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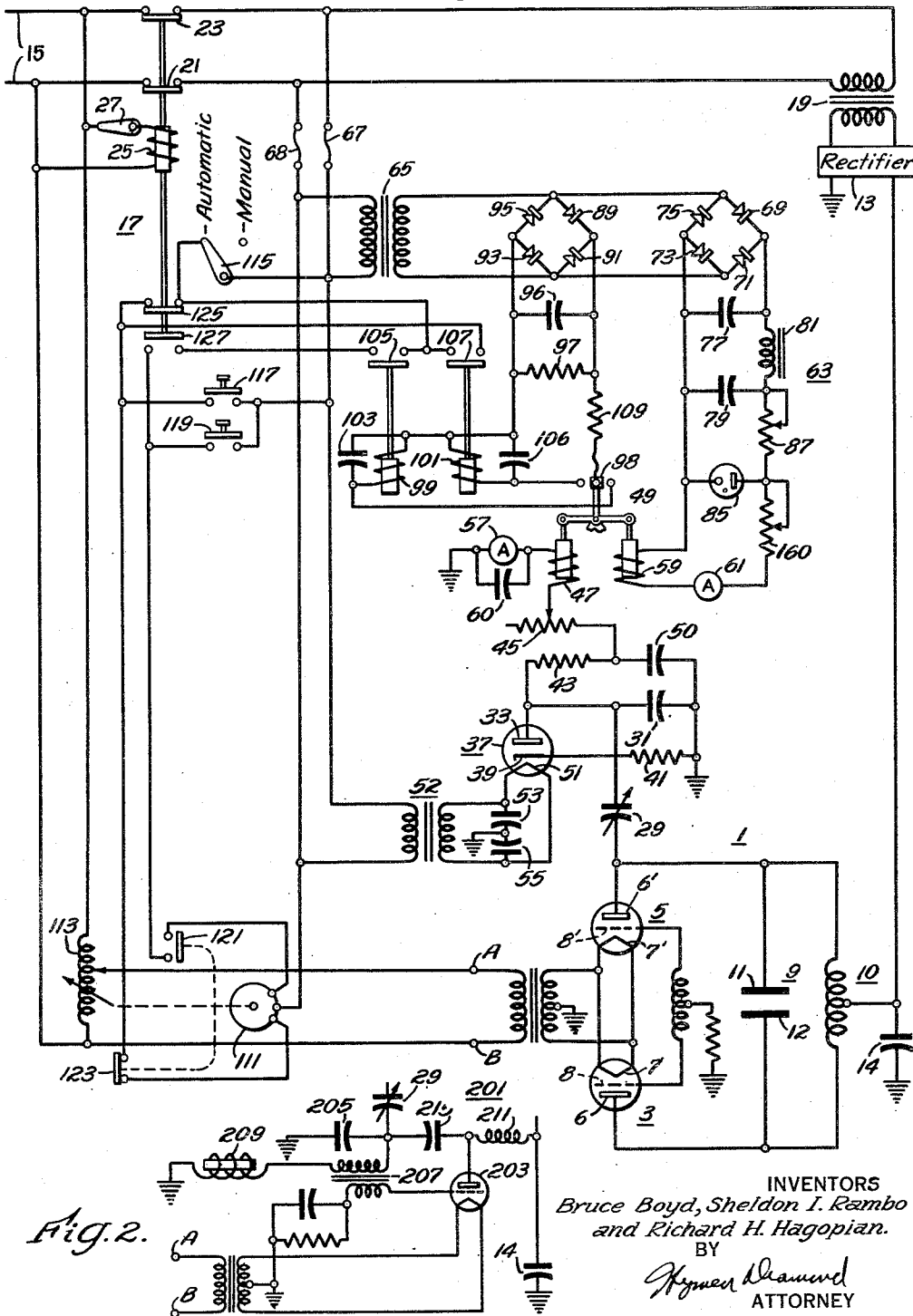
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# RADIO FREQUENCY GENERATOR

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*Fig. 1.*



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## RADIO FREQUENCY GENERATOR

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Our invention relates to high-frequency generators, and more particularly to high-frequency generators for use with induction and dielectric heating apparatus.

