United States Patent

[11] 3,622,839

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[21] Appl. No. 4,004
[22] Filed Jan. 19, 1970
[45] Patented Nov. 23, 1971
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[54] **CONTROL SYSTEM FOR ELECTROSTATIC PRECIPITATOR POWER SUPPLY**
6 Claims, 2 Drawing Figs.

[52] U.S. Cl. 317/3, 55/105, 55/139, 321/24
[51] Int. Cl. B03c 3/68, G05f 1/40, H02m 7/20
[50] Field of Search 317/3; 55/2, 105, 139; 307/233; 321/24

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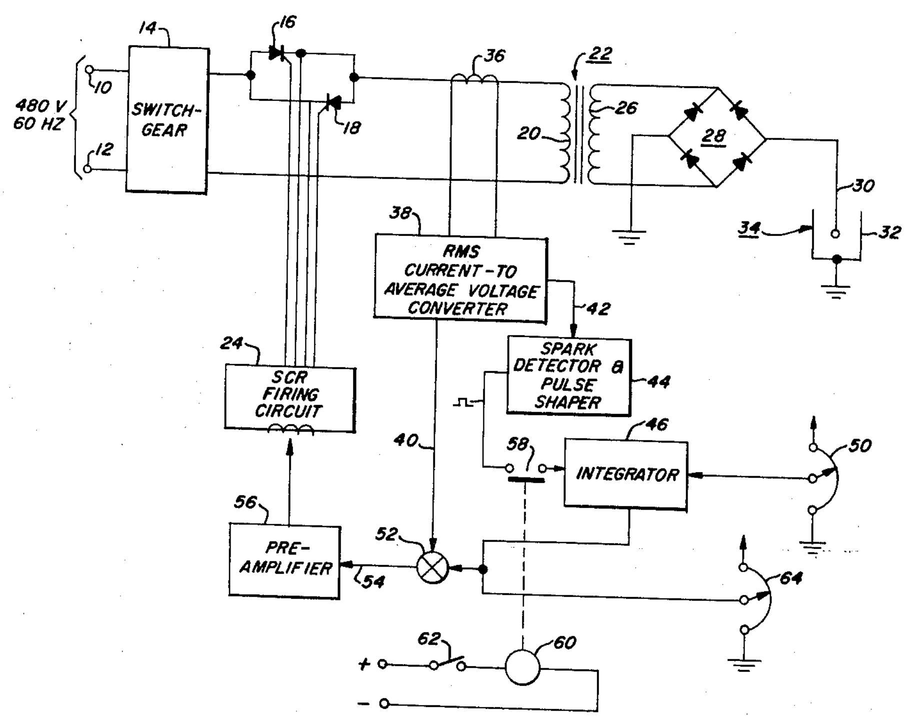
ABSTRACT: A sparking rate control system for electrostatic precipitators and the like wherein current supplied through a transformer to a rectifier connected to the precipitator is compared with a reference signal to produce an error signal for regulating the current supplied to the precipitator. In the automatic sparking rate control mode, the reference signal is integrated such that the precipitator voltage more or less gradually increases until a spark occurs. Circuitry is provided for sensing the spark and for converting it into a pulse which is combined in opposite polarity relationship with the reference signal fed to the integrator. This reduces the output of the integrator as well as the current supplied to the precipitator; whereupon the integrating action again increases the current until the next successive spark when the current is again reduced. The effect is to regulate the precipitator current and voltage near the value which provides a sparking rate set for optimum precipitator efficiency.



