Jan. 13, 1959 W. H. HICKOK 2,868,941

ELECTRONIC ARC-SUPPRESSOR

Filed March 11, 1958 2 Sheets-Sheet 1

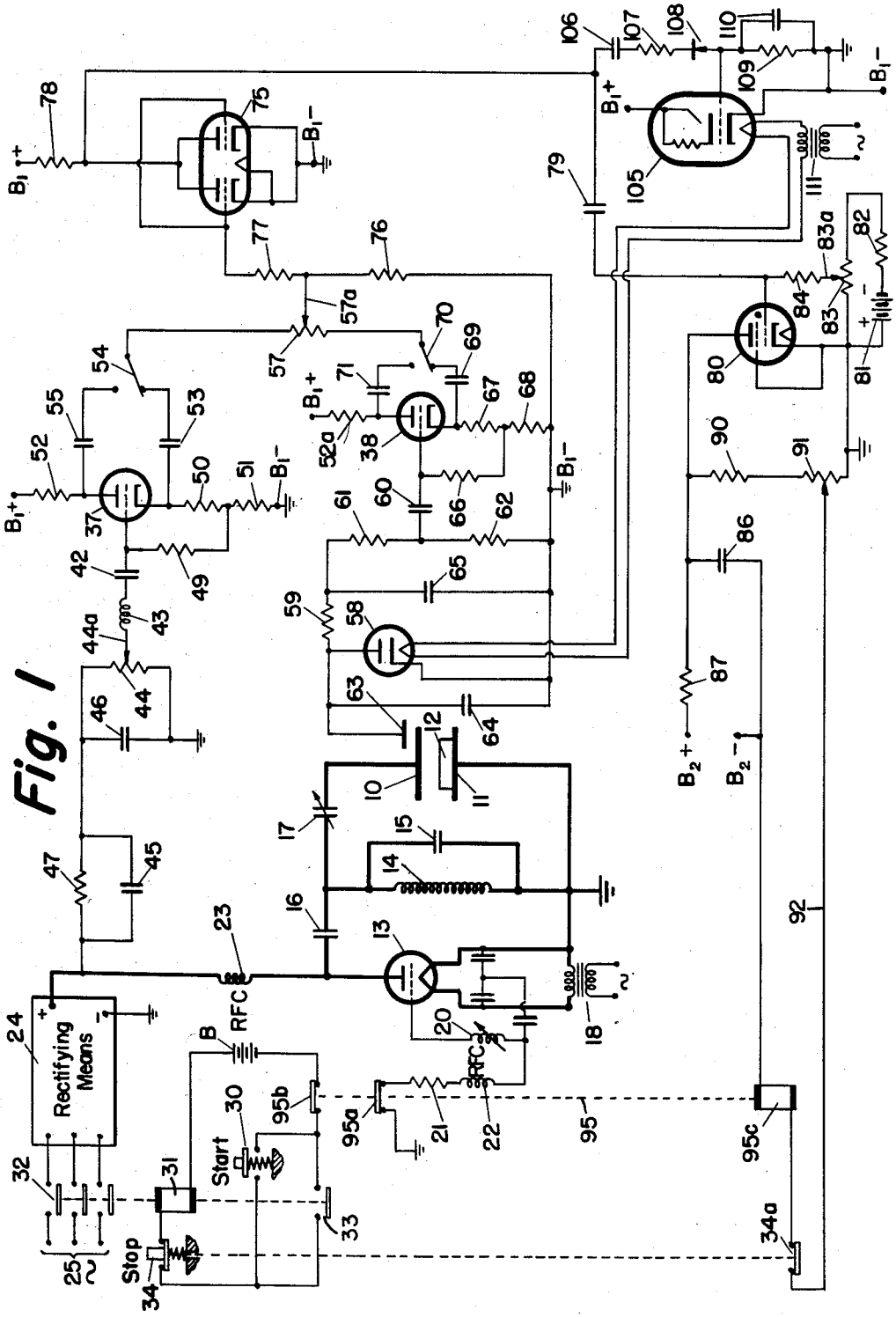


Fig. 1

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ELECTRONIC ARC-SUPPRESSOR

Filed March 11, 1958 2 Sheets-Sheet 2

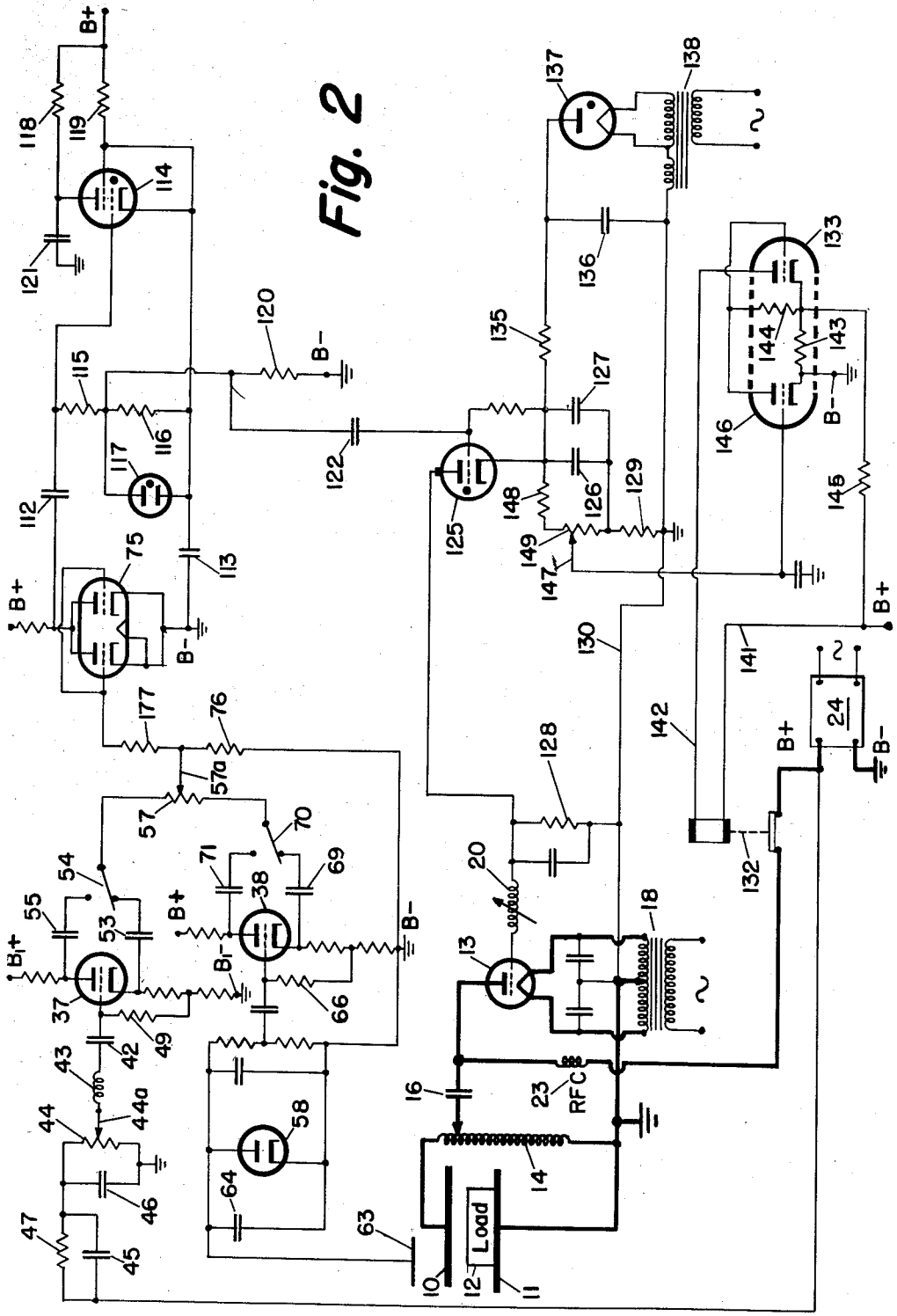


Fig. 2

United States Patent Office 2,868,941
Patented Jan. 13, 1959

2,868,941

ELECTRONIC ARC-SUPPRESSOR

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Application March 11, 1958, Serial No. 720,698

9 Claims. (Cl. 219—10.77)

This invention is concerned with methods of, and systems for minimizing or preventing the formation of arcs between the heating electrodes of high-frequency heating systems of the type particularly adapted for the heating of dielectric work.

The problem of protecting the work and the circuit components against damage due to the formation of arcs between electrodes is not new. Nevertheless, there has been lacking, until the present invention, a system which acts in response only to incipient or actual arcing conditions with sufficient speed and reliability to overcome costly arc-damage and at the same time is insensitive to starting transients and also insensitive to the ripple voltage present in a three-phase unfiltered anode supply system. Though generally applicable to high-frequency heating systems and to high-frequency sources or oscillators, the importance of the present invention will be best appreciated by reference to its application to a particular high-frequency heating system.

