Oct. 16, 1956 G. T. LARSEN ET AL 2,767,359

HIGH VOLTAGE CURRENT CONTROL

Filed June 29, 1951 3 Sheets-Sheet 1

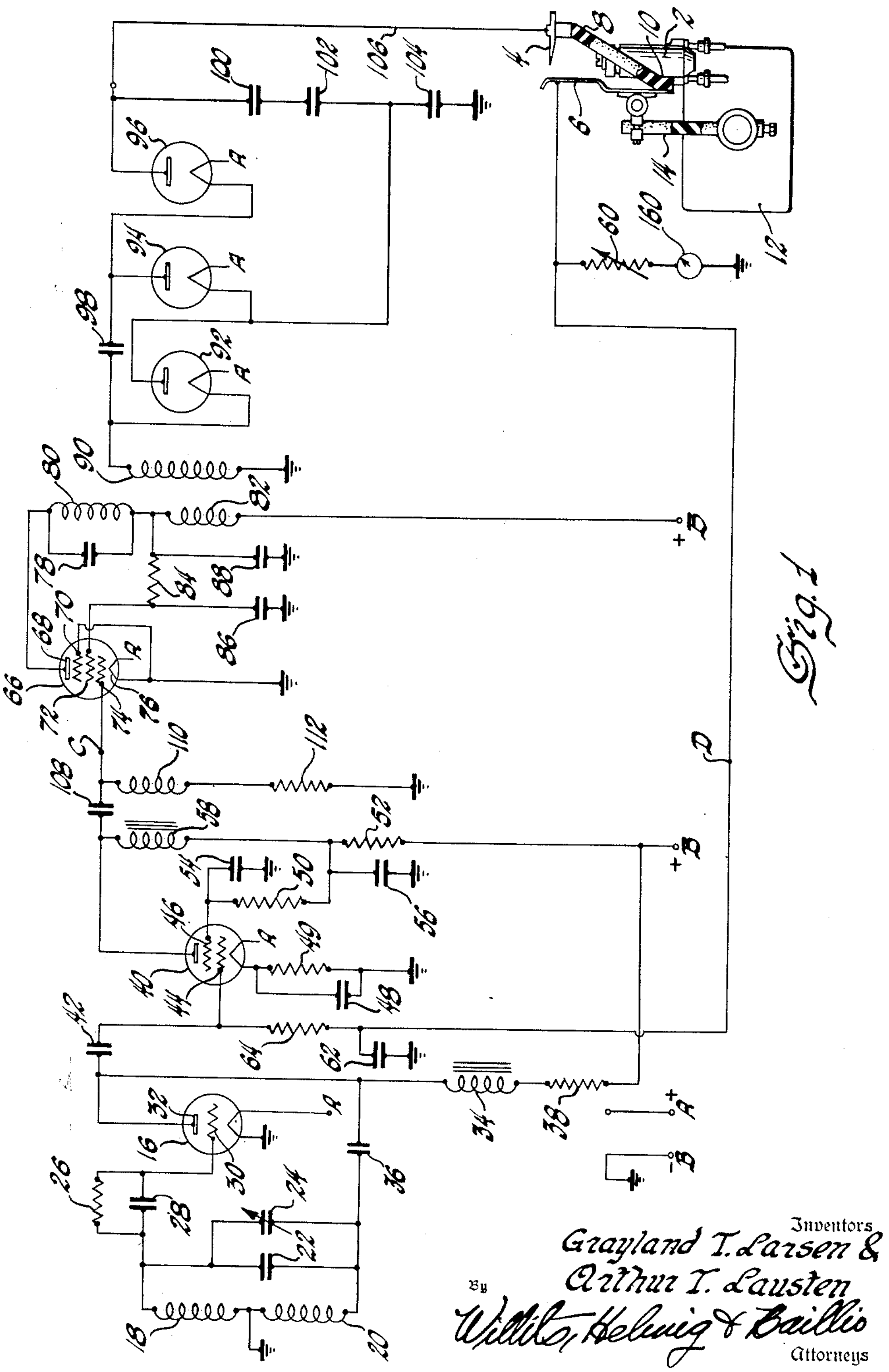

Fig. 1

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Filed June 29, 1951 3 Sheets-Sheet 2

