Nov. 14, 1950 B. A. LARYS 2,529,560

CONTROL APPARATUS FOR RADIO-FREQUENCY HEATING

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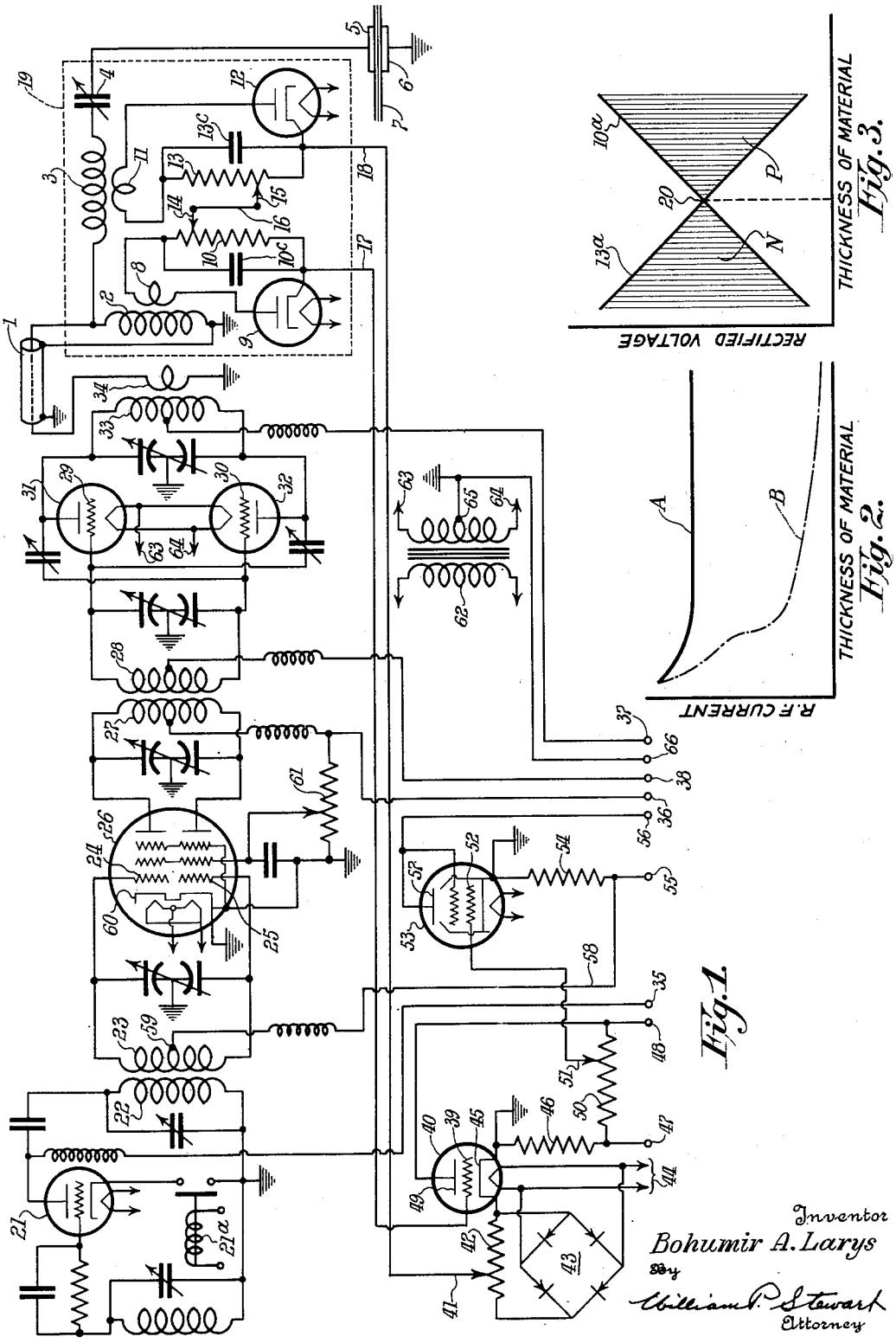


Fig. 1.