Dielectric heating systems are particularly adapted to the molding, curing, embossing and other processing of plastic materials. For example, one or both of the heating electrodes may comprise a die having on its face a simple, but more generally a fairly complex, design to be imparted to the plastic material. Dies which include patterns are expensive, and since thermoplastic materials faithfully reproduce the indentations, protuberances, etc., any impairment or damage to such surface will result in unacceptable final products. When the products are molded panels for automobiles or other components used in assembly lines, not only is the loss of material substantial, but also important is the lengthy shut-down time required to repair or replace the dies unless protective means, such as is the subject of this invention, are used.

Accordingly, it is highly important to minimize the formation of arcs which may not only damage the work but which also burn or otherwise mar and impair the surface of the dies. The minimum protection needed is to extinguish any arc which may form before it can damage the work or the dies.

Protective systems must be able to distinguish between a genuine arc or incipient arc and other disturbances in the entire equipment to which it is applied. For example, the ripple frequency from an unfiltered power supply, or the starting transient which may occur when an equipment is turned on, may cause false operation of the protective system thus shutting down the equipment needlessly. In the past it has been found that to avoid such needless operations, the sensitivity of the protective system will be reduced by the user of the equipment to the point of failing to protect the die. In the system herein described this problem is eliminated by making the protective system relatively insensitive to such extraneous signals which may cause false operations without impairing the sensitivity to the damage-causing arc signals.