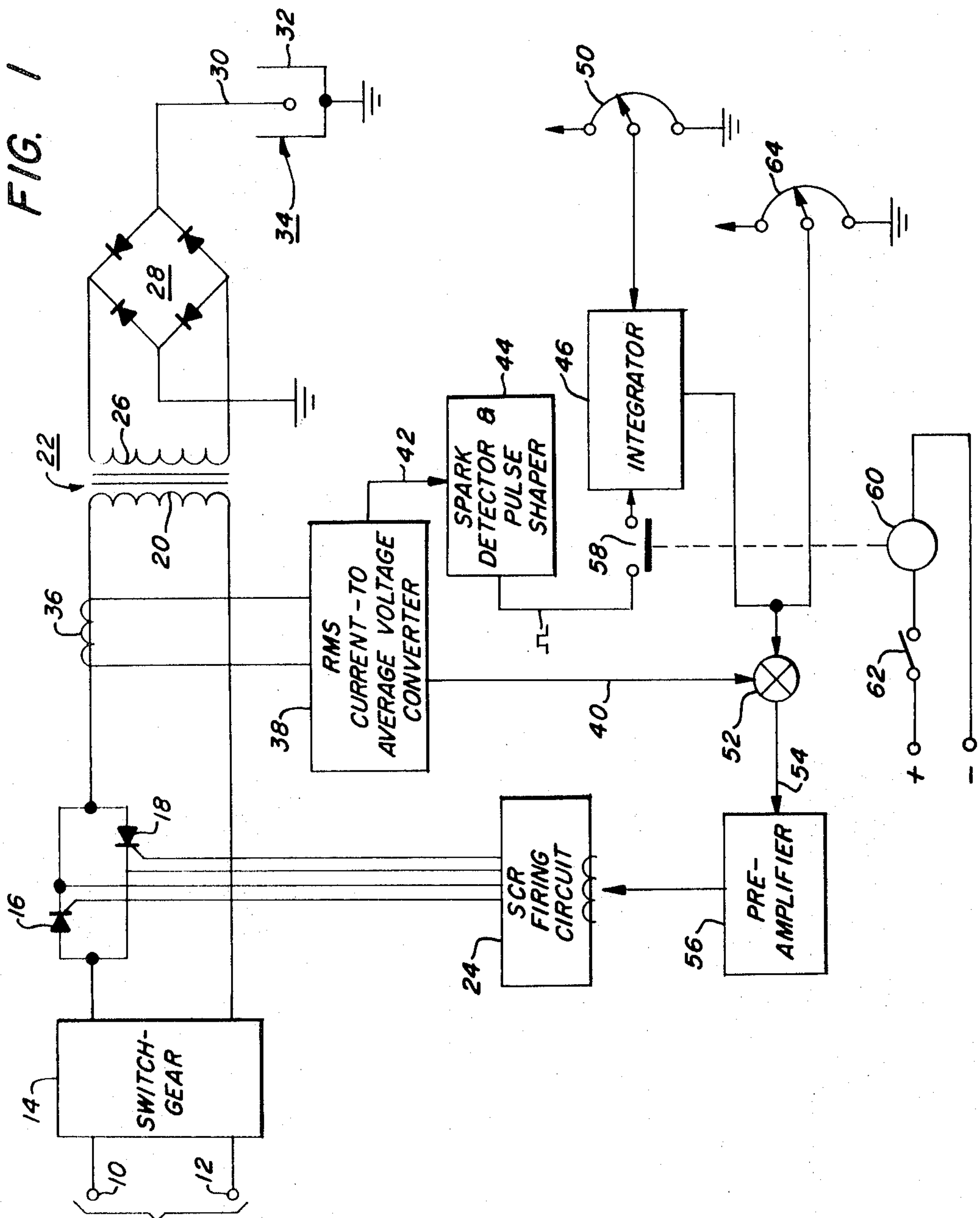


FIG. 1

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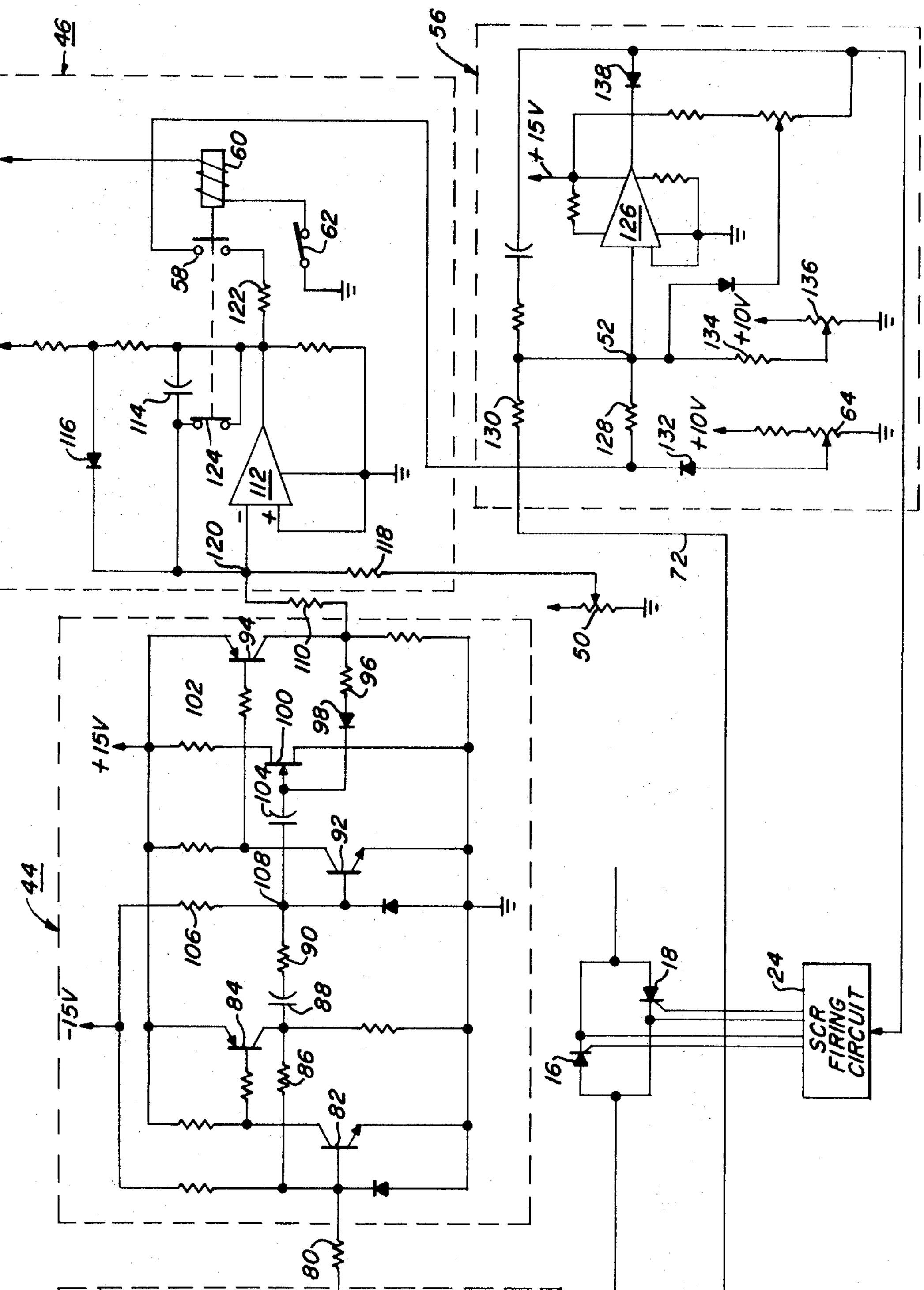

FIG. 2

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CONTROL SYSTEM FOR ELECTROSTATIC PRECIPITATOR POWER SUPPLY

BACKGROUND OF THE INVENTION

As is known, an electrostatic precipitator operates by setting up a very high direct current electrostatic field between collecting electrodes, usually large plates, and discharge electrodes which ordinarily comprise wires hanging between the plates. This field charges the particles with a large negative charge, causing them to drift to the collecting plates which are grounded with respect to the charged particles.

Since the collection efficiency is a function mainly of the field intensity which is proportional to the voltage applied between the electrodes, it is desirable to maintain the applied voltage as high as possible. On the other hand, the voltage is limited by the phenomena of sparking and/or arcing which occurs more and more frequently as the field strength, temperature of the gas, humidity, and/or number of particles in the gas is increased. The composition of the gas and the resistivity of the particles also have a major effect on the sparking voltage. Each time a spark or arc occurs, the voltage across the precipitator falls sharply and then, after the spark or arc is extinguished, recovers to its original value on a resistance-capacitance charging voltage transient. During an arc and while the voltage is recovering, the cleaning efficiency is reduced. As the applied voltage is increased, not only is the sparking rate increased, but also more and more arcs occur.

