March 26, 1957 M. ROTHSTEIN ET AL 2,786,926

PROTECTIVE ARRANGEMENTS FOR HEATING APPARATUS

Filed May 27, 1953

4 Sheets-Sheet 1

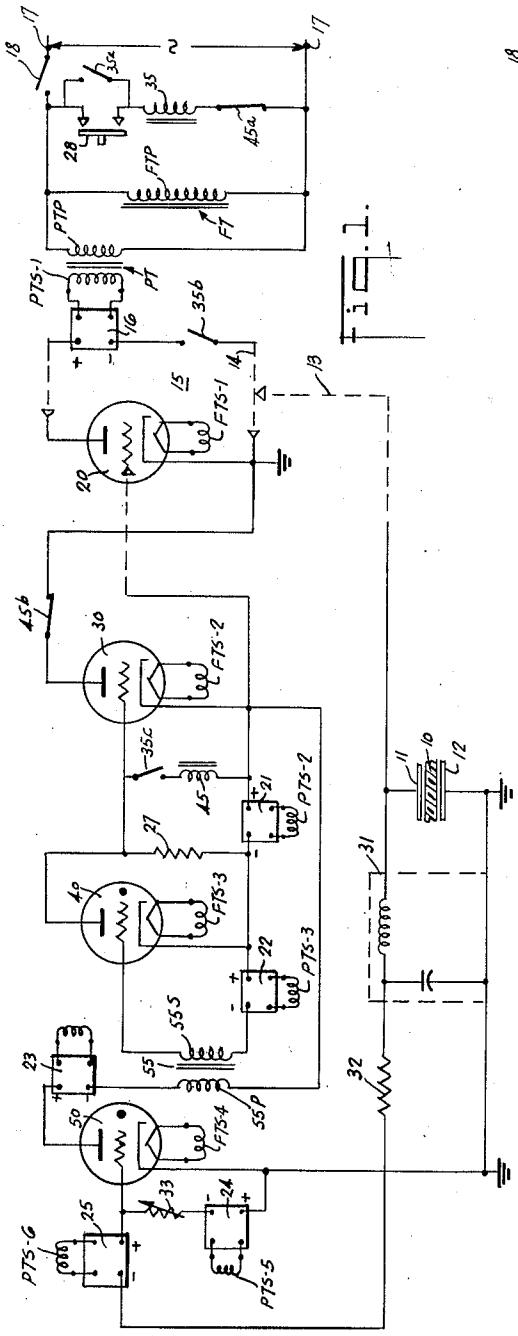


Fig. 1.

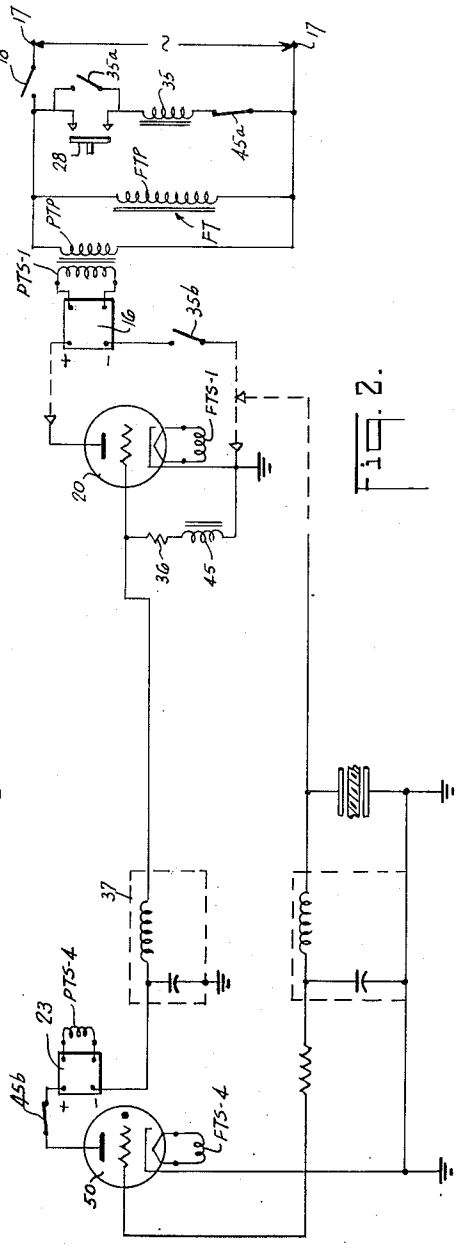


Fig. 2.

