and connected in series with the winding of the switching mechanism.

6. In combination, an electric load having a supply circuit including a switch operable to de-energize said load, an electron discharge device having a cathode, an anode and a control element, a circuit for applying to said control element a potential proportional to current flowing in said supply circuit for activating said device upon the current in said supply circuit reaching a predetermined value, an anode circuit for said device in which current flow is established upon activation of said device, said circuit including a source of anode voltage, means responsive to current flow in said anode circuit for opening said switch, and an interlocking means energized by said source of anode voltage and being responsive to a failure in said anode voltage source for opening said switch.

7. The invention set forth in claim 6 with the addition that said interlocking means comprises

a first relay having a set of normally open contacts and a winding energized by said anode voltage source for closing said first relay contacts; said switch is a normally open set of contacts of an electromagnetic switching device having also a second set of normally open contacts and a winding operative when energized to close all said sets of contacts of said electromagnetic switching device; said current responsive means comprises a holding circuit including said electromagnetic switching device winding, said first relay contacts, said second set of contacts of said electromagnetic switching device and a normally closed set of contacts of a second relay, said second relay having a winding connected in said anode circuit for being energized by current flowing in said anode circuit to open said second relay contacts and thereby deenergize said load.

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