Fig. 3.

Fig. 2.

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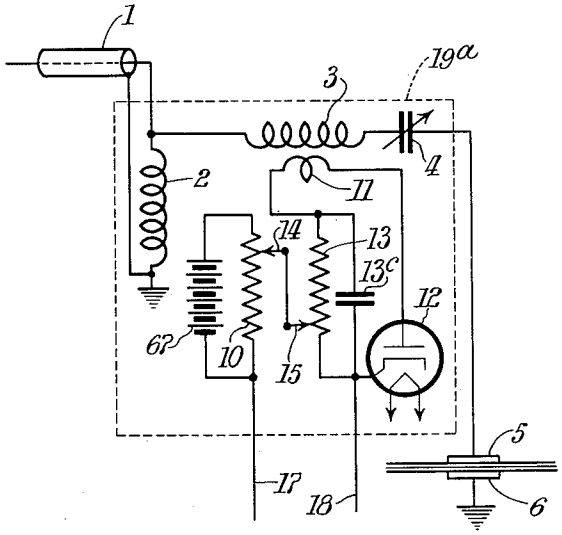


Fig. 4.

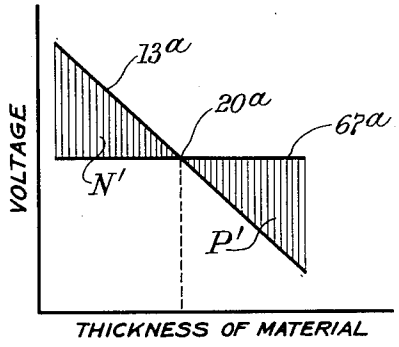


Fig. 5.

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CONTROL APPARATUS FOR RADIO-FREQUENCY HEATING

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6 Claims. (Cl. 219—47)

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This invention relates to systems for producing radio-frequency fields and more especially to means for controlling the strength of said fields in accordance with the requirements of the load which may be continually varying as, for example, when material of varying number of plies or thickness is being passed through said field.

The use of radio-frequency fields for the heating and bonding of progressively-fed dielectric materials is well known. Heretofore it has been customary to change the rate of feed of the material or the plate voltage of the oscillator to compensate for changes in the thickness of the material being heated or bonded. This may be a manual process, in which case the operator must anticipate the change in the material and make the required change in the feed or the voltage at exactly the right time. This dependence upon the human factor causes spoilage and reduces production. It also may be an automatic process, which requires a difficult-to-obtain nicety of adjustment between the detection of the change in the material and the proper correction of the bonding condition. In those systems in which relays and/or motors are used, the necessary time lag produces erratic results. When self-excited oscillators are employed and the plate voltage is altered to effect a change in power output, difficulty has been experienced due to shifts in the frequency.

In an effort to overcome the many difficulties which beset the production of a uniformly good bond in dielectric materials with variation in thickness, the problem has been reviewed from the standpoint of the basic requirements. It has been discovered that, for a given kind of material, frequency, electrode area, and rate of feed, the current through the material should be maintained substantially constant regardless of any thickness variation, if a uniform bond is to be produced.

It is, therefore, a primary object of this invention to provide a radio-frequency generating system which shall supply a current of substantially constant amplitude and frequency to a dielectric load.

A further object of this invention is to provide a control system for a radio-frequency generator which may be adjusted to supply a predetermined and substantially constant current to a variable load.

A still further object of this invention is to provide means to detect the departure and direction of departure of radio-frequency load current from a pre-established value and means responsive to such departure for restoring the

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current instantaneously to its preestablished value.

According to the invention, these objects are attained by employing a small exciter oscillator to establish a stable frequency, a driver amplifier, and a final power amplifier connected to the load. The grid of the driver amplifier is variably biased in response to the load current and either the amplifier output voltage or a stable reference voltage, and this bias voltage variation controls the grid swing of the final power amplifier and thus the voltage output thereof.