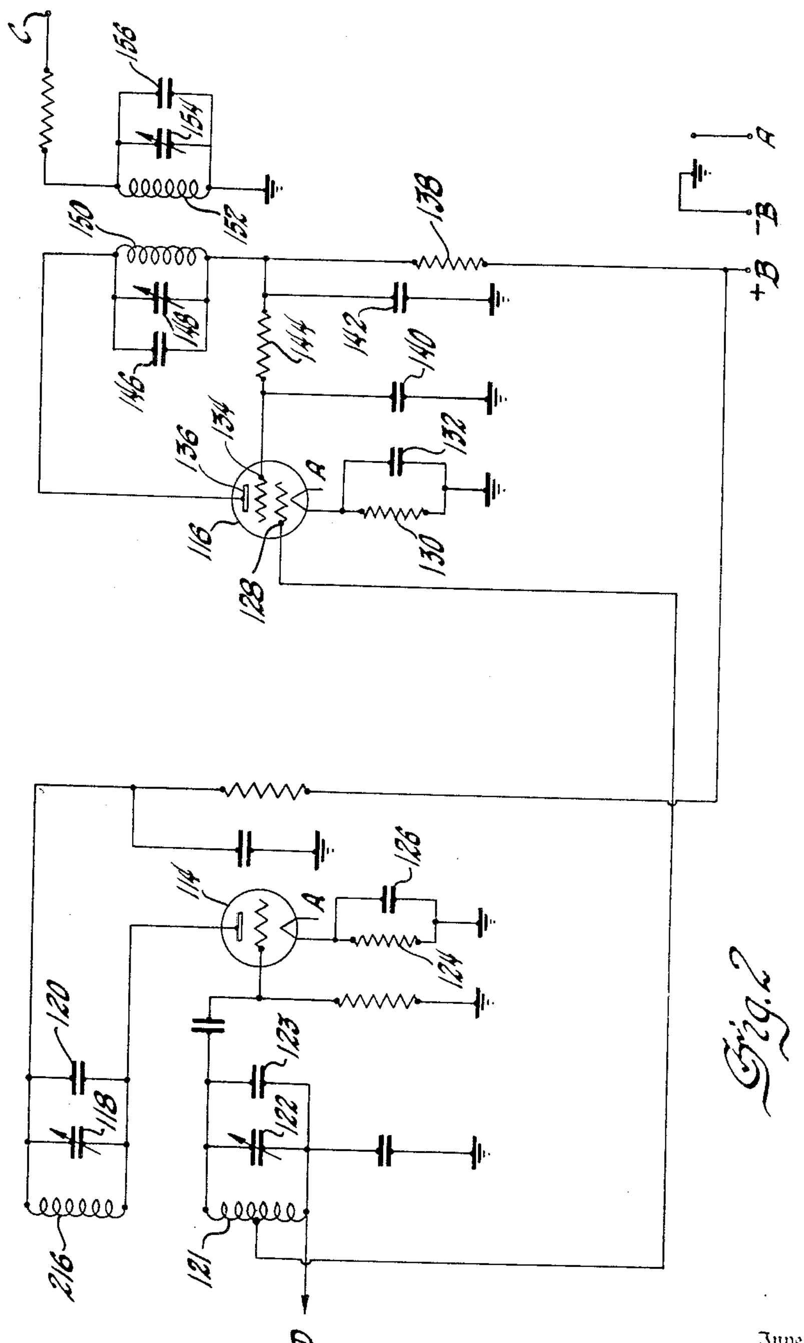

Fig. 2

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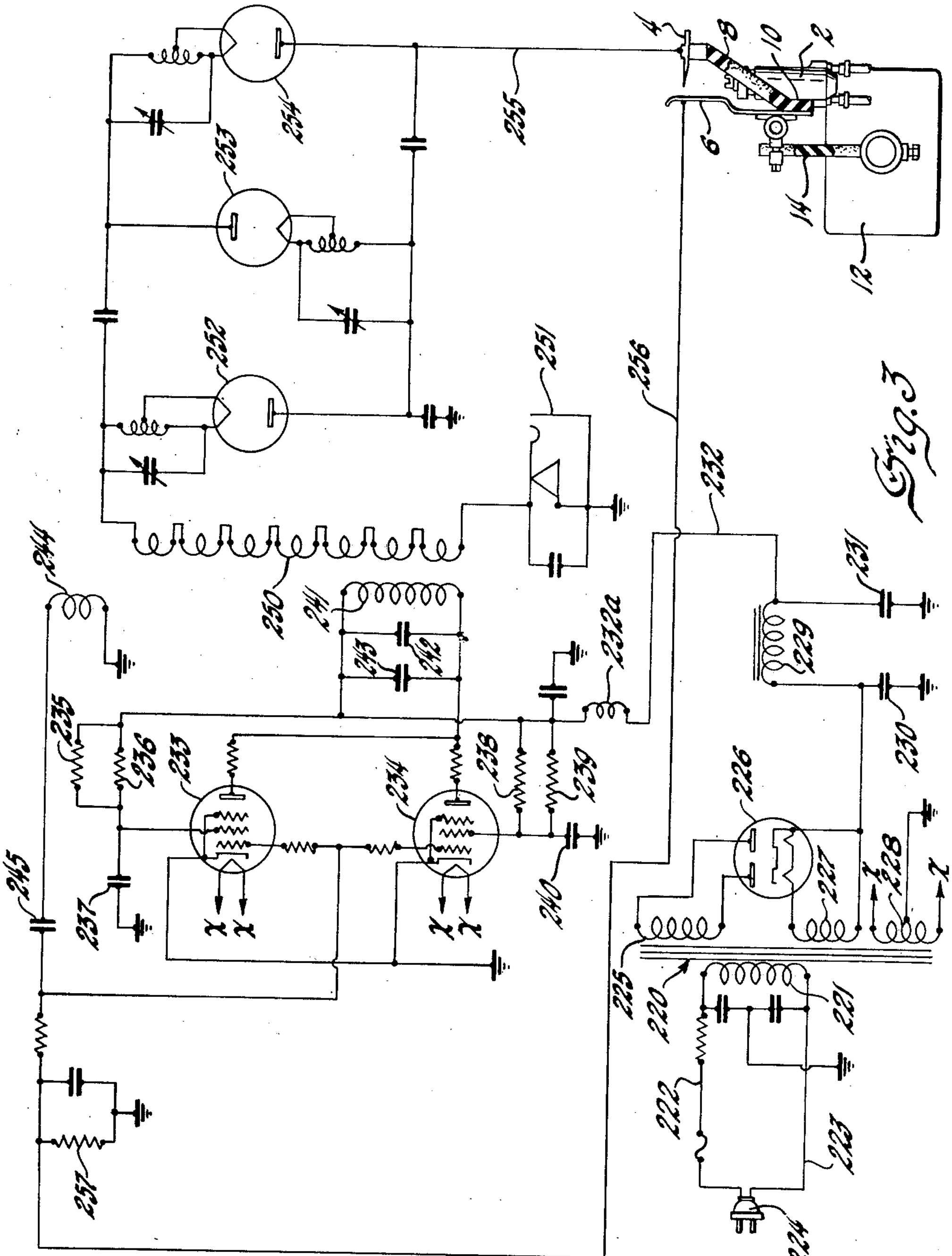

Fig. 3

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HIGH VOLTAGE CURRENT CONTROL

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Application June 29, 1951, Serial No. 234,312
14 Claims. (Cl. 317—262)

The present invention relates to current limited direct current power supplies. It further relates to means for anticipating arcing conditions at electrical discharge electrodes for placing an electrostatic charge on particles of coating material. This application is a continuation-in-part of our co-pending application S. N. 83,508, filed March 25, 1949, now abandoned. The present invention is particularly adapted for utilization with paint spraying apparatus of the general type shown in co-pending application S. N. 83,509, filed March 25, 1949, and assigned to a common assignee with the present application.