In apparatus constructed in accordance with the prior art, an attempt was made to maintain the power density, that is the power per unit volume, in the high-frequency load constant regardless of load magnitudes with a stabilizing system including a saturable reactor or a controlled induction regulator. Either system is costly and the latter is slow in responding. Because of the high cost of the stabilizing high-frequency heating apparatus of the prior art requiring stabilization is frequently not competitive with heating apparatus of other types. The lag in the response is an additional handicap; because of it the material to be heated, for example, a batch of raw rubber or gears under heat treatment, may be scrapped because of burning or underheating. In these days of material shortage such a mishap is a serious matter.

Apparatus typical of the prior art is shown in United States Patent No. 2,175,694. In apparatus shown in this patent, the power output of an RF generator is controlled from a thyatron which responds to a signal derived from the generator. This signal is proportional to the output current of the generator. However, the apparatus disclosed in the above cited patent is not entirely effective in that it responds only to an increase above a pre-set level and in particular the arrangement shown and described is not applicable where dielectric loads are treated.

It is, accordingly, an object of our invention to provide low cost apparatus for maintaining the power density in the load constant regardless of variations in load magnitude insofar as the power density is affected by a change in the applied voltage; that is, the high-frequency generator controlled as herein described is a constant voltage source (has zero regulation). Consequently, the network adjustments necessary to obtain the desired constant power density can be more easily made. Obviously, when a power density is desired which is not constant but varies as a function of load magnitude or characteristic of the material, the network adjustments can also be more readily made.

A further object of our invention is to provide apparatus, which shall have a rapid response, for maintaining the power density in the load constant regardless of variations in load magnitude insofar as the power density is affected by a change in the applied voltage.

A still further object of our invention is to provide apparatus that shall maintain the RF tank voltage of a high-frequency generator constant.

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Still another object of our invention is to provide dielectric heating apparatus that shall maintain the RF tank voltage of the high-frequency generator constant with wide variations in quantity and characteristics of the material being heated.

Still another object of our invention is to provide induction heating apparatus that shall prevent the RF tank voltage and, hence, oscillator grid current from increasing beyond a pre-set maximum.

Still a further object of our invention is to provide dielectric heating apparatus that shall simultaneously maintain the power density of the load, the material under treatment, constant regardless of variations in load magnitude, insofar as the power density is affected by a change in the applied voltage, and the RF tank voltage of the high-frequency generator constant with wide variations in quantity and characteristics of the material being heated.

Another object of our invention is to provide apparatus including an RF generator which shall automatically reduce the voltage adjustment of the generator to a minimum value when the power is removed from the generator.

Another object is to provide a means for operating the cathode of the oscillating tube or tubes at a minimum voltage consistent with the power demand at any given time, so as to secure a much longer life for the oscillating tube or tubes than if the cathode were maintained constant at full voltage.

Another object is to provide a means for maintaining the RF tank voltage of an HF generator constant with normal variations in the supply voltage to the generator.

Our invention arises from the realization of a need for a system to protect the generating apparatus from changes in voltage due to load or power supply variations, such systems being responsive to either increase or decrease in voltage. The system of the above cited patent is not effective because it responds only to decreases in the power load.

In accordance with our invention, we provide an RF heating system in which the power density is maintained constant, insofar as the power density is affected by a change in the applied voltages, by controlling the RF generator in accordance with the resultant derived by algebraically subtracting a signal from the RF heater from a standard signal. In dielectric heating systems, the signal is proportional to the voltage of the RF generator, and the effect of the stabilization is to maintain this voltage constant.

In the specific practice of our invention, the signal voltage rectified appears at one of the windings of the polarized relay and opposes the

standard on the other winding. Any unbalancing as a result of variation in load, for example, softening of the material or adding or removing material, causes a voltage regulator to restore the RF tank voltage to the initial value. Thus, the power density in the load, the material under treatment, will remain constant regardless of variations in load magnitude, insofar as the power density is affected by a change in the applied voltage.

