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Gregg et al.

[11] **3,875,892**

[45] **Apr. 8, 1975**

[54] **APPARATUS FOR AVOIDING SPARKS IN AN ELECTROSTATIC COATING SYSTEM**

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[21] Appl. No.: **433,266**

[52] **U.S. Cl.** **118/4;** 118/621; 118/627; 118/629

[51] **Int. Cl.** **B05c 2/00**

[58] **Field of Search** 117/93.4; 118/4, 9, 10, 118/11, 621, 627, 629; 239/3, 15

[56] **References Cited**

UNITED STATES PATENTS

3,356,597	12/1967	Schmidt	118/10
3,611,982	10/1971	Coriale	118/4
3,641,971	2/1972	Walberg	118/8

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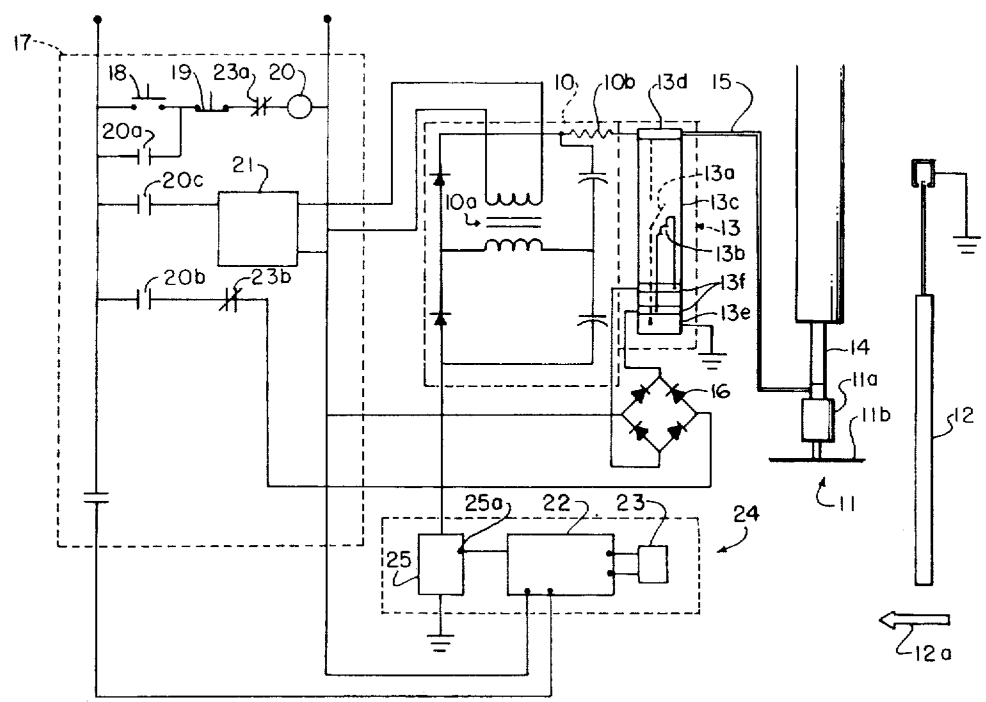
[57] **ABSTRACT**

This invention provides an electrostatic coating apparatus to avoid a disruptive electrical discharge from the high voltage electrode to an approaching grounded object. This apparatus employs the current of a high voltage electrostatic system to determine incipient grounding of the high voltage electrode and includes a fast-acting grounding device activated in anticipation of sparking conditions to connect the high voltage electrode to ground. The grounding device is held in the ungrounded position during operation of the electrostatic coating system. The electric current in the ground return of the high voltage source is sensed to provide a signal. All alternating current components of the signal above substantially pure direct current are removed to provide a resulting DC signal that increases as a grounded article approaches a charged electrode. The resultant DC signal is analyzed to determine the approach of a grounded article to the charged electrode. When the level of the signal indicates incipient grounding of the charged high voltage electrode, the grounding device is released from its ungrounded position and quickly connects the high voltage electrode to ground.