With the above and other objects in view as will hereinafter appear, the invention comprises the combination and arrangement of parts hereinafter set forth and illustrated in the accompanying drawings from which the several features of the invention and the advantages attained thereby will be readily understood by those skilled in the art.

In the drawings:

Fig. 1 is a schematic wiring diagram of a system embodying the invention.

Fig. 2 is a graphical representation of the relation of load current to thickness variation for good bonding and for a system with no regulation.

Fig. 3 is a graphical representation of the relation of rectified voltages to thickness variation in the detector portion of the system of Fig. 1.

Fig. 4 is a wiring diagram of a modification of the detector of Fig. 1.

Fig. 5 is a graphical representation of the relation of the voltages to thickness variation for the detector of Fig. 4.

Referring to Fig. 2 of the drawings, a curve A represents the current variation with thickness of the material being bonded for ideal conditions for good bonding according to this invention. It is seen that the current is substantially constant except for very thin materials where slightly larger currents are required. This is the result of the greater cooling effect of the electrodes on the thinner material.

Curve B represents the manner in which the current normally falls off as the load thickness increases in the case of a conventional self-excited oscillator without any automatic regulation of any kind. It is readily seen that, without regulation, the current falls off so rapidly that with conditions set for a given thickness, even a slightly thicker material will not be properly bonded.

Thus, to attain good bonding conditions over

a range of thickness, a control system must be devised to automatically provide for the discrepancies between Curves A and B. Fig. 1 shows such a system. This system is based upon the proper use of two well-known amplifier-load effects, viz. (1) the tendency for load current to decrease as the load thickness or resistance increases and (2) the tendency for the output voltage of the amplifier to increase as the load thickness or resistance increases.

Referring now to Fig. 1, a coaxial transmission line 1 is connected at its load end with a shunt inductance coil 2, a series inductance coil 3, a series variable tuning condenser 4 and electrodes 5 and 6 between which is disposed the material 7 comprising plies to be bonded. Elements 2, 3 and 4 constitute the load-end tuning device which is substantially the same as that shown and described in the co-pending U. S. application of Joseph P. Graham and Robert D. Lowry, Serial No. 576,657, filed February 7, 1945, now Patent Number 2,473,143, dated June 14, 1949. The electrodes 5 and 6 may be either of the reciprocatory or the roller type.

A pick-up coil 8 is placed in inductive relation to coil 2 and is connected in series with a diode rectifier 9 and a potentiometer 10. Similarly, a pick-up coil 11 is placed in inductive relation to coil 3 and is connected in series with a diode rectifier 12 and a potentiometer 13. The potentiometers 10 and 13 are shunted by condensers 10^c and 13^c, respectively, to provide low impedance paths for the high frequency components of the rectified currents. Sliders 14 and 15 are connected by lead 16, and leads 17 and 18 are connected to the ends of the respective potentiometers 10 and 13. It will be seen that the polarity of the diodes is such that the voltage across leads 17 and 18 is the difference between the voltages appearing between each slider and the bottom end of its respective potentiometer. The elements just described define a detector 19 and the single output control voltage therefrom appearing between leads 17 and 18 varies between a negative value, through zero, to a positive value as the thickness of the material 7 increases as will now be explained.

In Fig. 3, curve 10^a represents the variation in the voltage across the potentiometer 10 as the thickness varies. It increases with increase in thickness because it is a measure of the radio-frequency voltage as the load resistance increases towards open circuit. Curve 13^a represents the variation in the voltage across the potentiometer 13 as the material thickness or resistance increases. It decreases with increase in thickness because it is a measure of the load current which falls off due to increased thickness. The voltage between leads 17 and 18 is representated by the difference between the ordinates to the two curves 10^a and 13^a. Thus at point 20, a thickness is found for which the output voltage is zero. In the region N, the output voltage is negative and decreases with increasing thickness as shown by the vertical lines. In the region P, the output voltage is positive and increases with increasing thickness as shown. It will be seen that the thickness value at which the output voltage is zero may be changed by moving either one or both of the sliders 14 and 15. It is also possible to gang the sliders 14 and 15 to a single control for convenience. Ordinarily these are adjusted to produce zero output voltage for the average thickness to be encountered in order to minimize the necessary regulation.