Apparatus is provided for automatically reducing the control voltage of the generator to a minimum value when the main power source to the generator is removed. This apparatus is provided so that the generator may be started up at reduced voltage since the load presented to the generator at the start may be unknown.

The novel features that we consider characteristic of our invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation, together with additional objects and advantages thereof, will be understood from the following description of specific embodiments thereof when read in connection with the accompanying drawing, in which:

Figure 1 is a schematic diagram of apparatus and circuits embodying our invention as applied to dielectric heating; and

Figure 2 is a schematic diagram of apparatus and circuits embodying our invention as applied to induction heating.

Referring to Figure 1 the apparatus comprises a generator 1 which, as specifically shown, is an RF generator having two oscillator tubes 3 and 5. These oscillator tubes have anodes 6 and 6', cathodes 7 and 7', and control electrodes 8 and 8'. The RF generator 1 has a plate tank circuit consisting of a capacitor 9 and an inductance coil 10. Capacitor 9 has two electrodes 11 and 12 through which the materials under treatment are passed. These electrodes may also be a part of a remote circuit coupled, by means known to those skilled in the art, to the oscillating tank circuit 9, 10. The oscillator tubes 3 and 5 receive their plate voltage from a rectifier 13, one of the connections from the rectifier 13 being tapped onto the inductance coil 10. A capacitor 14 is connected to this same tap on the inductance coil 10, the other side of the capacitor 14 being grounded. The rectifier 13 is fed from an A.-C. source 15 through a circuit breaker 17 and a transformer 19. This circuit breaker 17 has contacts 21 and 23, a coil 25, and an on-off switch 27.

There is a connection from the junction of the capacitor 9 and the inductance coil 10 to an adjustable capacitor 29. There is also a connection from the other side of the adjustable capacitor 29 to a fixed capacitor 31. The junction of the adjustable capacitor 29 and the fixed capacitor 31 is connected to the anode 33 of a rectifier tube 37. The adjustable capacitor 29 and the fixed capacitor 31 serve as a voltage divider for sampling the RF tank voltage. One side of the fixed capacitor 31 is grounded and there is a connection from this ground side to the rectifier tube cathode 39 through a current-limiting resistor 41. Resistors 43 and 45 are connected between the anode 33 of the rectifier tube 37 and winding 47 of the polarized relay 49. Capacitor 50 by-passes resistor 45 and the winding 47 of the polarized relay 49 for RF voltage. The filament 51 of the rectifier tube 37 is supplied by a transformer 52 and is by-passed for RF

voltage by two capacitors 53 and 55. The transformer 52 receives its power from the A.-C. source 15. One end of the winding 47 of the polarized relay 49 is connected to the junction of the resistor 43 and the capacitor 50 through a variable resistor 45, and the other end of the winding 47 is connected to an ammeter 57. The other end of the ammeter 57 is connected to ground. This ammeter 57 gives an indication of relative RF tank voltage or can be calibrated to read RF tank voltage directly. The ammeter 57 is paralleled by a capacitor 60. The RF tank voltage required for the treatment of different materials varies. The variable resistor 45 is provided so that the voltages on the windings 47 and 59 of the polarized relay 49 can be balanced for several different tank voltages. A variable current-limiting resistor 160, in series with the winding 59, secures a fine adjustment of the voltage across winding 59. Thus, any desired RF tank voltage can be obtained and at the same time have the voltages on the windings 47 and 59 of equal magnitude with the polarized relay 49 in the neutral position shown in the drawing. In this manner, the desired power density in the material under treatment can be obtained. To aid in the actual balancing of the voltages on the windings 47 and 59 of the polarized relay 49, an ammeter 61, in series with the winding 59, is provided. Thus, the voltages on the windings 47 and 59 can be adjusted until the readings on ammeters 57 and 60 are equal.