It is quite desirable in this type of spraying apparatus to keep the paint particle charging electrical discharge substantially constant to insure proper particle charging. It is also quite desirable that this discharge current be as high as practical so as to efficiently place a high electrostatic charge on the particles. The electrical discharge in this type of apparatus causes an ionization of the atmosphere around the discharge electrode thereby making the atmosphere an electrical conductor. This is necessary to promote efficient charging of the particles. While this ionization of the atmosphere is desirable from a paint charging standpoint, it must be quite carefully controlled or under certain conditions it may creep over towards the current receiving electrode and promote arcing between the electrodes. This arcing if uncontrolled is very dangerous when spraying inflammable materials such as paint. It is therefore desirable that the current at the electrodes be so controlled that an arc or spark of sufficient energy content to ignite the material will not be produced under any condition of operation.

It is therefore an object of the present invention to provide a safety device for suppressing arcing between electrical discharge electrodes.

It is another object of the present invention to provide means responsive to an increase in discharge current to cause a decrease in discharge voltage.

It is a further object of the present invention to provide means for anticipating arcing conditions with means responsive thereto for reducing the potential across the electrodes subject to arcing.

It is a further object of the present invention to provide an efficient means for producing an electrical discharge.

Other objects of the present invention will become apparent upon reading the specification and inspection of the drawings and will be particularly pointed out in the claims.

Referring now to the figures in the drawings, Figure 1 is a circuit diagram of the present invention.

Figure 2 shows a means for modifying Figure 1 to form a modification of the present invention.

Figure 3 is a circuit diagram of another modification of the invention.

Referring now particularly to Figure 1, a spray gun **2** of conventional design is provided for projecting coating material through an electrical charging zone toward the articles to be coated (which articles are not shown in the present drawings). This charging zone is produced be-

tween electrical discharge electrode **4** and electrical current collecting electrode **6**. The discharge electrode **4** may contain small pointed discharge points or in some cases may contain fine wires. It is necessary that this electrode have points, wires, or edges with a very small radius of curvature to permit a charge concentration sufficient to produce electrical discharge. The current collecting electrode **6** may be a flat surface or a rod or may be made from any other configuration of conducting material having a large radius of curvature so as to prevent electrical discharge. The electrode **4** is insulated from the electrode **6** by means of insulator **8**. The electrode **6** is insulated from the gun **2** by insulator **10** and from the support **12** by insulator **14**.

In order to provide the high voltage direct current necessary to promote electrical discharge at the electrode **4**, circuit means are provided for developing a varying voltage, and this voltage is rectified. In the embodiment of Figures 1 and 2 the circuit for developing a varying voltage includes an oscillator and an amplifier, and the amplifier is controlled by a feedback voltage which is discharge current responsive.

Referring more particularly to this circuit, the oscillator is of conventional design and includes tube **16** and an associated tank circuit which is tuned to any desired high frequency. The tank circuit includes mutual inductance coupled coils **18** and **20** and is tuned to the desired frequency by means of fixed condenser **22** and variable condenser **24**. Negative bias for grid **30** of tube **16** is provided by resistor **26** and condenser **28**. The filament heating current for tube **16** as well as other tubes in this circuit is provided by a plurality of conventional heating current sources each here generally indicated as A. The plate voltage for the grid control tubes is provided in a similar manner by a conventional voltage source B. This source of plate voltage is de-coupled insofar as radio frequency is concerned from the plate **32** of the oscillator tube **16** by means of choke coil **34**. The plate **32** is coupled to the tank circuit above mentioned by means of condenser **36**. **38** is a voltage reducing resistor introduced to provide proper D. C. voltage on the plate **32**. The frequency of the signal generated by the oscillator may be a few hundred kilocycles. This signal is coupled to an amplifier including tube **40** through condenser **42**. This tube is a multigrid type tube having a control grid **44** and a screen grid **46** and having sharp cut-off characteristics, to permit quite sensitive control of its output voltage. The grid of this tube is self-biased by condenser **48** and resistor **49**. The proper screen grid and plate voltages for this tube are provided from source B through resistors **50** and **52**, condensers **54** and **56** and choke coil **58**.