As explained in Jennings and Smith application Serial No. 544,856, filed November 4, 1955, and assigned to the same assignee as the present invention, it has been found that losses due to arcing can be avoided almost entirely by providing a system which in response to an abnormal rate of change in the high-frequency voltage of the load circuit acts with such speed that arcing does not occur to any consequential degree. The abnormal rate of change of the high voltage of the load circuit is indicative of incipient or actual arc formation.

In accordance with the present invention, a protective system is provided which is insensitive to extraneous signals such as starting transients and ripple frequencies from the D. C. power supply but is quite sensitive to transients or signals representative of incipient or actual arcing conditions. The protective system of the present invention includes two sensing means, each having amplifiers with input and output circuits. The input circuit of one amplifier is connected to the direct current power supply circuit through an impedance element so that the first sensing means responds to voltage variations which occur in the direct current power supply circuit. The second sensing means has its input circuit coupled to the hgh-frequency heating circuit. There is included in the second input circuit a rectifying means so that the second sensing means likewise responds to voltage variations but this time those occurring in the heating circuit.

Both the direct current power supply circuit and the heating supply circuit include the starting transient and the ripple voltage. When arcing conditions occur, an arc transient appears only in the heating circuit. By connecting the output circuits of both sensing means to a balancing circuit and in phase opposition, that is with opposite instantaneous polarities, the ripple voltage and the starting transients may be balanced out leaving only the arc transient when it occurs.

Due to the effects of the intervening circuitry, it may be that the starting transient whch appears on the heating electrodes is not exactly like that occurring in the power supply although it originates in the latter place. Furthermore adjustments or changes in electrode voltage may alter the relative magnitudes. Therefore it may be that the starting transient is not completely balanced out. Since the starting transient is normally of one polarity, a third amplifier may be coupled to an impedance element in the balancing circuit so that it will only respond to a voltage change of opposite instantaneous polarity to that arising due to the starting transient. Accordingly, by reason of the two sensing circuits, and the balancing circuit, there may be produced an output signal from the third amplifier representative solely of arcing conditions. This third amplifier may be provided with high gain so that the signal representative of arcing conditions may be greatly amplified. By reason of the above described combination there may be utilized a sensitivity of an order several times greater than heretofore has been feasible. Accordingly a more favorable signal-to-noise ratio is attained.

In response to a signal representative only of arcing conditions, the supply of high-frequency power to the heating electrode is interrupted to protect the work and components of the system.

For further objects and advantages of the invention, reference may be had to the following detailed description taken in conjunction with the accompanying drawing in which there has been schematically illustrated a high-frequency heating system embodying the protective system of the present invention.

Referring now to the drawings, Fig. 1, the invention in one form has been shown as applied to a high-frequency dielectric heating system, including heating electrodes 10

and 11 arranged in a spaced relation to accommodate between them a load 12. The load, which may comprise work pieces of dielectric material, is heated when subjected to the high-frequency, high-voltage electric field produced between the electrodes 10 and 11. Inasmuch as the heating of the load increases as the square of the voltage between electrodes 10 and 11, it is desirable to have that voltage as high as possible to shorten the length of time the load is between the electrodes to bring it to a desired temperature or to a desired condition of dryness. However, as the voltage across or between the electrodes 10 and 11 is increased, there is the probability of an occasional arc between the electrodes. Even if the voltages between electrodes 10 and 11 be reduced to or maintained at a value which will normally be "safe" from the arc prevention standpoint, arcs may be formed. For example, if, as loads 12 are changed, foreign objects are brought between the electrodes, arc damage may occur. Such foreign objects may comprise iron fillings, metal staples, tacks or other parts used in the fabrication of automobile trim panels and the like. If an arc should form between electrodes 10 and 11, there will be burning or degradation of the load 12 disposed between them; and where electrode dies are employed, there may occur a pitting of them which may render them useless for further application and use.

Before describing the protective system itself, brief reference will be made to the power generator or source of high frequency which may be taken as representative of typical power generators. They may take various forms and may include one or more stages. As shown, the high-frequency source is of the T. N. T. type. It includes a power tube 13 of the thermionic type having the customary electrodes therein. It has a tank circuit comprising an inductance 14 and a capacitor 15. The tank circuit is connected to the anode of power tube 13 by way of a coupling capacitor 16. A variable condenser 17 is included in the high-frequency power output circuit and is utilized for coupling the heating circuit to the tank circuit. A filament transformer 18 provides the heating current for the filament of power tube 13. The grid-excitation circuit includes a grid inductance or coil 20. The grid-excitation circuit also includes a resistor 21 and an R. F. choke 22. The direct current power supply circuit for the oscillator includes a rectifying means 24 energized from alternating current supply lines 25. As shown, the rectifying means 24 is supplied from 3-phase supply lines. The rectifier itself may be of the full-wave type, of conventional design. As a result, a ripple frequency of 360 cycles per second will be present in the D. C. supply to tube 13. If single-phase alternating current were utilized, the ripple frequency would be 120 cycles per second. The direct current power supply circuit includes a high-frequency choke 23.

To start a heating cycle, a starting switch 30 is momentarily closed to energize, from source B, the operating coil 31 of a contactor 32 which closes the circuit from the alternating current supply lines 25 to the rectifying means 24. The contactor 32, upon closing, completes a holding circuit through contacts 33. Upon closure of the contactor 32, power is supplied to the power tube 13 and high-frequency alternating current is supplied to the heating electrodes 10 and 11 for the treatment or heating of the work-load 12. The power supply may be deenergized by pressing a stop button 34 which deenergizes contactor 32.