It has been found that the average sparking rate is an effective measure of desirable precipitator performance. That is, when the spark rate is too low, the precipitator voltage is too low for good collection efficiency; and when the spark rate is too high, it is likely that too many arcs will occur, again causing low average precipitator voltage and low collection efficiency. Beyond this, it has also been found that the optimum sparking rate varies as a function of particle and gas resistivity. For high gas resistivity, the sparking rate should ordinarily be on the order of about 100 sparks per minute or greater; whereas for moderate gas resistivity, the sparking rate should be about 10 to 100 sparks per minute.

Theoretically, and assuming that all system variables could be held constant, a set voltage between the precipitator plates would produce a given sparking rate. The fact of the matter, however, is that gas temperature, humidity, particle number and the like will all vary. This means that in order to obtain a given sparking rate, the current supplied to the precipitator and, consequently, the voltage must be constantly varied as these various factors change.

SUMMARY OF THE INVENTION

In accordance with the invention, the sparking rate of an electrostatic precipitator is regulated to maximize the efficiency of the precipitator by means including circuitry for converting current spikes indicative of the existence of sparks into pulses of fixed amplitude and width. These pulses are summed in opposed polarity relationship with a current reference signal and fed to the input of an integrator. Initially, and in the absence of a spark, the integrator slowly increases its output value to a predetermined maximum amount. However, upon the occurrence of a spark, the resulting pulse reduces the output of the integrator which again increases its value slowly.

In the embodiment of the invention shown herein, the output of the integrator is compared with a signal which is proportional to the average RMS value of current supplied to the precipitator. When the two differ, as upon the occurrence of a spark, an error signal is produced which reduces the current supplied to the precipitator as well as the voltage across the precipitator plates. The current will again increase as the integrator increases its output value to the aforesaid predetermined maximum amount; whereupon, when the next spark occurs, the cycle is repeated. In this manner, the current and voltage supplied to the precipitator are always maintained at or slightly below the sparking value, and this regardless of variations in gas density, particle density, and other factors.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification, and in which:

FIG. 1 is a block schematic diagram of the precipitator control system of the invention; and

FIG. 2 is a detailed schematic diagram of the current-to-voltage converter, spark detector and pulse shaper, integrator and preamplifier of FIG. 1.

With reference now to the drawings, and particularly to FIG. 1, the system shown includes a pair of input terminals **10** and **12** to which a single-phase power supply, typically of 480 volts and 60 hertz, is applied. The terminals **10** and **12** are connected through switchgear **14** and a pair of semiconductive controlled rectifiers **16** and **18** to the primary winding **20** of a high voltage transformer **22**. The semiconductive controlled rectifiers **16** and **18**, in turn, are connected to a firing circuit **24** in accordance with the usual practice whereby the rectifiers are caused to conduct after the lapse of a predetermined portion of each half cycle of the applied waveform, thereby varying the current and power supplied to the primary winding **20**. That is, the current and power supplied to the primary winding are controlled in accordance with conventional phase commutation techniques.

The secondary winding **26** of transformer **22** is connected through full-wave rectifier **28** to the opposite electrodes **30** and **32** of an electrostatic precipitator, generally indicated by the reference numeral **34**. The electrode **32** normally comprises large plates; while the electrode **30** normally comprises wires hanging between the plates.

In the operation of the precipitator **34**, the voltage applied across the electrodes **30** and **32** will build up until there is an electrical discharge therebetween. This discharge may be a transient voltage breakdown of about 0.001 second, comprising a spark, or may be an arc which may last for many cycles of the applied power frequency. In either case, when a spark or arc occurs, the voltage across the electrodes **30** and **32** falls sharply until the spark or arc is extinguished, whereupon the voltage recovers to its original value on a resistance-capacitance charging voltage transient. As was mentioned above, each time a spark or arc occurs, and while the voltage is recovering, the cleaning efficiency of the precipitator **34** is reduced. Thus, too high a voltage will create an excessive spark repetition frequency and reduced efficiency; whereas too low a voltage will result in not enough sparks and also in reduced efficiency. There is an optimum sparking rate which can be determined best by experiment for any gas cleaning operation; and at this sparking rate the efficiency is the greatest. However, if an attempt is made to adjust the current and voltage at a fixed value, the sparking rate will not remain constant for the reason that the density, temperature and other variables of the gas will vary.