9 Claims, 3 Drawing Figures



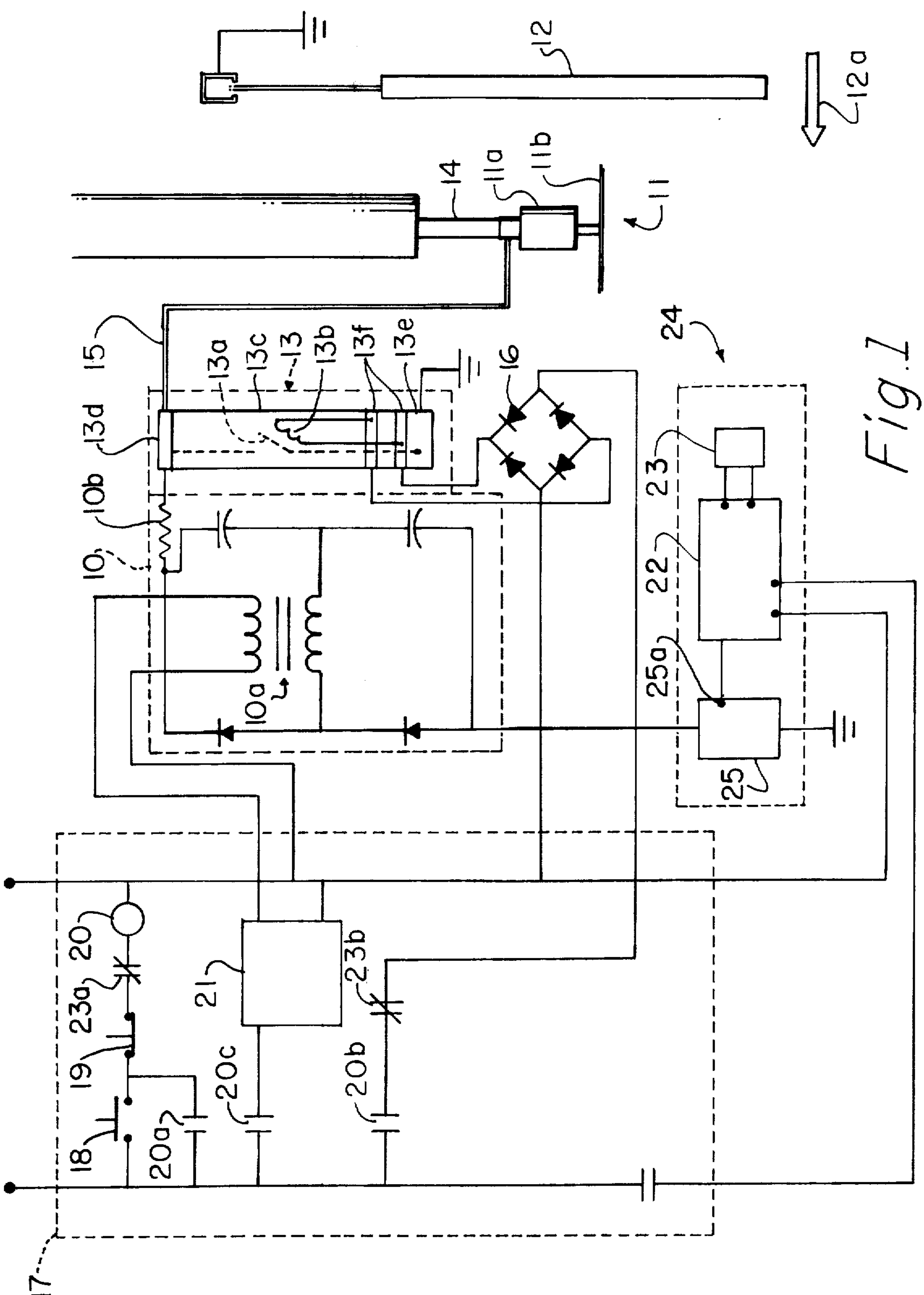

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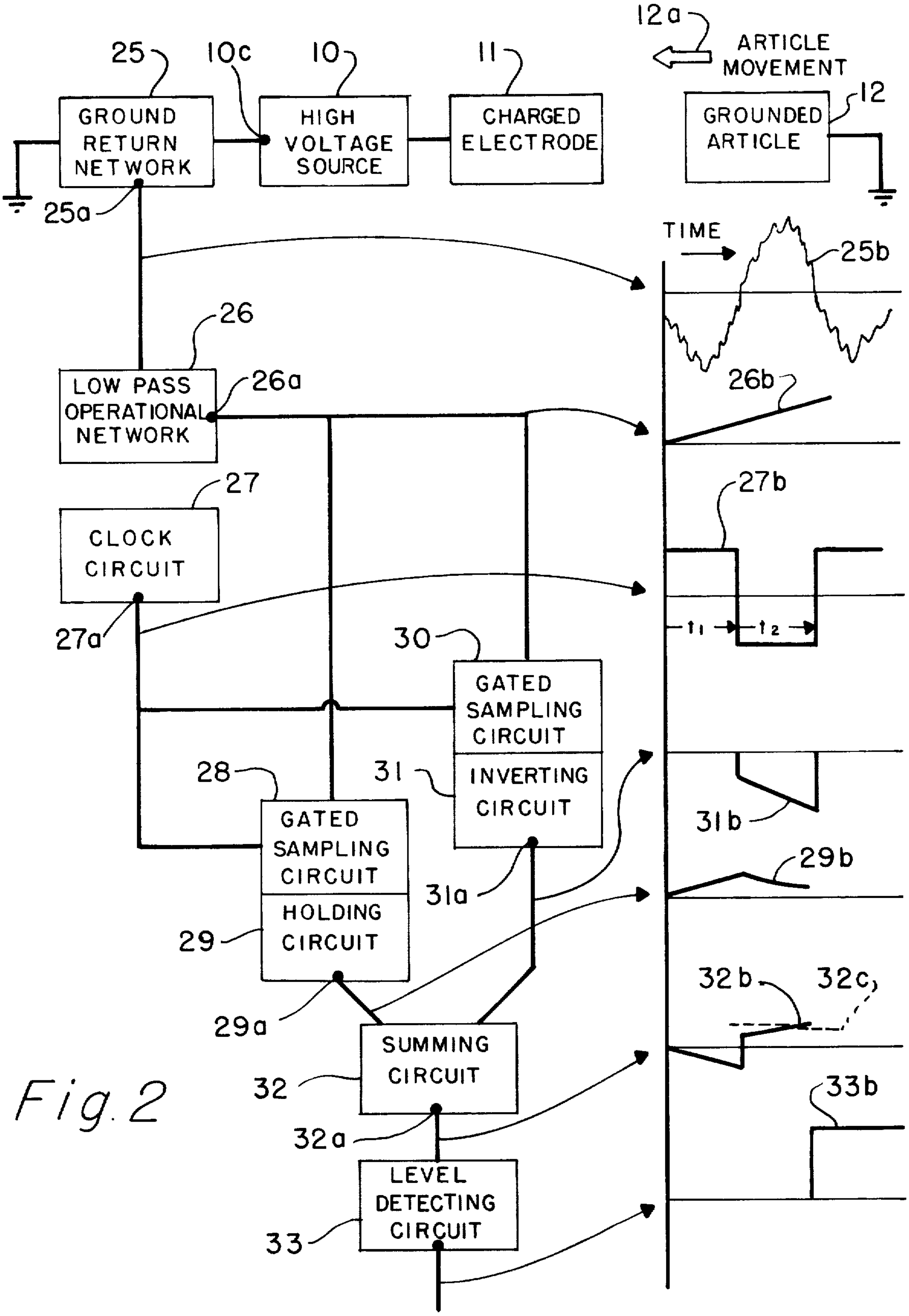
Fig. 1