Having thus obtained a D. C. control voltage which is a function of the load variations, let us see how this voltage is utilized to produce a substantially constant current to the load. Referring again to Fig. 1, a triode tube 21 is connected as a conventional tuned-grid, tuned-plate oscillator, and serves as the exciter for the entire system. This oscillator 21 may be turned on and off by connecting the cathode to ground through the agency of a keying relay 21^a. A plate coil 22 of said oscillator is inductively coupled to a grid coil 23 which is connected to provide push-pull input to grids 24 and 25 of a dual pentode tube 26, connected as a push-pull driver amplifier. A plate coil 27 of said amplifier is coupled inductively to a grid coil 28 which connects to the grids 29 and 30 of two triode tubes 31 and 32 connected as a push-pull power amplifier. The plate coil 33 of said power amplifier is inductively coupled to a coil 34 which is connected to the sending end of the coaxial line 1 referred to hereinbefore.

Thus, the exciter oscillator 21 sets the frequency and the small voltage generated thereby is amplified first by the driver amplifier 26 and then by the power amplifier 31 and 32 until considerable power is available for transmission to the load by the line 1. Terminals 35, 36 and 37 are provided for the application of the proper positive plate voltages for the exciter, driver and power amplifier respectively; the ground being the common negative voltage terminal 66. Terminal 38 is for the application of the proper negative grid bias voltage for the power amplifier. These voltages are maintained substantially constant by the use of conventional regulated power and bias supplies, not shown. Filament supply voltages are applied where shown by arrows on the heater and filament leads. An adjustable screen-grid voltage supply for the driver amplifier 26 is obtained from a potentiometer 61 placed across the plate voltage supply (terminal 36 to ground). A filament transformer 62 has leads 63 and 64 connecting to the filaments of the power amplifier tubes 31 and 32. The center-tap 65 of the secondary is grounded to complete the plate return for these tubes. The exciter oscillator 21 is self-biased and the driver amplifier 26 obtains its bias in a special manner now to be described.

As described above, leads 17 and 18 supply a D. C. voltage which increases in a positive direction as the material thickness increases. This voltage is impressed between grid 39 of triode tube 40 and the slider 41 of potentiometer 42. A bridge-type rectifier 43 receives alternating current voltage from the filament supply 44 and supplies D. C. voltage to the potentiometer 42 a portion of which voltage is applied as grid bias between the slider 41 and the cathode 45. The cathode 45 is grounded and a cathode resistor 46 is connected to terminal 47 which is for connection to the negative side of a conventional plate voltage supply which is well regulated. Terminal 48 connects to the plate 49 and permits connection to the positive side of a conventional regulated plate supply, not shown. A potentiometer 50 is connected across terminals 47 and 48 and has its slider 51 connected to the grid 52 of pentode tube 53 which is connected as a triode cathode follower. The cathode of tube 53 is grounded and a resistor 54 is connected between said cathode and terminal 55 which provides for connection to the negative side of a conventional regulated plate voltage supply, not shown. Ter-

minal 56 connects to plate 57 and provides for connection to the positive side of said plate voltage supply. A lead 58 connects from terminal 55 to the mid-point 59 of the grid coil 23 of the driver amplifier 26. The dual cathode 60 is grounded and, thus, it will be seen that the output voltage of the cathode follower tube 53 which appears across the resistor 54 is impressed directly as bias voltage on the grid circuit of the driver amplifier 26.

Operation

It will be apparent from the above description of the circuit that there is a certain thickness of material 7 for which the D. C. voltage output of the detector is zero. This value of thickness may be shifted by manual control of either or both sliders 14 and 15.