In accordance with the present invention, the sparking rate can be maintained, as well as the efficiency maximized, regardless of changes in the characteristics of the gas being cleaned by means including a current transformer **36** encircling a conductor connecting the semiconductive controlled rectifiers **16** and **18** to one end of the primary winding **20**. The current transformer **36**, in turn, is connected to a RMS current-to-average voltage converter **38** which converts the current signal induced in the current transformer **36** into a proportional direct current voltage on lead **40**. The circuit **38** also produces a current spike on lead **42** each time a spark or arc occurs between the electrodes **30** and **32** of the precipitator **34**. That is, when a spark occurs, the current momentarily increases, thereby producing the aforesaid spike. This current spike is applied via lead **42** to a spark detector and pulse shaper circuit **44**, hereinafter described in detail, which converts the current spike into a pulse of fixed width and amplitude. As will be appreciated, the number of pulses appearing at the output of circuit **44** will be dependent upon the sparking rate, the higher the sparking rate the greater the number of pulses of fixed amplitude and width, and vice versa.

These pulses are applied to the input of an integrator 46 which also has applied thereto a reference signal derived from a spark rate reference potentiometer 50 which may be typically calibrated for a spark rate of 0 to 200 sparks per minute.

ASsuming that no sparks are occurring and that no pulses are applied to the integrator 46 from spark detector and pulse shaper 44, the output of the integrator 46 will gradually increase when the reference signal on lead 48 is applied thereto up to a predetermined maximum value. Again assuming that no sparks are occurring, this output of the integrator is compared at summing point 52 with the signal on lead 40 proportional to RMS current. If the two differ, an error signal is produced on lead 54 which is applied through a preamplifier 56 to the firing circuit 24 for the semiconductive controlled rectifiers 16 and 18. Hence, as the output of the integrator 46 increases, so also will the current and power supplied through the rectifiers 16 and 18.

Now, if it is assumed that a pulse is fed to the input of the integrator 46 from circuit 44, its output will be reduced by an amount proportional to the width and amplitude of the pulse. If the error signal on lead 54 is zero at this time, reduction in the output of the integrator 46 causes an unbalance at summing point 52; whereupon the power and current supplied through the rectifiers 16 and 18 is reduced. Thereafter, as the output of integrator 46 again builds up slowly, so also do the power and current supplied to the primary winding 20 until a succeeding spark occurs, whereupon the process is repeated. The rate of increase in current and power supplied to the precipitator during each cycle is proportional to the setting of the spark rate reference potentiometer 50. Hence, the number of sparks per unit of time may be regulated independent of the actual voltage existing between the electrodes 30 and 32.

It will be noted that the integrator 46 is connected to the pulse shaper 44 through normally open contacts 58 of relay 60 which may be energized by closing switch 62. When the switch 62 is not closed, the contacts 58 remain open. Under these circumstances, the signal at the output of circuit 38 proportional to RMS current is compared with a manual current adjust potentiometer 64 which regulates the desired current and power supplied to the precipitator 34 independent of sparking rate. In the embodiment of the invention shown in FIG. 1, the output of the integrator 58 is superimposed upon the signal supplied by potentiometer 64 in order to effect spark rate control; however, if desired, the potentiometer 64 may be disconnected from the summing point 52 when the output of the integrator is connected thereto.

With reference now to FIG. 2, elements shown therein which correspond to those of FIG. 1 are identified by like reference numerals. The circuitry shown in detail includes the RMS current-to-average voltage converter 38, the spark detector and pulse shaper 44, the integrator 46 and the preamplifier 56.