12a
ARTICLE MOVEMENT
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10c
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GROUND RETURN NETWORK
HIGH VOLTAGE SOURCE
CHARGED ELECTRODE
GROUNDED ARTICLE
12
25a
TIME
25b
26
LOW PASS OPERATIONAL NETWORK
26a
26b
27
CLOCK CIRCUIT
27b
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t1
t2
30
GATED SAMPLING CIRCUIT
INVERTING CIRCUIT
31
28
GATED SAMPLING CIRCUIT
HOLDING CIRCUIT
31b
29b
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29a
32b
32c
SUMMING CIRCUIT
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32a
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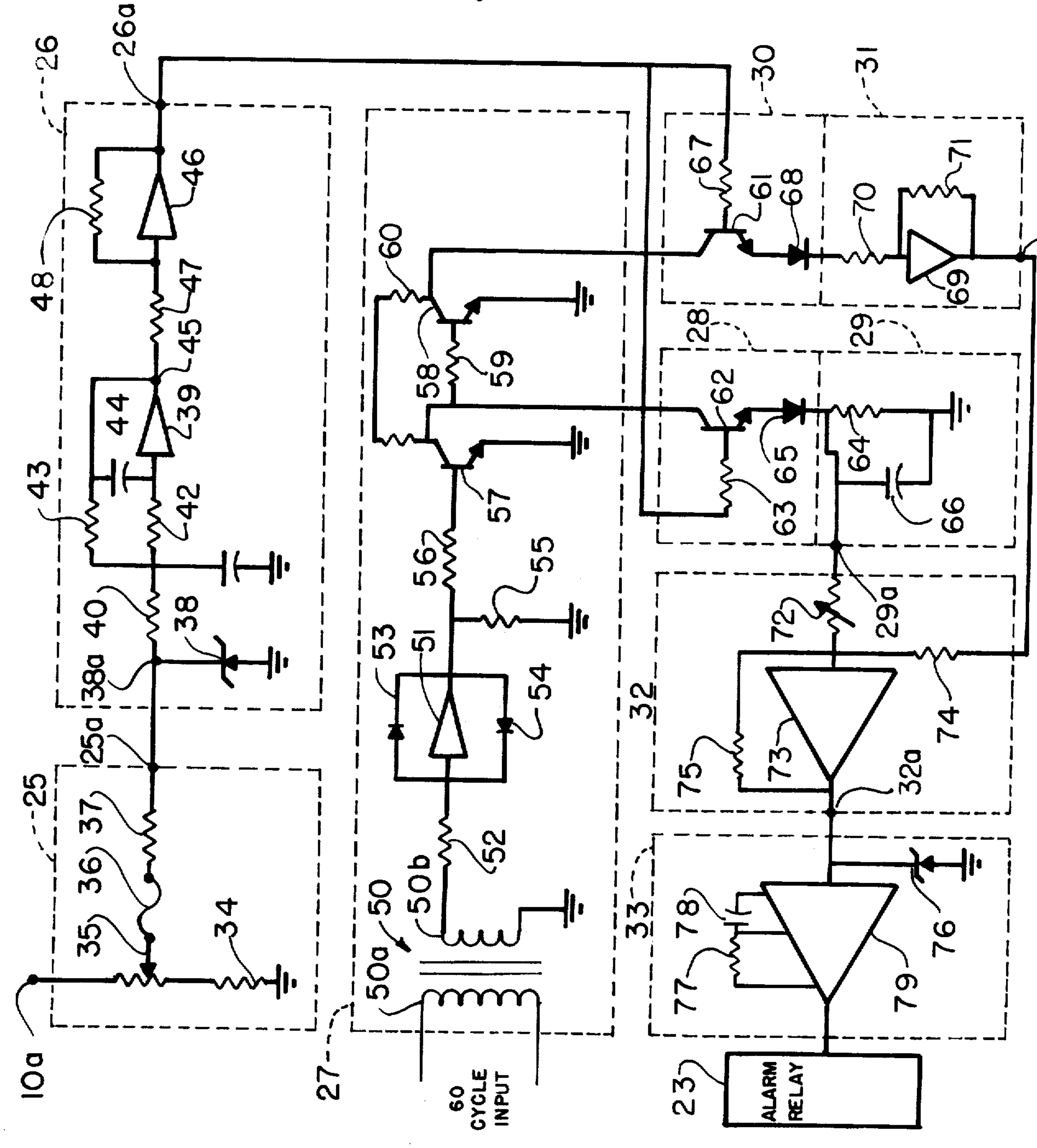
LEVEL DETECTING CIRCUIT
33

Fig. 2

Fig. 3



APPARATUS FOR AVOIDING SPARKS IN AN ELECTROSTATIC COATING SYSTEM

This invention relates to an electrostatic coating apparatus for avoiding a disruptive electrical discharge from the high voltage electrode to an approaching grounded object in an electrostatic coating system.

In industrial electrostatic coating systems, electrical potentials are used which may be as high as 100,000 volts or more. Electrostatic coating systems use these high voltages in many different ways to accomplish deposition of coating materials. Several of these ways are disclosed in U.S. Pat. Nos. 2,893,893; 2,893,894; Re. 24,602; 3,048,498; 3,169,882 and 3,169,883.