INVENTORS
Melton Rothstein
Arthur L. Rossoff
Leslie Levy
Peter Desmond
Dana Dennett

BY Douglas Mowatt ATTORNEY

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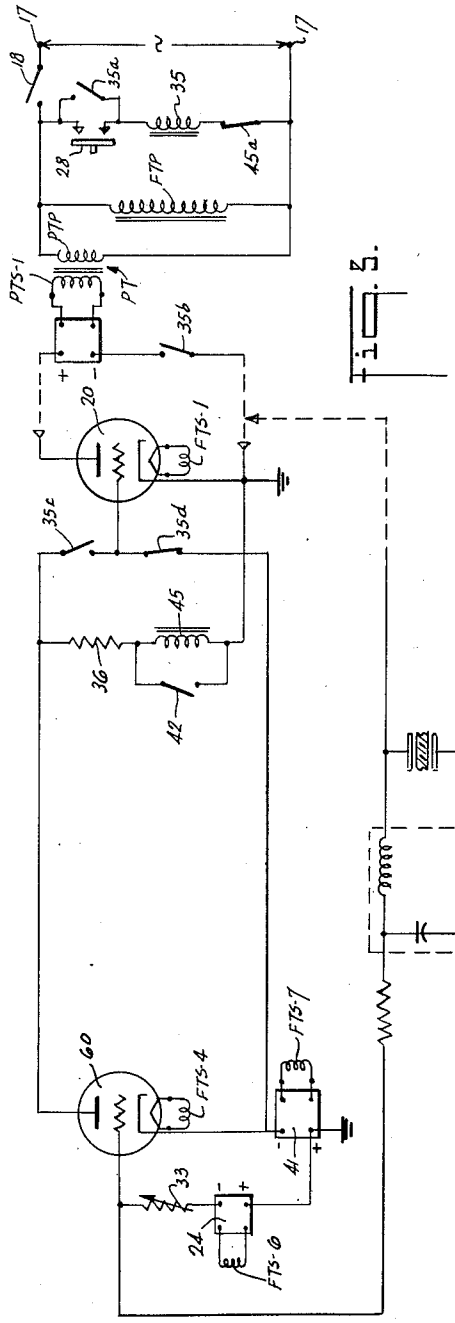


Fig. 3.

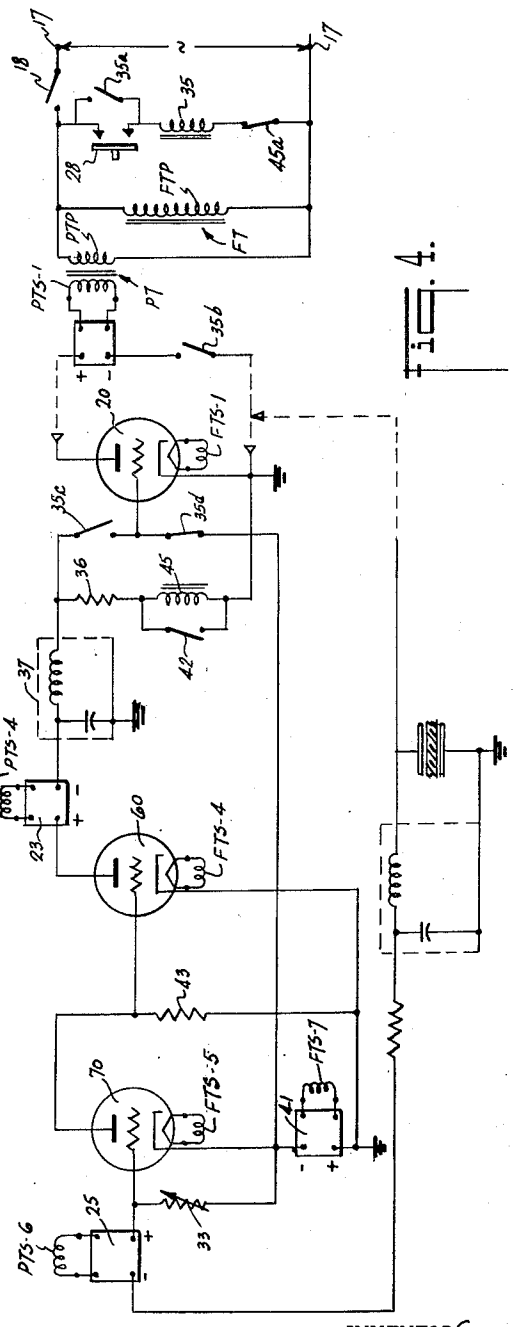


Fig. 4.

INVENTORS
Morton Rothstein
Arthur L. Rosenfeld
Lester Lang
Peter Baumbach
Dan Dennis

BY

ATTORNEY

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PROTECTIVE ARRANGEMENTS FOR HEATING APPARATUS

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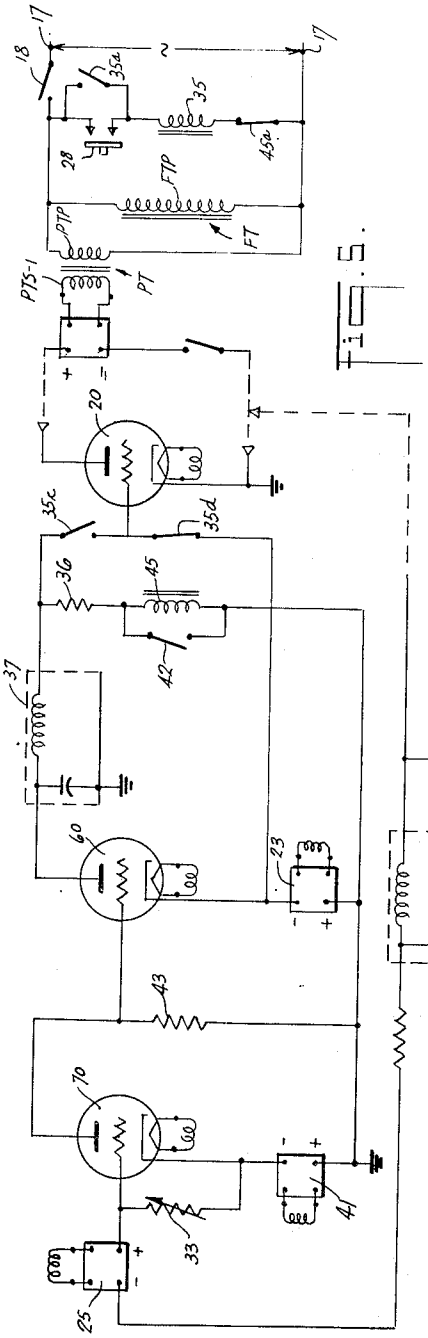