In order to provide the desired discharge voltage at electrode **4** the output of the amplifier including tube **40** is coupled to a second amplifier including tube **66**. This amplifier is a pentode type with a plate **68**, a suppressor grid **70**, a screen grid **72**, a control grid **74** and a filament **76**. This amplifier has a tuned plate circuit including condenser **78** and inductance **80** which has the same resonant frequency as the tank circuit of the oscillator. The plate and screen grid voltages are provided from the conventional source B by means of inductance **82** and filter circuit including resistor **84** and condensers **86** and **88**. The radio frequency output from this amplifier is inductively coupled to a rectifier by means of mutual inductance between the coils **80** and **90**. This rectifier includes tubes **92**, **94** and **96** and condensers **98**, **100**, **102** and **104**. The filaments of the three rectifiers may be supplied heating current from a plurality of standard sources A. The negative output voltage of this rectifier is produced across the condensers **100**, **102** and **104** and is impressed upon the discharge electrode 4 through conductor 106.

A very important part of this embodiment of the invention is providing a means for controlling the voltage output of one of the amplifiers as a function of current between electrodes 4 and 6. This control of output is obtained by providing a negative feedback voltage from variable resistor 60 to the grid 44 of the tube 40 by a filter network including condenser 62 and resistor 64. Resistor 60 is made variable so that the operator may adjust the discharge current to obtain the most efficient paint particle charging. The circuit also may be provided with a current measuring device 160 to indicate the discharge current. The magnitude of the voltage across the resistor 60 is directly proportional to the current passing between the electrodes 4 and 6 and therefore the negative grid bias and the resulting control of the output of this amplifier stage including tube 40 is a function of the current flowing between these electrodes 4 and 6. As arcing conditions between these two electrodes is approached, the current flowing therebetween increases rapidly. With this rapid increase of current a decrease in the voltage output of tube 40 occurs resulting in a reduction of the voltage on the electrode 4 to thus reduce the discharge current and thereby prevent arcing.

The operation of this circuit is as follows: When proper voltages are impressed upon A and B the oscillator including tube 16 generates a signal of some few hundred kilocycles, which signal is fed into the grid 44 of the amplifier tube 40. The output of this tube is fed into the grid 74 of a second amplifier including tube 66 through coupling condenser 108, then across inductance 110 and resistor 112. The tube 66 is operated in class C operation thereby efficiently producing a high voltage signal in the tank circuit 78—80 of the same frequency as that generated by the oscillator. This high voltage high frequency signal is impressed upon the rectifiers including tubes 92, 94 and 96 to produce a high negative direct current voltage in the order of negative 30 kilovolts on the discharge electrode 4. This voltage is of sufficient amplitude to cause what is herein referred to as electrical discharge with resulting ionization of the atmosphere surrounding the points of this electrode. This electrical discharge is of such magnitude as to cause charging of the particles of coating material which are projected by the spray gun 2. The area between electrodes 4 and 6 contains an electrical current of sufficient magnitude for the charging of the paint particles. Atmosphere ionization sufficient to cause arcing and resulting fire may be produced if the electrode discharge current is not properly controlled and maintained at sufficiently low magnitude. This current flows through resistor 60 and produces a voltage thereacross. The voltage across the resistor 60 is fed back into the amplifier including tube 40 to reduce the voltage on the electrode 4 thereby maintaining the discharge current of sufficiently low magnitude to prevent arcing.

Referring now to Figure 2, a modification of the oscillator and controlled amplifier is illustrated. The output at the point C of this circuit may be coupled to the point C in the circuit shown in Figure 1 and the control voltage at the point D in Figure 1 may be coupled into the point D in this Figure 2. The filament currents and plate voltages for the tube 114 in the oscillator and tube 116 in the amplifier are provided from conventional power supplied A and B substantially the same as shown and described in Figure 1. The circuit shown in Figure 2 differs from that shown in Figure 1 in that the oscillator has a tuned plate circuit including inductance 216, variable condenser 118 and fixed condenser 120 which is inductively coupled to a tuned grid circuit including inductance 121, variable condenser 122 and fixed condenser 123. The negative grid bias for the tube 114 is provided by a biasing circuit including resistor 124 and condenser 126. The output from the oscillator is coupled to the control grid 128 of the amplifier tube 116 by means of