These systems include high voltage sources to provide such potentials. Customarily, one terminal of the high voltage source is electrically grounded or connected to earth and is at zero potential. A high voltage electrode or atomizer is commonly connected to the other terminal of the high voltage source. In most such industrial coating systems, the high voltage electrode has a portion with a very small radius of curvature which can be referred to as "sharp". Such an electrode can be used to provide an electric charge on particles of coating material and move the coating material particles under the action of the imposed electric charge for deposition on an article to be coated.

The term "electrostatic field" is used to designate the condition in space existing in the region occupied by two spaced electrodes. An electrostatic field, in a sense, depicts the manner in which the energy stored in the high voltage electrostatic system is distributed throughout the region between the high voltage electrode and the grounded electrode or electrodes. Where the high voltage electrode is sharp, if the sharp portion is not shielded from the effect of the grounded electrodes, the energy of the electrostatic system is concentrated adjacent the sharp portion of the high voltage electrode. This concentration of energy is generally described by stating that the electrostatic field has a high intensity in this region. The intensity of an electrostatic field is measured by "potential gradient" to indicate how the energy of the field is distributed throughout the region between the electrodes, generally in such terms as kilovolts per centimeter.

Gases (including air which is a composite of many gases) may be ionized by the energy of an intense electrostatic field. If, for example, molecules of the gases forming air are exposed to an intense electrostatic field where the local potential gradient is about or above 30 kilovolts per centimeter, electrons are torn from the molecules under the action of the intense field; the remaining portions of the molecules are thus ionized (that is, they have a net charge) and they move in response to the energy of the electrostatic field.

In high voltage electrostatic coating systems, because of the intense electrostatic fields, that are used, ionization of the air can proceed under some conditions to a complete disruption of the space between the high voltage electrode and the grounded electrode. This disruptive electrical discharge is frequently in the form of sparks. Although local potential gradients on the order of 30 kilovolts per centimeter can exist closely adjacent the sharp portion of such an electrode without sparking, when the average potential gradient throughout the space between a high voltage electrode and a grounded electrode exceeds on the order of 12 kilovolts per centimeter under such conditions, danger of sparking is great. Such sparking generally dissipates most of the energy stored in the high voltage electrode.

Such sparks can be dangerous. In automatic electrostatic coating installations, articles to be coated are frequently carried on a conveyor and are free to swing to and fro so that it may be possible for the interval between the high voltage electrode and the grounded article to be coated to be diminished below the distances at which sparking occurs. In addition, since human personnel hang the articles on the conveyor, it is possible for them to make mistakes and hang the articles in such a manner that the interval between the high voltage electrode and the article to be coated is below the spacing at which sparking occurs. Such spark discharges can ignite any flammable vapors of coating material.

In electrostatic coating systems, sparking is to be avoided. Some electrostatic coating systems, disclosed for example in U.S. Pat. No. 3,048,498, avoid disruptive discharges by maintaining the potential gradient of the electrostatic field at values consistent with high transfer efficiencies, but at values below potential gradients at which objectionable sparking occurs even down to spacings of less than an inch. Such systems control the intensity of the electrical discharge otained from the high voltage electrode and include selected high resistance in the electrostatic coating system adjacent a high voltage electrode, the size and shape of the electrode and the electrical conductivity of the material of which the electrode is composed providing the electrode with low effective capacity.

Such features are not incorporated in other electrostatic coating systems. Attempts to prevent sparking from high voltage electrodes in these other electrostatic coating systems have included efforts to develop a signal from the electrical current flowing from the high voltage electrode to ground and to turn off the high voltage source. These attempts have included the use of apparatus such as that disclosed in early U.S. Pat. Nos. 2,509,277 and 2,650,329. Electrostatic coating systems using these inventions have even included oil-insulated, electrically operated shorting switches with contacts traveling several inches through the instlating oil to ground the high voltage electrode. Another patent showing an attempt to use a signal from the ground return current is U.S. Pat. No. 3,641,971.

High voltage relays are known and come in many configurations. Such relays use a high vacuum to provide insulation between the closely spaced contacts of the switch when they are in the open position. Examples of such relays are those manufactured by the Kilovac Corporation of Santa Barbara, Calif., and are shown in their catalog copyrighted in 1972. Although such relays have been frequently used in many applications, they have not been put into use in electrostatic coating systems.

Other efforts in electrostatic coating have attempted to control the voltage applied to the high voltage electrodes in response to the current flowing from that electrode. Such patents are U.S. Pat. No. 2,742,600 and U.S. Pat. No. 2,767,359.

These approaches to the solution of this problem in electrostatic coating have not been completely successful, even though they have put to use improvements in circuit design and components which have been developed since their innovation. These existing systems do not ground the high voltage electrode sufficiently in anticipation of incipient sparking conditions to prevent the formation of a spark. The signal representing an approaching grounded object is a very small increase in the DC leakage current from the sharp high voltage electrode, on the order of a few microamperes, while the average DC load current on such systems can be as high as several milliamperes, and the AC current components can be as high as several milliamperes. Because of the variable effect of these currents and of transients, users of systems that employed electrostatic coating apparatus of the type disclosed in U.S. Pat. Nos. 2,509,277 and 2,650,329 would set their apparatus so that it would not sporadically turn off the voltage in response to such transients. So adjusted, their systems were frequently not capable of detecting incipient sparking in many practical industrial installations.

This invention provides apparatus employing the currents of a high voltage electrostatic system to determine incipient grounded conditions and to ground the high voltage electrode with a fast-acting high voltage relay prior to sparking from the high voltage electrodes. Specifically, this current is detected in between the ground terminal of the high voltage supply and ground, commonly referred to as the "ground return". In this apparatus, the undesirable influences of the DC load currents and AC transients can be eliminated, and a reliable and fast-acting grounding contact can be made between the high voltage electrode and ground.

FIG. 1 is a diagrammatic showing of the major components of the apparatus of this invention for determining incipient grounding of the high voltage electrostatic system.