The sudden application of energy by closing contactor 32 applies a transient to both the rectifier means 24 and the electrode systems 10 and 11. These transients, which appear when starting the equipment have, in the past, given a signal to the protective device causing it to falsely operate. Furthermore, the ripple voltage appearing upon the high D. C. voltage applied to the plate of tube 13 appears as a modulation of the high-frequency voltage at the electrode system 10 and 11. Both of these effects, i. e. transients and ripple as well as sudden line voltage changes set the maximum sensitivity at which prior art protective devices could be operated in practice. In order to eliminate, or greatly minimize these factors limiting the sensitivity of the protective device a circuit, in accordance with the present invention, is described consisting of two sensing means each including amplifiers 37 and 38. The amplifier 37 includes an input circuit which is non-conductively coupled to the D. C. power supply circuit as by way of a capacitor 42, an R. F. choke 43, a voltage divider including a potentiometer 44, capacitors 45 and 46, and resistor 47.

The amplifier 37 includes a grid-leak resistor 49 connected between two resistors 50 and 51 in the cathode circuit. The resistor 50 supplies the proper bias for the grid circuit. The direct current power supply circuit for the amplifier 37 extends from the terminal labeled B_{1+} by way of a plate resistor 52, the tube which has the reference character 37 and by way of the resistors 50 and 51 to ground. As shown, the output circuit for the amplifier 37 is taken between ground and the upper end of resistor 50 by way of a coupling capacitor 53 to one side of a single-pole, double-throw switch 54. The signal at the cathode output circuit is an exact replica of the signal derived from the direct current power supply circuit extending from the rectifying means 24.

If the switch 54 be moved to its upper position, then an output circuit will extend from the anode by way of a coupling capacitor 55. The output signal will then be an inverted replica of the derived signal from the power supply circuit from rectifying means 24.

By moving the contact 44*a* of potentiometer 44, the amplitude of either output signal appearing at the switch 54 may be adjusted as desired. The output signal at switch 54 is applied to a potentiometer 57. The potentiometer 57 is an impedance element in a balancing circuit which includes the output circuits of both sensing means, only one of which has been thus far described.

The second sensing means including amplifier 38 has an input circuit which includes a non-conductive coupling element such as capacitor 60 connected between the two resistors 61 and 62 of a voltage divider. An electrode 63 spaced from heating electrode 10 forms with it a capacitor which capacitor in conjunction with a capacitor 64 forms a capacity voltage divider. Rectifying means shown as a diode 58 by-passes positive pulse and applies by way of resistor 59 and capacitor 65 a negatively-poled direct current voltage to the voltage dividers 61 and 62. Voltage changes appearing across resistor 62 are applied to the input circuit of the amplifier 38 by way of the capacitor 60. The amplifier 38 is provided with a grid-leak resistor 66 connected between cathode resistors 67 and 68. The amplifier 38 has an output circuit illustrated as extending from the upper end of cathode resistor 67 by way of a coupling capacitor 69 to a single-pole, double-throw switch 70 which is connected to the potentiometer 57. An exact replica of voltage changes, as derived by way of the capacitor formed between electrodes or plates 10 and 63 will appear at the output circuit of amplifier 38.

If the single-pole, double-throw switch 70 be moved to its upper position for completion of an output circuit by way of capacitor 71 to the anode, an inverted replica of the derived signals will be obtained.

As illustrated, the signals appearing at the two output circuits are applied to the balancing circuit including the potentiometer 57 in opposition one to the other. Normal voltage and circuit-component size-deviations may be compensated for by adjustment of either contact 57*a* on potentiometer 57 or by contact 44*a* on potentiometer 44.

With signals of equal amplitude applied to the grids of the two amplifiers 37 and 38, contact 57*a* may be adjusted to produce substantially zero output by way of that contact. In order to establish equality of the signals at the respective grids or input circuits of amplifiers 37 and 38, the contact 44*a* will be adjusted to the proper position for that result. These contacts 44*a* and 57*a* also permit operation short of balanced conditions or with over-compensation.

The means by which similar signals from the power supply and the heating electrodes, such as power supply ripple, line voltage fluctuations, power supply transients, and the like are balanced out, so they will not operate the protective system, has been described. An arc in the electrode system will produce a signal in the amplifier 38 but will not produce a like signal in amplifier 37. Then, since there is no balancing signal, a substantial signal due to the arc will appear at the contact 57*a* of the potentiometer 57. This signal is subsequently amplified by tube 75 as described below.

Inasmuch as spurious transients or signals which are not indicative of arcing or incipient arcing appear at both sensing means, the result of balancing out such signals at the balancing circuit indicates that substantial amplification may be provided for the arc-indicating signals which do appear at the output circuit connected to potentiometer contact 57*a*. Thus, that output circuit applies signals to the input circuit of an amplifier 75 shown as a pair of triodes connected in parallel. The amplifier 75 is connected to a source of anode supply, as from the terminal labeled B_{1+} and to have the negative terminal labeled B_{1-}. This tube is operated in a highly conducting fashion, i. e. practically no bias is used. Resistor 77 is used to limit the grid current which normally flows. Operated in this fashion this tube will accept only negative polarity pulses. The input circuit to the amplifier 75 includes the resistor 76 and the grid resistors 77.