The other winding 59 of the polarized relay 49 is supplied from a regulated rectifier supply 63 which furnishes a constant voltage. This regulated rectifier supply 63 receives its energy from a transformer 65 which is connected to the A.-C. source 15 through fuses 67 and 68. Selenium rectifier units 69, 71, 73 and 75 form a bridge rectifier circuit whose output is filtered by a Pi-network consisting of capacitors 77 and 79 and an inductor 81. The current-limiting resistor 160 is in series with the winding 59 of the polarized relay 49. In parallel with this resistor 160 and the winding 59 of the polarized relay 49 is a voltage regulator tube 85. This tube 85 maintains a constant voltage across itself for wide changes in line voltage. In series with the current-limiting resistor 160 is a voltage regulating resistor 87.

A group of selenium rectifier units 89, 91, 93 and 95 form a bridge rectifier circuit having its input connected to the transformer 65. The output of this rectifier is filtered by a capacitor 96, and a bleeder resistor 97 is in parallel with this capacitor 96. The contact arm 98 of the polarized relay 49 is adapted to complete the circuit from the bleeder resistor 97 and the selenium rectifier units 89, 91, 93 and 95 to the motor control relay coils 99 and 101. These two coils 99 and 101 are paralleled by capacitors 103 and 106, respectively. Capacitors 103 and 106 are used for spark suppression on the contacts of relay 49. A current-limiting resistor 109 is in series with the motor relay coils 99 and 101 when the circuit to these coils is completed.

The contacts 105 and 107 for the motor relay coils 99 and 101 control the direction of rotation of a reversible motor 111 which operates a variable auto-transformer 113, which in turn adjusts the filament voltage of oscillator tubes 3 and 5. Instead of using a variable auto-transformer 113, an induction regulator could be used, the motor 111 forming a part of the induction regulator.

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A manual-automatic switch 115 is in the circuit with the motor 111 and when in the position shown the RF tank voltage of the RF generator 1 is kept constant automatically. When the switch 115 is in the opposite position, the filament voltage and, hence, the RF tank voltage of the RF generator 1 can be either raised or lowered by means of the two manual switches 117 and 119. The motor 111 is provided with motor limit switches 121 and 123.

It is desirable to start up the RF generator 1 at a reduced output voltage since the load presented to the RF generator 1 at the start may be unknown. This is accomplished automatically by providing auxiliary contacts 125 and 127 on the circuit breaker 17. In the specific apparatus shown, the auxiliary contacts 125 and 127 are connected in the circuit so as to return the filament voltage on the oscillator tubes 3 and 5 to a minimum when the plate power to the RF generator 1 is removed. The contacts 125 and 127 are shown in the plate power on position.

The operation of equipment shown in Figure 1 is as follows:

Assume that the RF generator 1 has been adjusted to give its maximum rated output into a particular load. The adjustable capacitor 29 is adjusted to just balance the voltage on the winding 47 of the polarized relay 49 against the voltage on the other winding 59 of the polarized relay 49 which is supplied from a constant source of voltage. The variable resistor 45 can be adjusted so that the voltages on windings 47 and 59 can be balanced for different values of output of RF generator 1. The variable current-limiting resistor 160 can be adjusted to give the desired voltage on the winding 59, thus giving a further means of balancing these two voltages. When relay 49 is balanced, the motor relay contacts 105 and 107 will be in the position shown, and the motor 111 will not run.

Now suppose that the load presented to the RF generator 1 is reduced such as would be the case if a smaller piece of material passed between the electrodes 11 and 12 or the dielectric value of the load during treatment changed. The reduction of load causes the RF tank voltage to rise. Hence, a larger RF voltage appears across the rectifier tube 37 causing more direct current to flow through the winding 47 of the polarized relay 49. Thus, the polarized relay 49 is unbalanced in the left-hand position completing a circuit for the motor relay coil 101 which when energized closes its contact 107. This completes the power supply circuit to the motor 111 so that it rotates in a direction to reduce the filament voltage on the oscillator tubes 3 and 5. This reduction in filament voltage lowers the RF tank voltage. As soon as the tank voltage is reduced to the value which it had at the original maximum rated output, the polarized relay 49 again balances causing the motor 111 to cease reducing filament voltage. It can be readily seen that if the load is increased, resulting in a decrease in the RF tank voltage, the opposite motor relay coil 99 will be energized by operation of the polarized relay 49 to cause the motor regulator 111-113 to increase the filament voltage to thereby increase and restore the RF tank voltage to the original value.