FIG. 2 is a diagrammatic illustration showing the major circuit elements of this invention.

FIG. 3 is a more detailed circuit diagram of the apparatus.

FIG. 1 shows a hgh voltage electrostatic coating system of this invention in diagrammatic form. This system includes high voltage source **10**, a charged high voltage electrode **11**, grounded article **12**, and a high voltage grounding device **13**. In the electrostatic coating system, the grounded article **12** is free to move in the direction of a charged high voltage electrode **11**, shown by arrow **12***a*. Movement of the grounded article **12** in the direction of the charged electrode **11** will result in an increased flow of electrical current across the space between the high voltage electrode **11** and the grounded article **12**. This electric current will continue to increase until the space between the high voltage electrode and the grounded article breaks down and sparks are formed.

In such electrostatic systems, the high voltage electrode **11** frequently includes an air motor in a metallic housing **11***a* driving a bell-shaped, or as shown, a disk atomizer **11***b*. The electric motor and atomizing electrode are insulated from ground by a post **14** of suitable dielectric material, such as nylon, and is reciprocated vertically to paint the grounded article **12**. A high voltage cable **15** connects the motor and the atomizer with the high voltage source **10**. The high voltage conductor is comprised of a metallic conductor surrounded by a heavy layer of polyethylene to provide insulation for the high voltage. To generate the high voltage, the high voltage source **10** includes a step-up transfer **10***a* to provide AC voltage on the order of 60,000 to 100,000 volts, peak-to-peak. The secondary of high voltage transformer is connected into a half-wave doubler circuit with rectifiers and filter capacitors to provice a DC output voltage equal to the peak-to-peak voltage of the alternating current at the secondary of the transformer.

In the system of this invention, a high voltage grounding device **13** is connected to the output of the high voltage doubler circuit through a high resistance **10***b* of, for example, about 10 megohms. This high voltage grounding device includes a normally-closed, single-pole, single throw switch **13***a* (shown in the open position in FIG. 1) that is operated by an electromagnetic coil **13***b*. The switch **13***a* is housed by a hermetically sealed enclosure **13***c* mounted in an oil insulation. The coil **13***b* is housed in a separable portion of switch **13**. Enclosure **13***c* includes a high voltage connection **13***d* and a ground connection **13***e* to the contacts of switch **13***a*. The high voltage connection **13***d* is connected with the high voltage electrode **11** and the high voltage cable **15**. When the switch is in its normal position, the high voltage electrode and cable are connected to ground.

The space within enclosure **13***c* is adapted to provide insulation between the contacts of switch **13***a* when they are open, and the outer surface of the enclosure is adapted to provide insulation between the high voltage connection and ground connection when mounted in oil insulation. The device can be used to control 60,000 to 140,000 volts.

The switch contacts themselves are metallic. In their normal position, these contacts bear one against the other within enclosure **13***c*. The electromagnetic holding coil **13***b* pulls the contacts apart when energized by DC current. Connections **13***f* to coil **13***b* are carried by the switch **13** at the end remote from high voltage connection **13***d*. Because the switch contacts are located within the hermetically sealed space defined by the enclosure, the device operates very fast in moving from the actuated to normally-closed positions, in the order of 15 milliseconds. Resistance **10***b* protects the contacts of switch **13***a* from the high energy generated and stored in the high voltage source **10**.

Thus, in the start-up sequence of the high voltage electrostatic system, current is applied to this coil **13***b* before high voltage is applied to the system. A typical high voltage control **17** includes on and off pushbuttons **18** and **19**, respectively. In turning on the high voltage, pushbutton **18** is pressed, actuating the on/off relay **20**. Normally-open contacts **20***a* of on/off relay **20** close around the normally-open pushbutton **18**, holding relay **20** in an actuated state. Normally-open contacts **20***b* of the on/off relay **20** close, applying AC power to the bridge rectifier network **16**, actuating the holding coil **13***b* of the grounding device **13** and opening the contacts of switch **13***a*. Normally-open contacts **20***c* of the on/off relay **20** close, applying AC power to the control circuit **21**. Control circuit **21** gradually applies AC power to the high voltage transformer **10***a* of the high voltage source **10** to prevent the starting transients that accompany the sudden application of AC power.

The ground-anticipating device **24** includes a ground return network **25**, a circuit **22** for operating on the signal of the ground return network, and a relay **23**.

In the event that the grounded article **12** moves in the direction **12***a*, a signal will be developed in the ground return network **25**. The circuit **22** will operate on this signal as explained later. Upon determining from the signal in ground return network **25** that the high voltage electrode **11** and the approaching grounded article

12 are reaching a condition where sparking may begin between them, the circuit 22 will actuate alarm relay 23, opening its normally-closed contacts 23*a* and 23*b*. As normally-closed contacts 23*a* of the alarm relay 23 open, they interrupt the circuit holding the on/off relay 20 in actuation. Deactuation of on/off relay 20 opens its normally-open contacts 20*a*, 20*b* and 20*c*. Opening of contacts 20*c* removes power from the high voltage source 10 and opening of contacts 20*b* and 23*b* removes power from bridge rectifier 16 and the holding coil 13*b* of the grounding device. The contacts of switch 13*a* close, grounding the cable 15 and high voltage electrode 11.

In order to determine the incipient grounding of the high voltage electrostatic system, a ground return network 25 is connected between ground and the ground terminal 10*c* of the high voltage source 10. Current flowing from the charged electrode to the grounded article will be returned to the high voltage supply through ground and the ground return network 25, and a signal will be developed by the ground return network at its output 25*a*. Operation on this signal by circuit 22 is explained by referring to FIG. 2. The signal generated in the ground return network is complex, being comprised of a plurality of DC and AC components as illustrated in 25*b* (FIG. 2). The signal includes substantial 60-cycle portions including many higher harmonics. This complex signal is analyzed by circuit 22 to determine the signal component that represents an approaching grounded object. One example of such a circuit includes, for example, an operational network 26 comprised of the high gain DC amplifier and connected to transform the input signal 25*b* with the transfer function $-HWo^2/S^2+\alpha WoS+Wo^2$.