The output circuit from amplifier 75 extends from the anode side of plate resistor 78 by way of a coupling capacitor 79 to the input circuit of a high-speed circuit controlling arrangement. This arrangement includes a thyratron 80 having its grid-control circuit connected to a source of bias voltage 81 so as to be normally non-conductive. The source 81 is connected by way of a series resistor 82 to a potentiometer 83 from which a desired bias voltage is selected by contact 83*a*. The bias voltage is applied by way of the coupling resistor 84 to the grid of the thyratron 80. The anode supply for the thyratron 80 is derived from a direct current source whose supply contact has been labeled B_{2+}. It is to be noted that the capacitor 86 is charged during the time the thyratron 80 is non-conductive. It is to be further observed that current may flow, while thyratron 80 is non-conductive by way of resistors 87 and 90, a rheostat 91, conductor 92, operating coil 95*c* of a high-speed vacuum-type grid-relay 95, and thence to the other side of the B supply, B_{2-}. The current flow by way of the relay coil 95*c* is insufficient to operate the relay contacts to their open position. With current flow through the relay winding 95*c* of a value just insufficient to operate the contacts 95*a* to their open position, a much greater speed of opening of the contacts is attained upon the firing of the thyratron 80.

The high-speed vacuum switch or relay 95 is actuated to open the grid circuit of the power supply tube 13 upon the appearance of any positive-going pulse at the grid of thyratron 80. The opening of the grid circuit of the power supply tube 13 immediately interrupts the supply of high-frequency power to the heating electrodes 10 and 11. This action occurs within a few milliseconds after pulses indicative of arcing conditions occur. In order to attain maximum speed of operation, the capacitor 86 aids in increasing the discharge current through thyratron 80, once it is fired, and assures a large rush of current through winding 95*c* for maximum speed of opening of the vacuum switch 95. If desired, the vacuum switch 95 may have additional contacts 95*b* arranged to be opened with energization of operating coil 95*c*. The opening of the circuit through contacts 95*b* will deenergize the coil 31 of contactor 32 which will then open.

In this connection, it is to be noted that contactors and magnetic switches are generally slow in operation as compared with specially designed high-speed relays of the type utilized for the vacuum switch 95. Such relays are available on the market, as relay type VS–2 from Eitel-McCullough Company.

With contacts 95*b* open, the contactor 32 will move to its open position. Operation of the high-frequency heating system may be resumed by operating the stop button 34 to "reset" the protective system and then the starting button 30. It will be noted the stop switch 34 is provided with contacts 34*a* in the discharge circuit of the thyratron 80. Thus, as soon as contacts 34*a* have been opened, the thyratron 80 will be deenergized. While deenergized, the capacitor 86 will again be charged preparatory to a second protective operation in the event an arc-indicative input signal is again applied to the input circuit of thyratron 80.

Summarizing the operation of the system as a whole, when the starting switch 30 is closed and the contactor 32 closes to energize the rectifying means 24, starting transients appear both in the direct current sensing circuit and in the high-frequency sensing circuit. Similarly, the ripple voltage, 360 cycles per second for the 3-phase full-wave rectifier, appears in both of the sensing circuits. Thus both sensing means including amplifiers 37 and 38 have present the starting transients and the ripple voltages. These are balanced one against the other so that notwithstanding the fact there are signals present in both sensing means, nevertheless, properly adjusted, there is approximately zero output from the output of the balancing circuit, including the contact 57*a* and resistor 76. Accordingly, amplifier 75 may have high gain to provide great sensitivity in respect to transients which appear in but one of the sensing means. Thus, arcing conditions between electrodes 10 and 11 produce a transient of high magnitude which results in a signal of substantial magnitude at the input of amplifier 38 and at the amplifier 75. By reason of the highly amplified signal, the thyratron 80 is more reliably fired to interrupt the supply of high-frequency power to the heating electrodes in case of an arc.

In practice, it has been found that the balanced sensing means of the present invention has been highly reliable in operation in distinguishing between (1) ripple frequency, (2) starting transients and (3) other spurious fluctuations and transients due to arcing conditions. Down time has been decreased and the system as a whole is operated with much greater reliability. Furthermore the sensitivity to arcs has been maintained high so that loss of dies and load material has been substantially reduced.

Another feature of this invention is that the protective system is ready to function before the power is turned on. Thus, if there is a fault or arcing condition present at the start of the heating cycle as would be present if there were metal inclusions in the load material, as mentioned above, immediate protection is available to stop oscillations before damage can be done.

The switches 54 and 70 provide great flexibility in setting up the system in that they can be operated from one position to the other to assure balancing out the signals in the two sensing circuits, as in the balancing circuit including potentiometer 57. Thus with grounded anode-supply circuits the polarities or relative phases of the signals may be reversed by these switches.