The RF generator 1 is started up at reduced filament voltage on the oscillator tubes 3 and 5. This is accomplished by the auxiliary contacts 125 and 127 which, as soon as plate power is removed take up a position opposite from that shown

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which represents the position of the auxiliary contacts when plate power is on. When these contacts take up this opposite position from that when plate power is on, the motor 111 will be energized so as to reduce the filament voltage on the oscillator tubes 3 and 5 to a minimum.

These auxiliary contacts 125 and 127 are necessary since without them the filament voltage on the oscillator tubes 3 and 5 would be increased to a maximum as soon as the plate power was removed from the RF generator 1 since the rectifier tube 37 would be receiving no RF voltage and would signal the motor 111 to call for more filament voltage for the oscillator tubes 3 and 5. With these auxiliary contacts 125 and 127, the RF generator 1, having once been set for the desired RF output voltage, may be turned on regardless of load conditions and will automatically regulate its tank voltage to suit the load presented to it.

Referring to Figure 2, this figure replaces the RF generator 1 in Figure 1, all other parts of this circuit remaining as shown in Figure 1, and illustrates the case where an RF generator is applied to induction heating. This arrangement comprises a generator 201 and is specifically shown as an RF generator having an oscillator tube 203. The RF generator 201 has a plate tank circuit consisting of a capacitor 205 and an inductance coil 207. In series with coil 207 is an applicator coil 209 wherein the material to be inductively heated is placed. The oscillator tube 203 receives its plate voltage from a rectifier 13 as shown in Figure 1. One of the connections from the rectifier 13 is connected to the plate RF choke 211 and is by-passed by capacitor 14 as in Figure 1. The anode of the oscillator tube 203 is coupled to the tank circuit by capacitor 215. There is a connection from capacitor 205 and the inductance coil 207 to an adjustable capacitor 29 as shown in Figure 1.

The operation of the equipment shown in Figure 2 is essentially the same as described for Figure 1 except that variations in the tank voltage are produced by variations in the amount or characteristics of the material in the applicator coil 209 instead of variations in the material between the dielectric heating electrodes 11 and 12 in Figure 1.

It is to be understood by those skilled in the art that any conventional HF generator or oscillator could be used in the place of the one shown in the drawing.

It is also to be understood by those skilled in the art that some aspects of our invention may be applied to low-frequency generators.

It is to be further understood by those skilled in the art that an induction regulator could be used in the place of the auto-transformer 113 shown. The motor 111 and induction regulator could form one unit. Also other equipment could be used for furnishing the standard reference voltage.

In the specific embodiment of our invention, the auto-transformer 113 varies the filament or cathode voltage on the oscillator tubes 3 and 5. However, it is to be understood by those skilled in the art that the control voltage could be applied to any of the other elements of the oscillator tubes such as the anode, or control electrode.

Although we have shown and described certain specific embodiments of our invention, we are fully aware that many modifications thereof are possible. Our invention, therefore, is not to be restricted except insofar as is necessitated by the prior art and by the spirit of the appended claims.

We claim as our invention:

1. The combination of a high frequency generator having at least one oscillator tube having a control voltage applied thereto and adapted to supply a load voltage, means for maintaining a constant reference voltage, means for opposing said voltage by a voltage proportional to the said load voltage of said high frequency generator, and means responsive to the resultant of said opposed voltages for controlling the output of said high frequency generator by varying said control voltage.