The low pass operational network provides, for example, 20 db gain to DC signals and attenuates the AC components at 40 db per decade, being 3 db down at 10 hertz and having zero gain at about 30 hertz. Such a network effectively removes extraneous AC signals from the output of a low pass filter. Thus, in response to the approach of the grounded article 12 to the charged electrode 11, signal at the output 26*a* of the low pass operational network 26 is a signal which increases in value as the object approaches as shown at 26*b*. The increasing DC signal at the output 26*a* of the low pass operational amplifier 26 is sampled to provide two successive signals in different intervals of time for comparison. The sampling rate is determined by a clock circuit 27, which provides a series of gating impulses in more-or-less square wave form at its output 27*a*, as shown in 27*b*. The duration "t" of each gate pulse, as shown in 27*b*, is selected to provide successive samples which occur rapidly enough so that comparison of these signals will provide a detectable increase in signal level under the most rapidly changing conditions to be anticipated.

The output of the clock circuit is applied to two gated sampling circuits 28 and 30. The first gated sampling circuit 28 is coupled to a holding circuit 29 and is gated by the clock circuit 27 during the first sampling interval *t*1. The signal 26*b* from the low pass operational network 26 is passed by the gated sampling circuit 28 and retained in holding circuit 29. Thus, at the output of the holding circuit 29*a*, the signal 29*b* rises until the end of gate interval *t*1 in response to signal 26*b*. At the end of time interval *t*1, the gating signal is removed from the input of the first gated sampling circuit and is applied to the second gated sampling circuit 30 for the time interval *t*2. The signal 26*b*, during time interval *t*2, is passed through the gated sampling circuit 30 and inverted by inverting circuit 31. The signal 31*b* appearing at the output 31*a* of the second gated sampling circuit and inverting circuit is a negative pulse representing in amplitude the signal 26*b*, which occurs during the interval *t*2.

The output signal 29*b* of the holding circuit and 31*b* of the inverting circuit 31 represent those portions of the signal 26*b* which occur during the successive time intervals *t*1 and *t*2. These outputs are fed to a summing circuit 32. The instantaneous total or difference 32*b* at each instant of time of these signals 29*b* and 31*b* appears at the output of the summing circuit 32*a* but is inverted by the summing circuit 32. Signal 32*b*, corresponding to the output of the summing circuit, is applied to a level-detecting circuit 33. When the level of signal 32*b* reaches a level indicating that sparking may occur as shown at 32*c*, level-detecting circuit 33 produces a signal 33*b* at its output 31*a* that actuates the relay 23.

Thus, in the apparatus of FIG. 2 the electric current in the ground return to its high voltage electrostatic system is sensed to provide a signal. All alternating current components of the signal above substantially pure direct current are attenuated to provide a resulting DC signal that increases as a grounded article approaches a charged electrode. The resultant DC signal is sampled at a rate fast enough to anticipate the fastest expected approach of grounded article to the charged electrode. Every other sample is retained so that it may be compared with the sample immediately following it. The samples are compared in a summing circuit which provides a signal corresponding to the change in conditions in the ground return circuit. A level is selected corresponding to incipient grounding of the charged high voltage electrode. If a difference of the successive samples exceeds this level, high voltage is turned off and the high voltage electrode is grounded.

FIG. 3 shows the apparatus of FIG. 2 in greater detail. The elements of the ground return network are shown within the dashed block 25 and include between ground and the ground terminal 10*c* of the high voltage source 10, a fixed and a variable resistor, 34 and 35 respectively. The variable resistor 35 is used to adjust the level of the signal which is generated at output 25*a* of the ground return network. The ground return network also includes a fuse 36 and a current-limiting resistor 37 which functions with the input of the low pass operational network in the manner to be described.

The elements making up the low pass operational network include zener diode 38. This zener diode, operating in conjunction with the current-limiting resistor 37 and the other components of the ground return network, prevents the signal applied at the input of the low pass operational network from exceeding a preselected voltage level, for example, ± 12 volts. The low pass operational network uses an operational amplifier to transform the input signal in accordance with the transfer function set forth above. By "operational amplifier", I mean, for example, a Signetic Corporation N5741 type operational amplifier.

An active filter can be synthesized with the characteristics set forth above using operational amplifiers and design techniques known to those skilled in the art as, for example, taught in *Operational Amplifiers — De-*

sign & Application, Burr-Brown Research Corp. 1971, Library of Congress No. 74-163297. Such an active filter may use one or more operational amplifiers. An active filter having the desired characteristics and using one operational amplifier **39** is shown in FIG. **3.** The plurality of resistances and capacitances connected at the output and the input of the operational amplifier and numbered **40, 41, 42, 43** and **44** generate from the terminal **38***a* to terminal **45** the desired transfer function. In this case, the signal at the output **45** of the operational amplifier is without any significant AC component. The signal at terminal **45** is a substantially total DC signal which will rise and fall as a grounded object **12** approaches, or retreats from, the charged high voltage electrode **11** of the electrostatic system. The typical values of such components which would provide the characteristics set forth above are resistor **40**—11.3 Kohms, capacitor **41**—2.2 micro farads, resistor **42**—10.2 Kohms, resistor **43**—113 Kohms and capacitor **44**—0.1 micro farads. The output of the active filter is amplified by operational amplifier **46** and resistances **47** and **48** and presented at the output **26***a* of the low pass operational network **26.**

Sampling of the signal at the output **26***a* of the low pass operational network **26** is provided by the clock circuit shown within the dashed lines representing blocks **27.** The clock circuit includes a transformer **50.** The primary of the transformer **50***a* is connected to a 60-cycle power source. The secondary **50***b* is connected to ground at one side; the other side is coupled to an operational amplifier **51** through a resistor **52.** Feedback from the output of the operational amplifier **51** to its input is effected by two diodes **53** and **54.** Diodes **53** and **54** and operational amplifier **51** form, in the connection shown in FIG. **3,** a 0 to +15 volt limiter circuit. The positive half-cycle of the AC line is omitted and the negative half-cycle is clipped at 5 volts, inverted by the operational amplifier and formed into a square pulse to yield a 0 to +5 volt pulse of about 8 milliseconds duration.