While the adjusting means including the potentiometers 44 and 57 have been described, it will be convenient in many systems to provide additional features for ease in setting up the system for particular field conditions. For

example, a "magic eye" indicator tube **105** has been shown as connected to the output of the amplifier **75**. In the absence of any signal therefrom, the target or "eye" is wide open. However, when a signal appears at the output of amplifier **75**, it will be applied by way of a coupling capacitor **106**, a resistor **107**, a rectifier **108** and a resistor **109** shunted by a capacitor **110**, to the input circuit of the indicator tube **105**. The output signal of the amplifier **75** is thus rectified and the resultant voltage as appearing at the input or grid circuit of tube **105** causes the "eye" or target partially to close. The degree of closure will depend upon the amplitude of the signal from the amplifier **75**. It is to be noted that the filament of the tube **105** is supplied by way of a transformer **111** energized from alternating current supply lines. The filament supply transformer **111** not only energizes the filament of tube **105** but energizes in series therewith the filament of diode-detecting tube **58**. If this rectifier tube **58** should fail by reason of filament failure, the green fluorescence of the indicator tube will disappear thus providing visual indication of failure of tube **58**.

If, with the power tube **13** energized, the eye of the indicator tube **105** is partially closed, the contact *44a* of potentiometer **44** will be adjusted for maximum opening. Thus the indicator tube **105** provides an easy way of making one of the initial adjustments for the system.

The following typical values of the circuit components for one embodiment of the invention are to be taken as illustrative and not by way of limitation:

Tubes **37**, **38**	Type GL–5692.
Tube **75**	Type GL–5691.
Tube **80**	Type 6012.
Tube **105**	Type 6E5.

Capacitors	Value
42, **53**, **55**, **60**, **69**, **71** and **106**	.05
64, **65**	.0002
79	.02
110	0.001

Resistors		Value
44, **61**, **77**	K	100
49, **62**, **66**, **76**	meg	1
50, **67**	K	1
51, **68**	K	10
52, **52A**	K	12
57	meg	0.5
59	K	20
84	K	330
107	K	270
109	meg	4.7

The remaining circuit components are conventional and have conventional values adapted for the particular type of tubes utilized.

It is to be understood that the present invention is applicable to high-frequency generators of many types currently utilized in high-frequency heating. They may be of the type illustrated in said Jennings et al. application, Serial No. 544,856, of the type shown in Wilson Patent No. 2,684,433 and in Warren Patent 2,783,344. They may be provided with grounded positive circuits or, as shown in Fig. 1, with grounded negative circuits. For any of the various systems to which the invention may be applied, it will be found that adequate flexibility has been provided for operation in conjunction therewith.

In Fig. 2 there has been illustrated the present invention applied to a system for interrupting the supply of high-frequency power to the heating electrodes by developing a high negative bias in the grid circuit of the power supply tube **13**. A part of the system is like a portion of the system of Fig. 1 of aforesaid application S. N. 544,856.

In Fig. 2, the output from the amplifier **75** is applied by way of capacitors **112** and **113** to the control circuit of a thyratron **114**. As shown, the first thyratron **114** is used to control a second thyratron type of tube **125**. By providing a trigger circuit including the tube **114** and associated circuits, a control pulse or signal of adequate magnitude is produced to fire the tube **125**, which is of a type requiring a large pulse to render it conductive.

The tube **114** may be either of the GL–5727 or 2D21 type, both being gas-filled and the GL–5727 having an extra-duty rating. Whenever a signal pulse from the balanced sensing means appears at amplifier **75**, it is applied by way of the coupling capacitors **112** and **113** between the grid and cathode of tube **114**. The input circuit also includes a grid resistor **115** and a cathode-biasing resistor **116**, shunted by a regulator type of tube **117** of the neon-tube type. The anode and shield grid of tube **114** are connected respectively through resistors **118** and **119** to the positive or B+ conductor of a suitable source of anode potential. A normally negative bias potential for the grid of tube **114** is developed by a voltage-divider including resistors **116** and **119**. The circuit through said resistors extends from B+ by way of resistor **119**, the conductive connection to the cathode, the bias resistor **116** and by way of resistor **120** to B−. The potential difference developed across resistor **116** maintains the grid of tube **114** negative with respect to its cathode and thus maintains the tube non-conductive until there is applied to its input circuit a positive signal pulse from amplifier **75**.

During normal operation, the neon-tube **117** is non-conductive since the potential difference, of the order of 6 volts, across resistor **116** is insufficient to render tube **117** conductive. When the tube **114** fires, the voltage across resistor **116** rises and tube **117** is rendered conductive to provide a discharge path of decreased resistance through the tube **114** and resistor **120**.

Upon firing of the tube **114**, a surge of current flows through it and through resistor **120** by reason of the additional provision of a capacitor **121** which carries a charge equal to the potential difference or voltage of the "B" supply. The resistor **118** has a sufficiently high resistance to limit the current flowing through the circuit, including resistor **118**, the tube **114** and resistors **116** and **120**, to a value which will be insufficient to maintain ionization of the tube **114**.

Accordingly, as soon as the capacitor **121** has discharged, current flowing by way of resistor **118** is insufficient to maintain the tube **114** conductive. As it and tube **117** return to their non-conductive conditions, current flows by way of resistor **118** to re-charge the capacitor **121** to condition the trigger circuit of the protective system for a second operation.

The principal resistance in the discharge path is resistor **120**. It has a value for development of a high-voltage impulse, well in excess of 130 volts. The high-valued impulse is applied by coupling capacitor **122** to the input circuit of the second control tube **125**, which in one embodiment of the invention was of the AX–9911 type, an extra-duty 4C35 thyratron tube.