The RMS current-to-average voltage converter is connected, as shown, to the current transformer 36 and includes a full-wave rectifier 66 having one output terminal connected through diode 68 and resistor 70 to ground. Its other output terminal is connected to lead 72 on which a voltage proportional to the RMS current appears. The junction of diode 68 and rectifier 66 is connected through resistor 74 to lead 72; while the grounded side of resistor 70 is connected to the lead 72 through the parallel combination of smoothing capacitor 76 and resistor 78.

With the arrangement shown, a large surge in current, resulting from the existence of a spark, appears across resistor 74 and is applied through diode 68 and resistor 80 to the base of NPN-transistor 82 in the spark detector and pulse shaper 44. The transistor 82 is connected in a flip-flop arrangement with PNP transistor 84, the feedback from the collector of transistor 84 to the base of transistor 82 being through resistor 86. When transistor 82 is turned ON upon the occurrence of a positive spike at the input to circuit 44, transistor 84 turns ON. This causes the voltage at the collector of transistor 84 to rise and this rise in voltage is applied through capacitor 88 and resistor 90 to the base of a second NPN transistor 92 which turns ON. When transistor 92 turns ON, its collector voltage falls, thereby turning ON PNP-transistor 94. When transistor 94 conducts, the voltage on its collector rises; and this rise in voltage is coupled back through resistor 96 and diode 98 to the emitter of unijunction transistor 100 having its base 1 connected to ground and its base 2 connected to a source of positive potential through resistor 102.

The emitter of unijunction transistor 100 is also connected through capacitor 104 and resistor 106 to a source of negative potential which biases transistor 92 OFF. However, when the voltage on the collector of transistor 94 rises in the positive direction, the capacitor 104 will charge through resistor 106 raising the potential on the base of transistor 92, keeping this transistor ON until the breakdown potential of the unijunction transistor 100 is reached, whereupon the capacitor 104 will discharge. This causes the voltage at point 108 to fall; and this fall in voltage turns transistors 92 and 94 OFF. Hence, when a spike is applied to circuit 44, its output appearing at the collector of transistor 94 will rise in voltage and remain at an upper fixed value until the capacitor 104 charges to the point where the unijunction transistor 100 conducts. In this manner, a pulse of fixed amplitude and width is produced at the output of circuit 44; and this is applied through resistor 110 to the input of integrator 46.

The integrator circuit 46 includes an integrating operational amplifier 112 having a feedback path including an integrating capacitor 114 in shunt with a diode 116. The positive input terminal of the differential amplifier 112 is grounded as shown; while its negative terminal is connected through resistor 118 to the movable tap on spark rate reference potentiometer 50, also shown in FIG. 1. Assuming that no pulses are produced at the output of circuit 44 and that the circuit has just been turned ON, the output of the integrator 112 will slowly build up. However, when positive-going pulses from circuit 44 are combined with the reference signal from potentiometer 50 at summing point 120, the input to the operational amplifier 112 is more or less instantaneously reduced, thereby reducing its output. The rate at which the build up from this reduced valve occurs depends, of course, upon the setting of potentiometer 50; while the number of voltage excursions at the output of the operational amplifier depends upon the number of pulses per unit of time at the output of circuit 44 and, hence, the number of sparks occurring across the electrodes 30 and 32 (FIG. 1).

The output of the operational amplifier 112 is applied through resistor 122 and contacts 58 of relay 60, also shown in FIG. 1, to the input of the preamplifier 56. Note that relay 60 is provided with a second pair of normally closed contacts 124 such that when the relay 60 is deenergized upon opening of switch 62 to change from automatic spark rate control to manual control, the capacitor 114 in the feedback loop for operational amplifier 112 is discharged.

The preamplifier 56 includes an operational amplifier 126 having one of its inputs grounded and its other input connected through resistor 128 to the output of the integrator 46. Also applied to the input of operational amplifier 126 via resistor 130 and the summing point 52 (see also FIG. 1) is the signal on lead 72 from the RMS current-to-average voltage converter 38. As was explained above, this signal comprises a voltage proportional to the RMS current supplied to the precipitator 34. The end of resistor 128 opposite the summing point 52 is connected through diode 132 to the movable tap on the manual current adjust potentiometer 64, also shown in FIG. 1.