a center tap on the inductance 121. This amplifier tube is of the sharp cutoff variety. The automatic grid bias is provided by resistor 130 and condenser 132. The voltages for the screen grid 134 and plate 136 are provided from a conventional source B through resistor 138. The screen grid voltage is provided from source B through a filter including condensers 140 and 142 and resistor 144. The plate circuit of the tube 116 has a primary tank circuit including fixed condenser 146, variable condenser 148 and inductance 150. The coil 150 is inductively coupled to a second coil 152 in a similar tank circuit tuned by variable condenser 154 and fixed condenser 156. The coefficient of coupling between these two circuits is approximately at critical coupling in order to obtain a high voltage signal at the point C. The amplification obtained from the amplifier circuit including tube 116 is controlled by the control voltage from D providing a negative grid bias which is directly proportional to the discharge current between the electrodes 4 and 6 illustrated in Figure 1.

The circuit shown in Figure 2 when incorporated as described with part of the circuit shown in Figure 1 operates substantially as described above in connection with Figure 1 and therefore no further description is thought necessary.

Referring now to the embodiment of the invention illustrated in Figure 3, the means for developing a varying voltage includes an oscillator, but not an amplifier. The voltage at the discharge electrode 4 is controlled by applying a biasing voltage (which is developed as a function of current flow between electrodes 4 and 6) to the oscillator control grid.

In Figure 3 the circuit is illustrated as including a conventional power supply having a power transformer 220 with its primary 221 connected to power leads 222 and 223, these leads terminating in a conventional wall plug 224. The transformer 220 has a high voltage secondary 225 which is connected to the anodes of a full wave rectifier tube 226 which may be of tube type 5V4G. The filaments of this tube are heated by a connection with a low voltage or filament secondary winding 227, and another low voltage winding 228 is provided for heating the filaments of the other tubes in the circuit, the filament connections between these tubes and the secondary winding 228 being broken away and indicated at X to simplify the diagram.

The high voltage output of rectifier tube 226 is filtered in a circuit including an inductance 229 and condensers 230 and 231, and is applied to the anodes and screens of the oscillator tubes in the circuit by means of a B-plus lead 232 which incorporates a choke 232*a*.

The oscillator includes a pair of tubes connected in parallel to increase the power output. These tubes, designated at 233 and 234, may be pentodes of tube type No. 6L6. The cathodes of the tubes are connected in parallel and are grounded; and the anodes and screen grids are connected to the high voltage lead 232. Referring to tube 233, the screen grid is connected to the B-plus circuit through parallel resistors 235 and 236, an A. C. by-pass to ground being provided by condenser 237. The screen grid of tube 234 is connected to B-plus through parallel resistors 238 and 239 and the screen grid is by-passed for A. C. by a condenser 240. The anodes are connected in parallel to a tuned output circuit including an inductance 241 and condensers 242 and 243, feedback to the control grid or input circuit being provided by a "tickler" coil 244 inductively coupled to the coil 241 and connected to the control grids of the tubes through a coupling condenser 245.

The inductance 241 is the primary of a step-up transformer having a secondary 250, the low voltage end of which is connected through a meter jack 251 to ground and the high voltage end of which is connected to the input diode 252 of a conventional rectifier and voltage tripler circuit including said diode 252 and diodes 253 and 254. The anode of the diode 254 is connected by a lead **255** to the discharge electrode **4** in order to provide a high negative D. C. voltage at this electrode.

The collector electrode **6** is connected by a lead **256** to a resistor **257**, the other end of which is connected to ground. This resistor is analogous in function to the resistor **60** of Figure 1, current which flows between the electrodes 4 and **6** and through resistor **257** developing a negative bias voltage. This voltage is applied to the parallel-connected grids of the oscillator tubes to control the oscillator output as an inverse function of the current flowing in the discharge circuit including electrodes **4** and **6**.