The output of operational amplifier **51** is connected through the resistor network, including resistors **55** and **56,** and transistor **57** which is driven into saturation by this signal on alternative half-cycles of the 60-cycle input.

When transistor **57** is not driven into saturation by the gate signal of the clock, transistor **58,** by the action of the resistors **59** and **60,** is in saturation, effectively removing collector voltage from transistor **61** in the second gated sampling circuit within the dashed block **30.** During this half-cycle of 60-cycle input to the clock (which corresponds to the time interval *t***1** as shown at **27***b* of FIG. **2**), collector voltage is applied to transistor **62** of the first gated sampling circuit within the dashed block **28.** The signal output of the low pass operational network **26,** during this time interval *t***1,** is applied to transistor **62** through resistor **63.** This signal is amplified by transistor **62** and is integrated and stored by the holding circuit within dashed block **29** which includes a resistor **64** and capacitor **66.** A diode **65,** inserted between the emitter of transistor **62** and the holding circuit **29** protects the transistor **62.** The resistor **64** connected across capacitor **66** provides the apparatus with the ability to detect relatively stationary conditions corresponding to incipient grounding of the high voltage charged electrode in a manner that will be explained below.

In the alternate half-cycle of the 60-cycle input, corresponding to *t***2** at **27***b* of FIG. **2,** transistor **57** is in saturation, removing collector voltage from transistor **62**; however, transistor **58** is not in saturation and collector voltage is applied to transistor **61** of the second gated sampling circuit **30.** During interval *t***2,** the signal from the output **26***a* of the low pass operational amplifier **26** is applied through resistor **67** in the second gated sampling circuit and protective diode **68** to an inverter circuit shown connected with transistor **61.** The signal is transmitted to the inverting circuit within the dashed box **31,** comprised of an operational amplifier **69,** connected with resistors **70, 71** to perform the inversion-amplification function.

The signals at the outputs of the holding circuit **29***a* and of the inverting circuit **31***a* are fed to a summing circuit within the dashed box **32.** The output of the holding circuit **29** passes through a variable resistor **72** to the operational amplifier **73.** The output of the inverting circuit **31** is sent to the operational amplifier **73** through resistor **74.** A feedback resistor **75,** in conjunction with the variable resistor **72,** resistor **74** and the operational amplifier **73,** sums and provides the net difference of the retained signal from interval *t***1** which appears at the output **29***a* of the holding circuit **29** and the signal during the interval *t***2** which appears at the output **31***a* of the inverter circuit **31.** The difference appears at the output **32***a* of the summing circuit **32** but is inverted.

Level-detecting circuit within the dashed lines **33** detects when the difference between the signals which occur during interval *t***1** and which occur during *t***2** exceed a predetermined selected level that corresponds to incipient grounding of the high voltage electrostatic system. The level-detecting system may be of any kind sufficient to reliably detect a signal level. As shown in FIG. **3,** level-detector circuit **33** includes zener diode **76** to hold the input to monostable multivibrator **79** within predetermined voltage limits, for example ± 5 volts. The monostable multivibrator **79** connected with resistor **77** and capacitor **78** will trigger if the level appliled exceeds a predetermined preset value.

To provide an apparatus which will detect slowly moving or stationary conditions, suddenly imposed and representing incipient grounding of the high voltage electrostatic system, resistor **64** is connected across capacitor **66** in the holding circuit **29.** During the interval *t***2,** resistor **64** bleeds the stored charge from capacitor **66** that represents the integrated signals occurring during period *t***1.** The charge bled through the resistor reduces, during time interval *t***2,** the level of the signal at the output of the holding circuit **29***a* to be summed with the inverted signal appearing at the output **31***a* of the inverter circuit, and results in an increased difference at the output of the summing circuit **32***a*. Thus, if incipient grounding of the high voltage electrostatic electrode is suddenly imposed by a very rapidly moving grounded object in a period less than the sampling interval (which in the device illustrated in FIG. **3** is one one hundred twentieth of a second) that subsequently remains relatively stationary, a large difference signal will nevertheless be generated by the apparatus and actuate the level-detecting circuit and the relay **23.**

This electrostatic coating system thus includes means to sense the electrical current returning from ground to the high voltage source and to develop a signal with a component related to an incipient grounding condition. This signal is split into two channels.

Two separate and independent signal channels are formed to perform independent operations in each channel and to develop different signal components at their outputs. These different signal components are combined to develop the component relating to an incipient grounding condition. The signal component corresponding to incipient grounding is detected from the level of this signal. Upon detection of incipient grounding, the grounding switch is deactuated.

The electrostatic coating apparatus described above is capable of use with either a disk or a bell atomizer made of metallic materials to avoid sparking from the atomizer to an approaching grounded article. The invention is capable of modification from the specific apparatus described above without departing from its scope as claimed below.