Fig. 5.

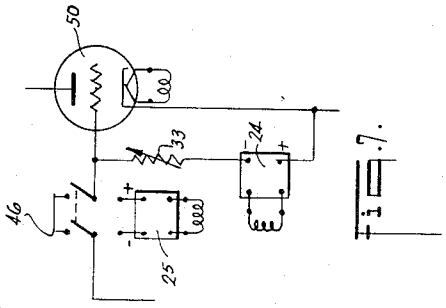


Fig. 7.

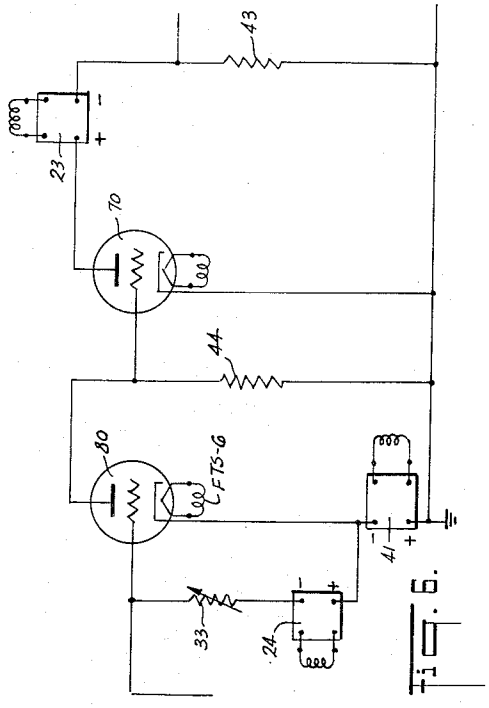


Fig. 6.

INVENTORS
Morton Rothstein
Arthur L. Rossoff
Lester Levy
Peter Goldman
Louis Demott

BY

ATTORNEY

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PROTECTIVE ARRANGEMENTS FOR HEATING APPARATUS

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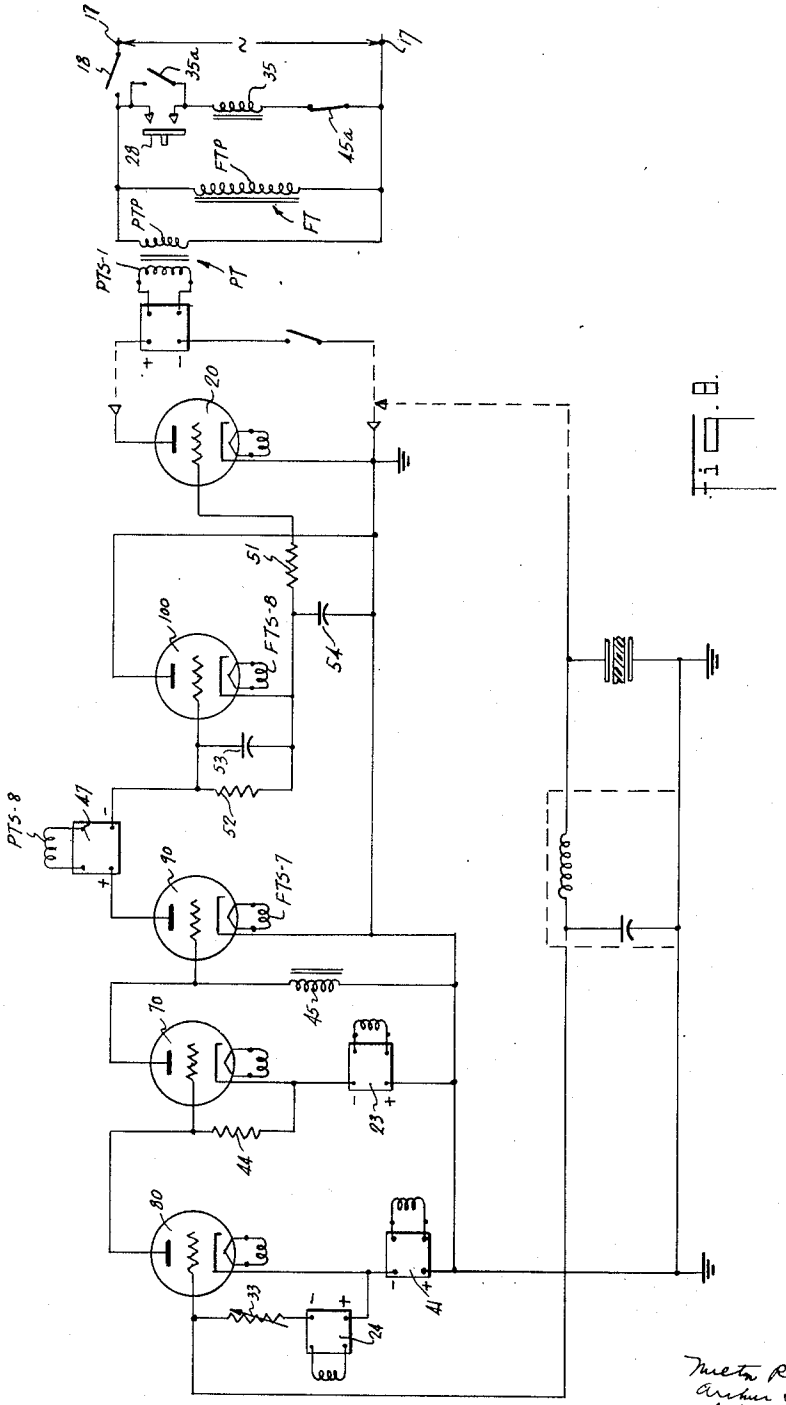