Though a permanent source of anode voltage may be provided for tube **125**, such as from a conventional rectifier system, the system of Fig. 2 utilizes a source of stored electrical energy such as one or more charged capacitors. Thus when tube **125** fires, electrical energy stored in capacitors **126** and **127** produces current flow through the grid resistor **128** of tube **13** of magnitude and direction to bias that tube to and beyond cut-off. As a result, the supply of high-frequency power to the heating electrodes **10** and **11** is instantly interrupted. In this manner the power tube **13** itself serves the function of interrupting the supply to the high-frequency load circuit including electrodes **10** and **11**. Thus, the power tube **13**, an electronic discharge device, is utilized not only for the delivery of high-frequency power to maintain high-frequency oscillations within the tank circuit, but it is utilized also as an electronic switch or circuit-interrupter to shut off the power to the tank circuit upon the occurrence of incipient or actual arcing conditions.

The tube 13 also interrupts the direct-current anode supply circuit which includes the R. F. choke coil 23.

The discharge circuit for the capacitors 126 and 127 may be traced from the positive side thereof by way of resistor 129, conductor 130, grid-leak resistor 128, and by way of the thyratron 125 to the other side of them. Because the energy-storing means comprising capacitors 126 and 127 represents a temporary source of supply, the tube 13 is maintained nonconductive by the negative bias developed by resistor 128 only during the period of adequate current flow through that resistor. With a permanent source of supply, the tube 13 can be maintained non-conductive as long as may be desired.

To provide continued protection against an immediately recurring arc, which might appear if the heating cycle were to be resumed as capacitors 126 and 127 are discharged, additional provisions are made to maintain interrupted the supply of high-frequency power to the electrodes 10 and 11 after discharge of the capacitors. As will be later explained in detail, the relay or contactor 132, normally closed by current flow through its operating coil and a tube 133, is deenergized and operates to its open position during the time tube 13 is maintained non-conductive by the discharge current supplied by capacitors 126 and 127.

A more detailed consideration of the circuitry including the capacitors 126 and 127 will now be presented. The energy stored in the capacitors 126 and 127 is supplied by a charging circuit which includes a series-resistor 135, a filtering capacitor 136 and a rectifier or diode 137. The diode 137 is supplied from a transformer 138 having the usual filament windings and an anode supply winding connected in the charging circuit. This circuit may be traced from the left-hand side of the anode-supply winding by way of the resistor 129, the capacitors 126 and 127, the resistor 135 and by way of the diode 137 to the other side of the anode-supply winding.

The series resistor 135 has a value which limits the magnitude of the charging current to a value which will not maintain the thyratron 125 conductive. Accordingly, after it fires and the capacitors 126 and 127 have been substantially discharged, the thyratron 125 ceases to conduct. As soon as it becomes non-conductive, the charging circuit is effective to initiate the re-charging of the capacitors 126 and 127. The relay 132 is maintained in its open position until sufficient energy has been stored in the capacitors to assure effective protection of the system in the event of incipient arcing upon resumption of the high-frequency heating cycle.

Returning now to the operation of the relay 132, it is normally energized to close the anode-supply circuit of power tube 13. The coil of relay 132 is energized by reason of the flow of current from the source of supply B+ by way of conductor 141, the operating coil of the relay 132, conductor 142, the tube 133, which may be one-half of a heavy-duty 6SN7 type of tube, and thence by way of resistor 143 to ground, which is the other side of the "B" supply.

The tube 133 is conductive in the absence of current flow through a resistor 144 since the grid is not then biased to cut-off. More specifically, in the absence of current flow through resistor 144, the grid of tube 133 will be at the same potential as its cathode, a condition for conduction by tube 133. The magnitude of current flowing through tube 133 is determined by voltage-dividing resistors 145 and 143. These resistors determine the potential of the cathode of tube 133 relative to the anode. The current flow through the coil of relay 132 and the tube 133 is limited to a value which will close the relay 132 and which will hold it in closed position.

The tube 146 has its grid negatively biased relative to its cathode by reason of the grid connection to the tap 147 of the voltage-divider formed by resistors 148, 149, and 129, the latter resistor having its lower end connected to the ground path to which the cathode of tube 146 is directly connected. The resistor 129 is small compared with resistors 148 and 149. It is incorporated to accelerate the deenergization of relay 132.

It will be recalled that when the thyratron 125 fires, the discharge circuit included resistor 129. The potential difference resulting from current flow through the resistor 129 makes its upper end positive relative to ground. This cancels the negative potential between tap 147 and the top of resistor 129. The result is immediate removal of the negative bias on the control grid of the tube 146. The removal of this negative bias from the input circuit of the tube 146 allows anode conduction of that tube by way of resistors 145 and 144. The resultant voltage drop across resistor 144 makes the grid of tube 133 negative with respect to its cathode so as to reduce the flow of the current through tube 133. In this manner, the current is reduced below the hold-in value of relay 132 which immediately opens to interrupt the anode supply of the power tube 13.

There will now be described the manner in which the high-frequency heating cycle is automatically resumed. As the capacitors 126 and 127 are charged, the voltage across resistor 149 rises. It rises to a value which biases the tube 146 to cut-off as the level of charge of capacitors 126 and 127 rises to a circuit-protecting level. As the tube 146 is made non-conductive, current flow through resistor 144 is reduced to zero and the potential drop across resistor 144 disappears. The result is that the potential on the grid of tube 133 again rises to that of the cathode. The tube 133 conducts with flow of current to energize the operating coil of relay 132 to reclose it and, in the illustrated embodiment, to initiate a further cycle of heating by the dielectric heating system. Alternatively, the system may be set up for manual initiation of such further heating cycle, as by suitable contactors provided in supply means 24.