We claim:

1. In an electrostatic coating system including a high voltage source having a high voltage output and a ground return; a conveyor for transporting articles to be coated; means to spray a coating material, said high voltage output and ground return of the high voltage source being connected to create electrostatic deposition of sprayed coating material on the articles to be coated; and means connected to the ground return of the high voltage source to sense the electric current between the high voltage source and ground and to turn off the high voltage source, the improvement comprising

means to sense the electrical current returning from ground to the high voltage source and to develop a signal with a component related to an incipient grounding condition;

means to split the developed signal into two channels;

means forming two separate and independent signal channels and performing independent operations in each channel to develop different signal components at each channel output;

means to combine the different signal components to develop the component relating to an incipient grounding condition;

means to detect the level of the signal component corresponding to incipient grounding;

means including a hermetically sealed enclosure housing a normally-closed high voltage switch connected between the high voltage output of the high voltage source and ground, and an electromagnetic coil to open said switch; and

a control to operate said coil and high voltage source during electrostatic coating operations and to disconnect said coil and high voltage source in response to said means to detect the level of signal component corresponding to incipient grounding, said switch rapidly closing in the hermetically sealed space defined by the enclosure to ground the high voltage system.

2. The apparatus of claim **1**, wherein the means to sense the electrical circuit returning from ground to the high voltage source and to develop the signal includes an operational amplifier connected to transform the signal developed across resistance connected from ground to the ground return of the high voltage source by the transfer function $-HWo^2/(S^2+\alpha WoS+Wo^2)$, the means to split the developed signal into two channels includes a clock circuit to create a series of successive time intervals and two gated sampling circuits triggered alternatively in successive time intervals thereby, the means forming two separate and independent signal channels includes a holding circuit to retain the developed signal from one time interval and an independent inverting circuit to invert the developed signal in the successive time intervals, and the means to combine the retained signal and the inverted signal includes a summing circuit.

3. The apparatus of claim **1**, wherein the means including a hermetically sealed enclosure housing the switch is insulated by oil at its outer surface and the high voltage source includes a multimegohm resistor.

4. In an electrostatic coating system including

a high voltage supply having two terminals;

a conveyor for transporting grounded articles to be coated;

an electrostatic coating device connected with the one terminal of the high voltage supply to create electrostatic deposition of atomized coating material;

and means connected between the other terminal of the high voltage supply and ground to sense the electric current between the high voltage supply and ground, and to disconnect the high voltage supply from its energizing source, the improvement in which the means connected between the above terminal and ground includes

an operational network to provide a signal with attenuation of all electrical current components significantly above direct current, while amplifying direct currents;

a clock to generate a sampling gate for the signal;

two gated sampling circuits to detect the direct current level of the signal when gated by the clock, one of the gated sampling circuits being connected to a holding circuit for the detected signal for one cycle of the gating signal, and the other gated sampling circuit being connected to an inverting circuit to invert the signal from the other gated sampling circuit;

a summer to determine the difference of the signal from the holding circuit and the inverted signal from the other gated sampling circuit;

a level detector to generate an operative signal in the event the level exceeds a predetermined level which represents incipient grounding of the high voltage electrode; and

a grounding device having a normally-closed switch connected between the one terminal of the high voltage supply and ground, and being held open by a control during normal operation of the electrostatic system and closed by the level-detector in the event of incipient grounding.

5. A system of claim **4**, wherein the low pass operational network includes an active filter designed to transform the voltage input into an output by the transfer function $-HWo^2/S^2+\alpha WoS+Wo^2$ in which H equals 10, Wo equals 10 cycles per second, and α equals $\sqrt{2}$ for maximally flat butterworth response.

6. A system of claim **5** wherein the clock circuit provides gating pulses with a time interval of 120th of a second to apply to the gated sampling circuits.

7. A system of claim **4** wherein the first holding circuit includes means to subtract a signal from its output proportional to the magnitude of the output signal during the time interval generated by the clock.

8. In an electrostatic coating system including a source with a high voltage output, an electrostatic coating device including means to spray a coating material, a high voltage electrode connected with the source of the high voltage output, said high voltage source being connected with ground to create electrostatic deposition of sprayed material on articles to be coated, a grounding device connected between the high voltage output and ground, and an electrical circuit actuated by the electric current flowing from ground to the high voltage source and adapted to disconnect the source, the improvement comprising a normally-closed spring switch housed within a hermetically sealed nonconductive enclosure forming said grounding device, said enclosure defining a space being adapted to insulate said contacts when open and carrying connections to the switch, a holding coil to open said switch, a high voltage control to actuate the holding coil and to open the normally-closed switch, said circuit including means to attenuate all electrical components of the electrical current flowing from ground to the high voltage source above substantially pure direct current, and to provide a substantially pure DC signal portion that corresponds to incipient grounding of the high voltage electrode and to detect such incipient grounding, and means to deactivate the holding coil of the grounding means and thereby ground the high voltage output upon detection of incipient grounding.

9. A high voltage electrostatic coating system comprising means to electrostatically deposit coating material on an article to be coated including means to spray a coating material, a charged high voltage electrode and a grounded electrode, said electrodes being free to move toward each other; means to supply high voltage to the charged high voltage electrode, said high voltage means being connected with ground to create electrostatic deposition of sprayed material on articles to be coated; means to ground the charged high voltage electrode; means to generate a signal including the current between the charged high voltage electrode and the grounded electrode; means to attenuate all electrical current components of said signal above substantially pure direct current and to provide the amplified DC portion of said signal; means to sample the amplified DC portion of said signal to provide samples from successive time intervals faster than the anticipated rate of approach of the grounded electrode to the high voltage electrode; means to compare the levels of the signals from successive time intervals; means to determine if the comparison of the signals from the successive time intervals indicate incipient grounding of the high voltage electrode; and means to actuate said means to ground the charged high voltage upon incipient grounding.

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