Fig. 8

INVENTORS
Meyer Rothstein
Arthur L. Rosoff
Lester Levy
Peter Dirnbach
Donald Dewart

BY

ATTORNEY

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2,786,926

PROTECTIVE ARRANGEMENTS FOR HEATING APPARATUS

Milton Rothstein, Flushing, Arthur L. Rossoff, Lynbrook, Lester Levy, Brooklyn, Peter H. Dirnbach, New York, and David De Witt, Northport, N. Y., assignors to Radio Receptor Company, Inc., Brooklyn, N. Y., a corporation of New York

Application May 27, 1953, Serial No. 357,836

7 Claims. (Cl. 219—10.77)

This invention relates to protective arrangements for industrial apparatus and, more particularly, to an improved sensitive control arrangement operable to rapidly interrupt the supply of heating energy to a medium responsive to a sensed change of a predeterminable magnitude in a state of the medium.

While the invention control arrangement is useful in many applications, a particular and solely exemplary application is in the high frequency electric field heating of dielectric materials, particularly thermoplastics. In such high frequency heating operations, the material being heated, or the electrodes, or both, frequently are damaged as a result of excessive current flow or arcing. Such excessive current flow or arcing may be due to any one or more of several factors, such as the presence of included conductive impurities in the material, variations in thickness of the material causing severe localized heating and/or flash-over, the application of excessive H. F. power or voltage, the application of H. F. power for excessive periods of time, or excessive compression of the material by the electrodes.

The present invention takes advantage of the observed fact that the aforementioned arcing is preceded by an increase in the conductivity of the heating material, such increase continuing until the arcing condition occurs. To this end, the invention arrangement includes sensing means, in operative association with the electrodes and the material being heated, to sense any such increase in conductivity of the material, and utilizes any detected increase in such conductivity to rapidly interrupt the supply of heating energy to the material.

More specifically, a moderate D. C. potential is applied between the H. F. energy applying electrodes by a sensing circuit. If the afore-mentioned increase in conductivity of the material being heated occurs, the current flow in the sensing circuit increases. This increase in the sensing circuit current flow is utilized to substantially instantaneously apply an immediately effective blocking potential to a radio frequency (R. F.) generator supplying the heating energy. Thus, the heating energy supply is interrupted before either the electrodes or the material being heated are injured.

In a particular practical application of the invention principles, the H. F. energy is supplied by an R. F. oscillator whose grid current flows through one or more normally conductive amplifier valves acting as a variable grid resistance. Where the D. C. sensing circuit has a high current flow, due to increased conductivity of the material being heated, a thyratron circuit is made conductive. The resultant high voltage D. C. potential is applied to the amplifier tubes which act momentarily as a heavy drain of the D. C. potential supply. This sudden flow of current produces a pulse in a pulse transformer in the high voltage D. C. circuit, and this pulse initiates conduction in another thyratron circuit. The latter immediately applies a sufficiently high negative voltage to the amplifier grids to reduce the amplifier conductance

to a negligible value, greatly increasing the resistance in the oscillator grid circuit. This, in turn, greatly reduces the intensity of the oscillations, minimizes the drain on the high voltage D. C. supply to permit use of relatively small components, and allows the terminal voltage of the latter supply to rise and thus expedite the termination of oscillation.

For an understanding of the invention principles, reference is made to the following description of typical embodiments thereof as illustrated in the accompanying drawings. In the drawings:

Fig. 1 is a schematic wiring diagram of a preferred embodiment of the invention;

Figs. 2 through 5 are schematic wiring diagrams of alternative embodiments;

Fig. 6 illustrates a modification of a portion of the circuit arrangement shown in Fig. 5;

Fig. 7 illustrates a sensitivity selection arrangement applicable to the embodiments of Figs. 1 and 2; and

Fig. 8 is a schematic wiring diagram of a further modified form of the invention.