From the foregoing, it will be seen that upon occurrence of corona or flash-over, the system operates immediately to interrupt the flow of power to the load circuit. The operation is positive and certain by reason of the several stages of amplification and the large pulses produced which immediately shut off the power tube 13.

What is claimed is:

1. A protective system for a high-frequency heating system which includes heating means for a load, an oscillator supplying high-frequency power through a power output circuit to said heating means, and a power supply circuit for said oscillator for supplying current to said oscillator, comprising a first sensing means including first amplifying means having input and output circuits, means for connecting said input circuit to said power supply circuit for applying to said first amplifying means signals representative of voltage changes in said power supply circuit, a second sensing means including second amplifying means having input and output circuits, means including a coupling element connected to said power output circuit for applying to said input circuit of said second amplifying means signals representative of voltage changes in said high-frequency power output circuit, a balancing circuit including an impedance element and said output circuits of said sensing means, said output circuits of said sensing means being connected into said balancing circuit for applying in opposing relation therein output signals having the same instantaneous polarities, a third amplifying means having an output circuit and an input circuit connected to said impedance element and responsive to output signals developed by said impedance element, and means connected to said output circuit of said third amplifying means for interrupting the supply of high-frequency power to said heating means in response to said output signals developed upon application to one only of said sensing means of an input signal.

2. The protective system of claim 1 in which said means connected to said output circuit of said third am-

plifying means comprises a high-speed switch for interrupting the supply of high-frequency power to said heating means, and electric discharge means operable in response to an output signal from said third amplifying means for producing high-speed operation of said switching means.

3. The protective system of claim 1 in which said impedance element of said balancing circuit comprises a potentiometer with a contact adjustable to vary in the balancing circuit the relative amplitudes of the signals from the output circuits of said sensing means for reducing them to minimum values, and in which said means connected to said output circuit of said third amplifying means includes a thyratron having an input circuit responsive to output signals from said third amplifying means for rendering said thyratron conductive, and a high-speed switch operable upon discharge of said thyratron for interrupting the supply of high-frequency power to said heating electrodes.

4. A protective system for a high-frequency heating system which includes heating electrodes for a load disposed therebetween, a power oscillator tube for supplying high-frequency through a power output circuit to said heating electrodes, and a direct current power supply circuit for said oscillator including rectifying means energized by alternating current for supplying direct current to said oscillator, comprising a first sensing means including a first amplifier having input and output circuits, means including a coupling capacitor for connecting said input circuit to said power supply circuit for applying to said first amplifier signals representative of voltage changes in said power supply circuit, a second sensing means including a second amplifier having input and output circuits, means including a capacitor and rectifying means connected to said high-frequency power output circuit for applying to said input circuit of said second amplifier signals representative of voltage changes in said high-frequency power output circuit, a third amplifier having an output circuit and an input circuit, means including a potentiometer having a variable arm which is connected into said input circuit of said third amplifier and which forms in conjunction with said output circuits of said first amplifier and of said second amplifier a balancing circuit for combining in opposing relation therein the output signals from said first and said second amplifiers, and means connected to said output circuit of said third amplifier for interrupting the supply of high-frequnecy power to said heating electrodes in response to output signals from said third amplifier.

5. The protective system of claim 4 in which said means connected to said output circuit of said third amplifier comprises a thyratron having an input circuit with biasing means normally biasing said thyratron to be nonconductive and upon application thereto of a signal from said output circuit of said third amplifier being rendered conductive, and means operable in response to discharge current through said thyratron for interrupting the supply of high-frequency power to said heating means.

6. The protective system of claim 4 in which there is provided an indicating means having an energizing circuit connected to be responsive to the output from said third amplifier whereby the ampiltude of the signals applied to said balancing circuit may be adjusted to minimize the output signal from said third amplifier.

7. A protective system for a high-frequency heating system which includes heating electrodes for a load, an oscillator supplying high-frequency power through a power output circuit to said heating means, and a direct current power supply circuit for said oscillator having rectifying means energized by alternating current for supplying direct current to said oscillator, comprising a balancing circuit including a potentiometer, means for applying to said balancing circuit signals derived from said direct current power supply circuit, said means including a capacitor and an amplifier, means for applying a second signal to said balancing circuit representative of voltage variations at said heating electrodes, said last-named means including a rectifier and an amplifier, means for adjusting the relative amplitudes of said signals applied to said potentiometer so that said signals during steady state conditions balance each other, and means responsive to unbalanced signals from said potentiometer for interrupting the supply of high-frequency power to said heating eelctrodes.

8. The protective system of claim 7 in which signal indicating means is connected to said balancing circuit for indicating unbalance during steady state conditions whereby said amplitude adjusting means may be operated to positions for a minimum output signal from said balancing circuit.

9. The protective system of claim 8 in which said signal-indicating means is an indicator tube having an electron beam and means including an amplifier connected to said balancing circuit for controlling said beam in accordance with output signals from said amplifier.

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