If the current in the discharge circuit increases, the negative voltage appearing across resistor **257** will increase proportionally. This negative voltage is applied to the grids of the oscillator tubes to decrease the oscillator output and thereby decrease the voltage at the electrode **4** to prevent arcing in a manner similar to that described in connection with Figure 1.

While we have shown and described one embodiment of our invention, it is subject to many modifications. Changes, therefore, in the construction and arrangement may be made without departing from the spirit and scope of the invention as set forth in the appended claims.

What is claimed is:

1. An electrical discharge system power supply of the character described, including: electronic means for developing a varying voltage, said means having control means responsive to voltage impressed thereon for controlling the amplitude of said varying voltage; rectifying means supplied by said electronic means; a discharge circuit including electrode means supplied by said rectifying means; impedance means connected directly to said electrode means for developing a biasing voltage, the amplitude of which varies as a direct function of variations of current flow in said discharge circuit and a circuit connecting said impedance means to said control means so that said biasing voltage varies the output of said electronic means in infinitely variable increments as an inverse function of the magnitude of current flow in said discharge circuit.

2. An electrical discharge system power supply of the character described, including: electronic means for developing a varying voltage, including an oscillator and amplifying means, said oscillator having control means responsive to voltage impressed thereon for controlling the amplitude of said varying voltage; rectifying means supplied by said electronic means; a discharge circuit including electrode means supplied by said rectifying means; and impedance means connected to said electrode means for developing a biasing voltage whose amplitude varies as a direct function of variations in current flow in said discharge circuit; and circuit means connecting said impedance means to said control means to control the output of said voltage developing means as an inverse function of the current flow in said discharge circuit.

3. An electrical discharge system power supply of the character described, including: electronic means for developing a varying voltage, including an oscillator and amplifying means, said oscillator having control means responsive to voltage impressed thereon for controlling the amplitude of said varying voltage; rectifying means supplied by said electronic means; a discharge circuit including electrode means supplied by said rectifying means; impedance means connected to said electrode means for developing a biasing voltage which varies in amplitude as a direct function of current flow in said discharge circuit; and a circuit connecting said impedance means to said amplifying means to control the output thereof as an inverse function of the current flow in said discharge circuit.

4. An electrical discharge system power supply of the character described, including: an oscillator for developing a varying voltage, said oscillator having control means responsive to voltage impressed thereon for controlling the amplitude of said varying voltage; rectifying means supplied by said oscillator; a discharge output circuit for said power supply including electrode means supplied by said rectifying means; impedance means connected directly to said electrode means for developing a biasing voltage which varies in amplitude as a direct function of current flow in said discharge circuit; and a circuit connecting said impedance means to said control means to vary the amplitude of voltage output of the oscillator in infinitely variable increments as an inverse function of the current flow in said discharge circuit.

5. An electrical discharge system power supply of the character described, including: electronic means for developing a varying voltage, said means having control means responsive to voltage impressed thereon for controlling the amplitude of said varying voltage; rectifying means supplied by said electronic means; a discharge output circuit for said power supply including a high voltage discharge electrode supplied by said rectifying means and a low voltage collector electrode spaced from said discharge electrode; resistance means connected directly to one of said electrodes for developing a biasing voltage which varies in amplitude as a direct function of the magnitude of current flow between said electrodes; and circuit means connecting said biasing voltage directly to said control means so that said biasing voltage varies the output of said electronic means in infinitely variable increments as an inverse function of the magnitude of current flow between said electrodes.

6. Apparatus of the character claimed in claim 5, wherein said electronic means includes an oscillator and an amplifier and wherein said resistance means is connected to the amplifier.

7. Apparatus of the character claimed in claim 5, wherein said electronic means includes an oscillator with a control grid element having said resistance means connected thereto.

8. An electrical discharge system power supply of the character described, including: electronic means for developing a varying voltage, said means including an oscillator having control means responsive to voltage impressed thereon for controlling the amplitude of said varying voltage, and having an output circuit; rectifying means; means coupling said output circuit to said rectifying means; a discharge circuit including a high voltage discharge electrode supplied by said rectifying means and a low voltage collector electrode spaced from said discharge electrode; a resistor connected between said collector electrode and ground for developing a biasing voltage which varies in amplitude as a direct function of current flow between said electrodes; and a circuit connecting said resistor to said control means to control the output of said electronic means as an inverse function of the current flow in said discharge circuit.