Referring first to Fig. 1, the invention control arrangement is illustrated as applied to apparatus for electric field heating of dielectric material 10 which may be a thermoplastic. The electric field is applied to material 10 by spaced, cooperable electrodes 11 and 12 supplied with H. F. energy from an R. F. oscillator generally indicated at 15. Portions of the oscillator 15 not necessary to an understanding of the invention have been omitted to simplify and clarify the illustration. Thus, the connection 13 of electrode 11 to the oscillator output is shown as a partially broken line tapping into another partially broken line 14 representing non-illustrated conventional output components of oscillator 15. Electrode 12 is grounded.

The oscillator includes a valve 20 whose plate voltage is supplied from D. C. power supply 16 having the D. C. output polarities indicated. Power supply 16 may be a battery, but is preferably a rectifier and filter unit supplied with A. C. potentials from secondary winding PTS–1 of plate transformer PT whose primary winding PTP is connected in an A. C. supply circuit derived from terminals 17. Plate transformer PT has other secondary windings for other power supplies referred to hereinafter.

The filament heating voltage for valve 20 is supplied by a secondary winding FTS–1 of a filament heating transformer FT having its primary winding FTP connected across the A. C. power supply in multiple with winding PTP. Primary windings PTP and FTP are energized whenever a main control switch 18 is closed.

In the embodiment of Fig. 1, the invention control arrangement includes an amplifier valve or tube 30 in series with the grid-cathode circuit of oscillator tube 20, and a pair of grid-controlled, gaseous conduction tubes or valves 40 and 50. The filaments of these three tubes are heated from secondary windings FTS–2, FTS–3, and FTS–4 of filament transformer FT. Alternatively, the filament heating currents may be battery supplied, in these tubes as well as in tube 20. Several D. C. power supplies, such as 21 through 25 are included in the control arrangement, with polarities as indicated. These power supplies may be batteries but preferably are rectifier filter units receiving A. C. input potentials from secondary windings PTS–2 through PTS–6 of plate transformer PT. Alternatively, power supply 25 may be a charged capacitor.

When control switch 18 is closed, power is applied to all the heating filaments and to all bias medium and high voltage power supplies, through energization of transformers PT and FT. Valves 40 and 50 are maintained in non-conducting condition by bias power supplies 22

and 24, respectively, whereas amplifier tube 30 is maintained in a state of low conductivity by medium voltage power supply 21 connected between its grid and cathode in series with limiting resistor 27. This is the condition of the apparatus during stand-by periods after main switch 18 has been closed but before "start" button 28 is depressed.

When start button 28 is depressed, relay 35 is picked up through the normally closed contacts 35*a* of a relay 45 in shunt with resistor 27. Relay 35 closes its contacts 45*a*, completing a holding circuit in shunt with button 28 so that relay 35 remains energized even if button 28 is released. Relay 35 also closes its contacts 35*b* to apply plate power to oscillator tube 20, and 35*c* to connect relay 45 from grid to cathode of tube 30.

With the closing of contacts 35*b*, tube 20 is ready to oscillate when the D. C. potential difference and the total grid circuit resistance between its grid and cathode are of the correct magnitude. At the same time, the connection of the coil of relay 45 greatly reduces the grid circuit resistance, and thus the voltage between the grid and cathode of tube 30 drops to a negligible value. This increases the conductivity of tube 30, thus reducing the resistance of the grid circuit of oscillator tube 20 so that the latter begins to oscillate at full power. Closing of contacts 35*c* also applies plate potential to tube 40 so that the latter is ready to conduct when it is triggered.

The generated R. F. energy is now applied to material 10 through electrodes 11 and 12. At the same time, a D. C. "sensing" potential is applied across the electrodes and material 10 from power supply 25. This power supply ordinarily forces a negligible current through the circuit comprising material 10, electrodes 11, 12, R. F. filter 31, limiting resistor 32, power supply 25, variable resistance 33, and power supply 24 to ground.

Resistance 33 is adjusted to a value such that, during the normal heating cycle, the voltage drops across this resistance, and thus the grid voltage of tube or valve 50, is small enough that tube 50 remains non-conductive. However, the adjusted value of resistance 33 is high enough that tube 50 will be triggered when material 10 has been heated at least to the proper temperature, becoming thus more conductive, or when the conductivity between electrodes 11, 12 reaches a value higher than normal for any other reason. When the instantaneous value of conductivity between electrodes 11, 12 reaches the predetermined value, the voltage drop across resistance 33 is of sufficient magnitude and correct polarity to trigger tube 50 to the conductive state.

When tube 50 is triggered to conductivity, it effectively grounds the positive terminal of power supply 23. A current then flows from ground to the anode of tube 30, through the cathode thereof, primary winding 55 P of transformer 55, power supply 23, and tube 50 to ground. Most of the voltage of supply 23 appears across tube 30 as the resistance of the latter, under the operating voltage selected, is much greater than the sum of all other impedance components in series in the above circuit. As the grid circuit of oscillator tube 20 is in shunt with tube 30, the voltage drop across tube 30 appears between the grid and cathode of tube 20.