2. The combination of a high frequency generator adapted to supply a load voltage and comprising at least one oscillator tube having a control voltage applied thereto, a polarized relay having at least two windings, means for applying a constant reference voltage on one of said windings, means including a rectifier for applying an opposing voltage on the other said winding which is proportional to the said load voltage of said high frequency generator, and means responsive to the resultant of said opposed voltages for controlling the output of said high frequency generator by varying said control voltage.

3. The combination of a high frequency generator comprising at least one oscillator tube having a control voltage applied thereto, a plate power supply for said high frequency generator, a voltage control device whose output controls said control voltage, and means for returning the output of said voltage control device to a minimum value when said plate power supply is removed.

4. The combination of a high frequency generator comprising at least one oscillator tube having a control voltage applied thereto, a plate power supply for said high frequency generator, a main breaker in said plate power supply line, a voltage control device for controlling said control voltage, and means for returning the output of said control device to a minimum value when said plate power supply is removed, said means comprising a reversible motor for operating said voltage control device, and auxiliary contacts on said breaker, said contacts being in circuit with said reversible motor.

5. The combination of a high frequency generator adapted to supply a voltage to a load and comprising at least one oscillator tube having a control voltage applied thereto, a plate power supply for said high frequency generator, means for maintaining a constant reference voltage, means for producing a rectified voltage proportional to the voltage supplied to said load, means responsive to the resultant of said last-mentioned two voltages for controlling the output of said high frequency generator, and means for returning said control voltage to a minimum value when said plate power supply is removed.

6. In dielectric heating apparatus the combination of a high frequency generator adapted for connection to a load and comprising at least one oscillator tube having a control voltage applied thereto, an radio frequency tank circuit for said generator, said tank circuit comprising electrodes for passing the material under treatment there-through, means for maintaining a constant reference voltage, means for producing a rectified voltage proportional to the voltage applied to said load of said high frequency generator, and means responsive to the resultant of said last-mentioned two voltages for maintaining the radio frequency tank voltage of said high frequency generator constant by varying said control voltage.

7. The combination of a high frequency generator adapted to supply a load voltage and having at least one oscillator tube having a control voltage applied thereto, means for rectifying a portion of the output of said high frequency generator, means for varying the magnitude of said rectified output, means for maintaining a constant reference voltage, said last-mentioned means including means for making said reference voltage adjustable, means for opposing said reference voltage by a voltage proportional to the said load voltage of said high frequency generator, and means responsive to the resultant of said opposed voltages for controlling the output of said high frequency generator by varying said control voltage.

8. The combination of a high frequency generator adapted for connection to a load and having at least one oscillator tube comprising at least an anode, a cathode, and a control electrode, means for maintaining a constant reference voltage, means for producing a rectified voltage proportional to the output voltage of said high frequency generator supplied to said load, and means responsive to the resultant of said voltages for controlling the output of said high frequency generator by varying the voltage on the cathode of said oscillator tube.

9. The combination of a high frequency generator adapted for connection to a load and comprising at least one oscillator tube having a control voltage applied thereto, a plate power supply for said high frequency generator, means for maintaining a constant reference voltage, said last-mentioned means including means for making said reference voltage adjustable, means for producing a rectified voltage proportional to the output voltage of said high frequency generator which is applied to said load, means for varying the magnitude of said rectifier voltage, and means responsive to the resultant of said adjusted reference voltage and said adjusted rectified voltage for controlling the output of said high frequency generator by varying said control voltage, and means for returning said last-mentioned voltage to a minimum value when said plate power supply is removed.

10. In induction heating apparatus the combination of a high frequency generator comprising at least one oscillator tube having a control voltage applied thereto, an radio frequency tank circuit for said generator, an applicator coil connected in circuit with said radio frequency tank circuit for passing the material under treatment there-through, means for maintaining a constant reference voltage, means for producing a rectified voltage proportional to the output voltage of said high frequency generator which is applied to said material, and means responsive to the resultant of said last-mentioned two voltages for maintaining the radio frequency tank voltage of said high frequency generator constant by varying said control voltage.

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