During manual control, the switch 62 will be open, relay 60 deenergized, and contacts 58 open such that no signal will be applied to the input of circuit 56 from integrator 46. At this time, the voltage established by the position of the tap on potentiometer 64 will be compared with that on lead 72 to manually control the output of preamplifier 56. Summing point 52 is also connected through resistor 134 to the movable tap on potentiometer 136 which adjusts the maximum output voltage of the operational amplifier **126**. The output of the operational amplifier **126** is connected through diode **138** back to the firing circuit **24** for the semiconductive controlled rectifiers **16** and **18**.

Assuming that it is desired to control the system under spark rate control conditions, the switch **62** is closed, thereby removing the shunt around capacitor **114**. Consequently, the output of operational amplifier **114** will build up to the point where a spark occurs. When the spark does occur, the circuit **44** converts the current spike from converter **38** into a fixed duration, fixed amplitude pulse which is fed to the integrator **46** in opposite polarity to the spark rate reference signal from potentiometer **50**. The output of the integrator **46** will then be reduced by a fixed amount, causing the current supplied to the primary of transformer **22** shown in FIG. **1** to recover to a slightly lower value than existed before the spark, then slowly increase until another spark occurs. Thus, if the actual sparking rate is lower than the reference value, the net effect will be a lengthening of the time between pulses and a net increase in the current through the primary winding **20** of transformer **22**. Conversely, if the sparking rate is high, the time between pulses will be shortened, causing a net decrease in transformer **22** primary current. The total effect, then, is to regulate precipitator voltage near the value which provides the sparking rate set for optimum collecting efficiency for the particular application in question. Note that the control automatically seeks the optimum level of precipitator voltage, as determined by the spark rate setting, regardless of changes in ambient conditions, thus providing automatic regulation to near optimum collection efficiency.

In starting up the system, the voltage limit potentiometer **136** is set at 100 percent or at the highest anticipated normal operating voltage level. Finally the spark rate potentiometer **50** is set to the desired average sparking rate, assuming that switch **62** is closed. No further adjustment of controls is necessary; and the system will operate at an essentially constant spark rate regardless of variation in the characteristics of the gas being cleaned.

Although the invention has been shown in connection with a certain specific embodiment, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention.

We claim as our invention:

1. In apparatus for controlling the current supplied to an electrostatic precipitator as a function of the repetition rate of current impulses between the electrodes of the precipitator, the combination of means for sensing the magnitude of the current supplied to said electrodes, means for sensing current spikes in said supplied current which result upon the occurrence of current impulses between said electrodes, means for converting said current spikes to pulses, integrating operational amplifier means having input terminal means, means for applying said pulses to the input terminal means of said amplifier means, means for supplying a reference signal to said input terminal means of the amplifier means to control the rate of increase in the signal at the output of the amplifier means, means for comparing the output of said amplifier means with a signal having a magnitude essentially proportional to the current supplied to said electrodes whereby an error signal will be produced when the magnitude of the output of said amplifier means differs from said signal proportional to electrode current, and means responsive to said error signal for controlling the power supplied to said electrodes, said pulses being supplied to the input terminal means of said amplifier means in opposed polarity relationship with said reference signal to reduce the input to said amplifier means each time a current impulse occurs.

2. The apparatus of claim **1** wherein said pulses are of fixed width and amplitude.

3. The apparatus of claim **1** including means for producing a direct current signal proportional to the RMS value of current being supplied to said precipitator, and means for comparing said direct current signal with the output of said amplifier means to produce said error signal for varying the current supplied to the precipitator.

4. The apparatus of claim **3** wherein current and power are supplied to said precipitator through phase-controlled semiconductive controlled rectifiers, a firing circuit for said semiconductor controlled rectifiers, and means for applying said error signal to said firing circuit.

5. The apparatus of claim **4** including a transformer for applying power to said precipitator, and a rectifier interposed between said transformer and the precipitator.

6. The apparatus of claim **3** wherein the means for producing a direct current signal includes a current transformer coupled to power leads supplying power to said precipitator.

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