This drop, when tube 50 is conductive, is of sufficient magnitude and correct polarity to interrupt the flow of anode current in tube 20 and thus stop oscillations of the latter. Thus, the application of H. F. energy to material 10 is interrupted, preventing or minimizing arcing, sparking, or overheating of electrodes 11, 12.

The sudden flow of current through primary winding 55 P of transformer 55 induces a voltage pulse in secondary winding 55 S. The magnitude and polarity of this voltage pulse are such as to trigger tube 40 to conductivity. Current thus flows from power supply 21 through relay 45, contact 35*c*, and tube 40. The relatively heavy current flow through relay 45 produces a grid voltage in tube 30 of sufficient magnitude and proper polarity to reduce the conductivity of tube 30 to a negligible value, thus reducing the drain on power supply 23. This reduction permits use of a small power supply for 23, it being designed for intermittent duty only. Also, the short duty cycle of tube 30, when tube 40 is conductive, permits use of a relatively small tube.

Under the aforementioned heavy current flow, relay 45 is energized sufficiently to open its normally closed contacts, 45*a* and 45*b*, to break the holding circuit of relay 35 and to stop current flow through tube 20. Relay 35 drops to open its contacts 35*a*, 35*b* and 35*c*, removing the shunt around "start" button 28, disconnecting anode power from tube 20, and dropping relay 45. This restores the circuit to its normal "stand-by" condition pending a reclosing of button 28, with contacts 45*a* and 45*b* again re-closed.

The R. F. filter 31 prevents conduction of R. F. components into the sensing and control circuits. This filter is designed to have negligible series resistance in the sensing circuit and negligible conductance in shunt with electrodes 11, 12. The filter may comprise one filter or several filters in cascade, either of the same or differing types such as "low-pass," "band-reject," etc., and employing various combinations of resistance, capacitance and inductance. Resistor 32 limits the drain on supply 25 and minimizes shock hazard to personnel during stand-by periods.

In the arrangement of Fig. 2, parts the same as those in Fig. 1 have been given the same reference characters. Resistor 36 is the grid resistor of oscillator tube 20. When tube 50 is triggered to conductivity by the sensing circuit, current flows from ground through relay 45, resistor 36, R. F. filter 37, power supply 23, contacts 45*b*, and tube 50 to ground. As the total resistance of relay 45 and resistor 36 is much greater than that of the rest of this circuit, most of the voltage of supply 23 appears across the 36—45 series combination. As this combination is in shunt with the grid circuit of tube 20, the voltage thereacross is of the correct magnitude and polarity to cut off anode current through tube 20 and thus interrupt its oscillations.

Relay 45, when energized, opens its contacts 45*a* and 45*b* to drop relay 35 and interrupt plate power to tube 50. In turn, relay 35 opens its contacts 35*a*, and 35*b*, breaking the shunt for button 28 and cutting plate power from tube 20. Relay 45 drops to re-close contacts 45*a* and 45*b*, restoring the circuit to stand-by condition.

Filter 37 minimizes transmission of R. F. into the circuit of tube 50, thereby preventing unintentional ionization of this tube, which latter would cause erratic operation.

Figure 3 illustrates an arrangement employing only vacuum tubes or valves, vacuum tube 60 being substituted for "thyratron" 50. Circuit components similar to or identical with those of Fig. 1 have been given the same reference characters.

In this arrangement, the grid-cathode voltage of tube 60 is the algebraic sum of the potentials of power supplies 24 and 41, and the voltage drops across resistance 33, power supply 41 being similar to the other power supplies. Normally, a high net negative grid-cathode voltage is applied, resulting in a low state of conductivity of tube 60.

When the conductivity of material 10 reaches a high enough value, consistent with the setting of resistance 33, the potential difference between the grid and cathode of tube 60 drops and the tube conductivity increases. This results in increased current flow from ground through relay 45, grid resistor 36, tube 60, and power supply 41 to ground. The voltage drop across 36—45 is of correct polarity and magnitude to reduce the anode current of oscillator tube 20 to substantially reduce the intensity of its oscillations.

By proper selection of circuit components, the intensity of the oscillations relative to the inter-electrode con-

ductivity may be controlled between any predetermined limits from full output to zero output. Furthermore, since the current in relay 45 varies with the inter-electrode conductivity, this relay, through operation of its contacts 45*a* controlling relay 35 and its contacts 35*b*, can be adjusted to interrupt plate power for oscillator tube 20 either for only very high interelectrode conductivities or for specific conductivity levels, in the latter case acting as a process timer. For certain types of operations, relay 45 may be shunted by closing switch 42.

The starting of this arrangement is generally similar to that of Fig. 1. Relay 35 has additional active contacts 35*d* which open, when relay 35 is picked up, to remove the blocking voltage from the grid of tube 20 as contacts 35*c* are closed to connect the 36—45 series combination in the grid circuit. When relay 45 is sufficiently energized to open contacts 45*a*, relay 35 is dropped. This circuit has the advantage of preventing flow of oscillator plate current if the initial inter-electrode conductivity is too high.