9. Apparatus of the character claimed in claim 8, wherein said means for developing a varying voltage includes an amplifier having its input coupled to said oscillator, and wherein said last mentioned circuit connects said resistor to the input of said amplifier.

10. In a system for spraying a coating material, a spray producing nozzle, a means for charging the particles of coating material in the spray including: an elongated discharge electrode having a small radius of curvature located forward of said nozzle, a second electrode also located forward of said nozzle of greater radius of curvature than said discharge electrode, said two electrodes being arranged transverse the direction of travel of said spray of coating material and said elongated electrode extending in a direction transverse of the direction of travel of said spray, and a direct current power supply for producing a voltage difference between said two electrodes of sufficient magnitude to cause the placing of a surface charge on said particles of coating material by electrical discharge from said discharge electrode, said power supply including a control circuit having an elec-

trical circuit element therein connected in circuit with said electrodes of said particle charging means and developing a control voltage which varies in amplitude as a direct function of the current flow between the electrodes, said control circuit connecting said electrical circuit element to said control means to supply said control voltage thereto and control the output of said power supply as an inverse function of the current flow between the said electrodes.

11. In a system for spraying a coating material, a spray gun; a discharge electrode having a small radius of curvature and positioned in the general direction of spray from said gun; a collector electrode positioned in the general direction of spray from said gun and having a greater radius of curvature than said discharge electrode, said electrodes being spaced from each other in a direction transverse of the direction of spray; means for developing a varying voltage, said means including an oscillator and having voltage responsive control means and having an output circuit; rectifying means; means coupling said output circuit to said rectifying means; means connecting said rectifying means to said discharge electrode; a resistor connected between said collector electrode and ground for developing a biasing voltage which varies in amplitude as a direct function of current flow between said electrodes; and a circuit connecting said resistor to said control means to control the output of said oscillator as an inverse function of the current flow in said discharge circuit.

12. A current limited power supply including means generating a periodically varying voltage and including control means responsive to voltage impressed thereon controlling the amplitude of said periodically varying voltage, rectifying means supplied by said generating means, a discharge output circuit for said power supply including electrode means supplied by said rectifying means, impedance means connected in series circuit relation with said electrode means and developing a biasing voltage which varies as a direct function of the current flow in said discharge output circuit, and a circuit connecting said impedance means to supply said biasing voltage to said control means varying the output of said generating means in continuously variable increments as an inverse function of the current flow in said discharge circuit.

13. A current limited power supply including means generating a periodically varying voltage and including control means responsive to voltage impressed thereon controlling the amplitude of said periodically varying voltage, rectifying means supplied by said generating means, a discharge output circuit for said power supply including a high voltage discharge electrode supplied by said rectifying means and a low voltage collector electrode spaced from said discharge electrode, resistance means connected in series circuit relation with said electrodes and developing a biasing voltage which varies in amplitude as a direct function of the magnitude of current flow between the said electrodes, and circuit means connecting said biasing voltage directly to said control means so that said biasing voltage varies the output of said generating means as an inverse function of the magnitude of current flow between said electrodes.

14. In a system for spraying a coating material on an article of manufacture comprising in combination, a discharge electrode having a small radius of curvature and positioned in the general direction of spray from said gun, a collector electrode positioned in the general direction of spray from said gun and having a greater radius of curvature than said discharge electrode, said electrodes being spaced from each other in a direction transverse of the direction of spray from said gun, means for developing a varying voltage, said means including an oscillator having an output circuit and voltage responsive control means therefor, rectifying means, means coupling said output circuit to said rectifying means, means connecting said rectifying means to said discharge electrode, a resistor connected in series circuit relation with said discharge electrode and said collector electrode and developing a biasing voltage which varies in amplitude as a direct function of current flow between said electrodes, and a circuit connecting said resistor to said control means to control the output of said oscillator as an inverse function of the current flow in said discharge circuit.

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