Fig. 4 illustrates a modification of the Fig. 3 arrangement, including an additional stage of amplification, and a relocation and a polarity re-orientation of the power supplies to obtain, on the grid of oscillator tube 20, a grid voltage which increases in the negative direction with an increase in the inter-electrode conductivity.

This circuit operates in the same manner as that of Fig. 3 when "start" button 28 is depressed. Normally, power supply 41 keeps the oscillator grid voltage sufficiently negative to block the flow of oscillator plate current when contacts 35*b* are closed. Vacuum tube amplifier 70 has a zero grid bias and is thus normally highly conductive, resulting in current flow from power supply 41 through resistor 43 and tube 70. The drop across resistance 43 is of the correct magnitude and polarity to maintain tube 60 non-conductive. Since there is thus no current flow from supply 23 through the 36—45 series combination, tube 20 has no grid bias voltage applied thereto, when relay 35 opens its contacts 35*d* and closes contacts 35*c*, and tube 20 begins to oscillate.

As the inter-electrode conductivity increases, power supplies 25 and 41 add algebraically to increase the drop across resistor 33 in the direction of correct magnitude and polarity to reduce the conductivity of tube 70. The reduced current flow through resistance 43 decreases the grid-cathode voltage of tube 60, increasing the plate current therethrough. This increases the drop across the 36—45 series combination and thus the grid voltage of oscillator tube 20, thereby reducing the oscillation intensity of the latter. As tubes 70 and 60 are amplifiers, the circuit of Fig. 4 is more sensitive than that of Fig. 3.

The arrangement of Fig. 5 is a modification of the circuit of Fig. 4, with power supply 23 re-located and contacts 35*d* connected to this power supply rather than to power supply 41.

The arrangement of Fig. 6 is a modification of the circuit of Fig. 5, differing in the addition of an additional vacuum type amplifier tube 80 preceding amplifier 70. Tube 80 is normally in the low conductivity state because of the bias voltage from power supply 24. When current flows through resistance 33, the voltage drop increases the conductivity of tube 80. The voltage drop across resistor 44 thus increases, decreasing the plate current of tube 70. The remainder of the circuit functions in the same manner as that of Fig. 5.

Fig. 7 illustrates a means of obtaining either high or low sensitivity by a double pole, double throw shunting switch 46 connected to selectively shunt power supply 25. This arrangement may be incorporated in either the circuit of Fig. 1 or that of Fig. 5. In the position of switch 46 connecting power supply 25 into the circuit, sensitivity is determined by power supplies 24 and 25 aiding each other. In the shunting position of switch 46, only power supply 24 is effective, and the sensitivity is reduced.

Fig. 8 illustrates a further embodiment of the invention in which an amplifier tube 100 is connected in series with the grid resistor 51 of oscillator tube 20 so that the normal grid current path is from the grid through resistor 51 and tube 100 to ground. An amplifier tube 90 is so connected that current flows from power supply 47 through tube 90, ground, tube 100, and resistor 52. As tube 70 is normally conductive, a voltage drop appears across relay 45 biasing tube 90 to the plate current cut-off condition.

When the inter-electrode conductivity increases, the voltage drop across resistance 33 decreases the negative grid-cathode potential of tube 80, permitting more current to flow through resistor 44 so that the grid of tube 70 becomes negative relative to its cathode. The current through relay 45 decreases, and tube 90 begins to conduct so that current flows through resistor 52. Thus, the grid of tube 100 becomes relatively negative.

The conduction of tube 90 effectively grounds the positive terminal supply 47 and applies a negative potential to the oscillator tube grid. If the inter-electrode conductivity is sufficiently high, tube 90 will have a low enough resistance so that most of the voltage of supply 47 will appear across tube 100. As the oscillator grid circuit is in parallel with tube 100, tube 20 will be biased to cut-off and oscillations will cease.

Resistor 52 and capacitor 53 have a unique function. If the change in inter-electrode conductivity is very rapid, tube 90 is made conductive at a corresponding rate. Current flows from ground through tube 100, capacitor 53 (by passing resistor 52), power supply 47, and tube 90 to ground. The current through tube 100 will be relatively large. When capacitor 53 begins to charge, current flows through resistor 52 producing a voltage drop reducing the conductivity of tube 100. The advantage is that power supply 47 and tube 90 may be designed for an average D. C. flow much smaller than the peak D. C. flow delivered. Capacitor 54, in conjunction with resistor 51, provides an R. F. filter for the control circuit.

The invention arrangements may be used for other applications such as a rapidly acting thermostat controlling the temperature of a material being heated, a rapidly acting control switch responsive to selected values of the sensing circuit current, and a rapidly acting thermostat with the sensing current acting as the heating current.

While specific embodiments of the invention have been shown and described in detail to illustrate the application of the invention principles, it will be understood that the invention may be embodied otherwise without departing from such principles.

What is claimed is:

1. A control arrangement for electric heating apparatus comprising, in combination, an R. F. oscillator; control means including a triode connected in the grid-cathode circuit of said oscillator, and relay means, selectively operable to apply an operating grid potential to said oscillator and anode potential thereto; spaced electrode means connected to the output of said oscillator for applying H. F. energy therefrom to a material to be heated; a sensing circuit, including a source of D. C. power, operable to apply a relatively small D. C. potential across said electrode means to measure the inter-electrode conductivity; normally non-conductive valve means rendered conductive, responsive to current flow of a predetermined magnitude in said sensing circuit, to condition said triode to vary the oscillator grid potential to reduce the oscillator output; and means, including said valve means when conductive, effective immediately thereafter to operate said relay means to interrupt the supply of anode potential to said oscillator.

2. A control arrangement for electric heating apparatus comprising, in combination, an R. F. oscillator; control means including a triode connected in the grid-cathode

circuit of said oscillator, and relay means, selectively operable to apply an operating grid potential to said oscillator and anode potential thereto; spaced electrode means connected to the output of said oscillator for applying H. F. energy therefrom to a material to be heated; a sensing circuit, including a source of D. C. power, operable to apply a relatively small D. C. potential across said electrode means to measure the inter-electrode conductivity; normally non-conductive valve means rendered conductive, responsive to current flow of a predetermined magnitude in said sensing circuit, to vary the oscillator grid potential to reduce the oscillator output; and other normally non-conductive valve means rendered conductive, responsive to conduction of said first-named valve means, to operate said relay means to interrupt the supply of anode potential to said oscillator.

3. A control arrangement for electric heating apparatus comprising, in combination, an R. F. oscillator; control means, including a triode connected in the grid-cathode circuit of said oscillator and interlocking relay means, selectively operable to apply an operating grid potential to said oscillator and anode potential thereto; said interlocking relay means including a first relay having an energizing circuit controlled by a second relay and a normally open switch in a holding circuit for said second relay, said second relay having a normally open switch controlling the supply of anode potential to said oscillator spaced electrode means connected to the output of said oscillator for applying H. F. energy therefrom to a material to be heated; a sensing circuit, including a source of D. C. power, operable to apply a relatively small D. C. potential across said electrode means to measure the inter-electrode conductivity; and normally non-conductive valve means rendered conductive, responsive to current flow of a predetermined magnitude in said sensing circuit, to vary the oscillator grid potential to reduce the oscillator output, and to de-energize said first relay to open the holding circuit for said second relay to deenergize the latter to interrupt the supply of anode potential to said oscillator.

4. An arrangement as claimed in claim 3 in which said triode comprises an amplifier in parallel with the oscillator grid circuit and having its conductivity controlled by flow of current in said sensing circuit.

5. A control arrangement for electric heating apparatus comprising, in combination, an R. F. oscillator; control means, including first relay means, selectively operable to apply an operating grid potential to said oscillator and anode potential thereto; spaced electrode means connected to the output of said oscillator for applying H. F. energy therefrom to a material to be heated; a sensing circuit, including a source of D. C. power, operable to apply a relatively small D. C. potential across said electrode means to measure the inter-electrode conductivity; electronic valve means operable, responsive to current flow of a predetermined magnitude in said sensing circuit, to vary the oscillator grid potential to reduce the oscillator output; and second relay means operable, responsive to operation of said first-named relay means, to interrupt the supply of anode potential to said oscillator; said electronic valve means including an amplifier in parallel with the oscillator grid circuit and a gaseous conduction tube controlling

conductivity of said amplifier; such current flow in said sensing circuit triggering said tube.

6. A control arrangement for electric heating apparatus comprising, in combination, an R. F. oscillator; control means, including first relay means, selectively operable to apply an operating grid potential to said oscillator and anode potential thereto; spaced electrode means connected to the output of said oscillator for applying H. F. energy therefrom to a material to be heated; a sensing circuit, including a source of D. C. power, operable to apply a relatively small D. C. potential across said electrode means to measure the inter-electrode conductivity; electronic valve means operable, responsive to current flow of a predetermined magnitude in said sensing circuit, to vary the oscillator grid potential to reduce the oscillator output; and second relay means operable, responsive to operation of said first-named relay means, to interrupt the supply of anode potential to said oscillator; said electronic valve means including an amplifier in parallel with the oscillator grid circuit and a gaseous conduction tube controlling conductivity of said amplifier; such current flow in said sensing circuit triggering said tube; said second relay means interrupting flow of current through said amplifier and said tube to de-activate the arrangement.

7. A control arrangement for electric heating apparatus comprising, in combination, an R. F. oscillator; control means, including first relay means, selectively operable to apply an operating grid potential to said oscillator and anode potential thereto; spaced electrode means connected to the output of said oscillator for applying H. F. energy therefrom to a material to be heated; a sensing circuit, including a source of D. C. power, operable to apply a relatively small D. C. potential across said electrode means to measure the inter-electrode conductivity; electronic valve means operable, responsive to current flow of a predetermined magnitude in said sensing circuit, to vary the oscillator grid potntial to reduce the oscillator output; and second relay means operable, responsive to operation of said first-named relay means, to interrupt the supply of anode potential to said oscillator; said electronic valve means including an amplifier in parallel with the oscillator grid circuit and a gaseous conduction tube controlling conductivity of said amplifier; and an adjustable resistance in said sensing circuit in parallel with the control grid circuit of said tube, the voltage drop across said resistance determining triggering of said tube.

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