First, let us suppose that conditions are such that no net voltage appears across leads 17 and 18. In this case, the setting of the slider 41 of potentiometer 42 determines the voltage on the grid 39 which determines the plate current of tube 40 and thus the voltage drop in the resistor 46. The voltage impressed on the grid 52 of the cathode follower 53 is made up of a positive component taken from the potentiometer 50 by the slider 51, and a negative component equal to the voltage drop in the resistor 46. This voltage will determine the value of the plate current of the cathode follower tube 53 which, in turn, fixes the value of the voltage drop in the resistor 54. This voltage is the bias voltage on the grids of the driver amplifier 26 and determines the output voltage thereof. Thus, potentiometer sliders 41 and 51 may be adjusted so that the proper current is being supplied for a given thickness and kind of material to make a satisfactory bond. If, now, thicker material is encountered a more positive voltage appears as the output voltage of the detector 19 and this provides a less negative grid voltage for the tube 40. The plate current of tube 40 increases and this increases the negative voltage applied to the grid 52 of the cathode follower. This lowers the negative grid bias voltage supplied to the grids of the driver amplifier by the cathode follower and provides a higher output voltage from said amplifier. This higher voltage increases the voltage drive on the power amplifier and the output voltage is boosted so that the current increases substantially to its original value. If the material gets thinner, the reverse action takes place because of the ability of the detector to discriminate between the directions of thickness change. In general, the action is such that the tendency for the load current to change is substantially counteracted by the voltage change produced by the grid bias control as described. That is to say, there tends to be a constant voltage gradient maintained in the material by automatic voltage control responsive to thickness change.

It is also possible to obtain regulation by using only one detector coil 11 and comparing the rectified voltage obtained therefrom with a constant D. C. voltage obtained from a battery or similar source of constant voltage. Accordingly, Fig. 4 shows a detector, 19a, modified from the one shown in Fig. 1 by the substitution of a battery 67 for the pick-up coil 8 and rectifier 9.

It will be seen that the operation is the same as above explained in connection with the detector 19 except that instead of the rising voltage characteristic (10a of Fig. 3) of the rectified voltage supplied by the coil 8, a constant voltage characteristic supplied by the battery 67 is used. This is shown in Fig. 5 as curve 67a. The regions of negative and positive control voltages are shown at N' and P', while at point 20a the thickness corresponds to zero control voltage, or no regulation. A control voltage increasing positively with increasing thickness is obtained as shown by the vertical lines of Fig. 5, and operation of the circuit is the same as explained above.

It is to be noted that no motors or relays are used and the speed of response is, therefore, limited only by the time taken for currents to traverse the circuits, which time, relative to the rate of feed of the material, is practically instantaneous.

By employing an exciter which need produce only a very small output power and by employing amplifiers between said exciter and the load it is possible to make the frequency very stable and practically independent of the variations in the load. This insures that the frequency will remain within the band allocated for the equipment and that the heating effectiveness will not be changed by change of frequency. Inasmuch as it works into a high impedance grid circuit, the detector unit 19 does not supply much current, and may be made very small, physically, by the use of miniature components. It may, therefore, be placed very close to the electrodes 5 and 6, in close proximity with the load itself.

Having thus set forth the nature of the invention, what I claim herein is:

1. In a control system for maintaining constant the radio-frequency current to a variable-thickness dielectric load, a radio-frequency generator, a dialectric load, means for deriving a first voltage proportional to the current to the load, and a second voltage proportional to the output voltage of said generator, means for rectifying said voltages, means for combining preselected portions of said rectified voltages to produce a single voltage which is a function of the thickness of the load, and means responsive to said single voltage for maintaining substantially constant the current to the load.

2. In a bonding apparatus, an oscillator, an amplifier fed from said oscillator, a load comprising plies of material of varying thickness, a transmission line for transferring current from said amplifier to said load, means for deriving a first D. C. voltage proportional to the current to the load, means for deriving a second D. C. voltage proportional to the voltage at the load-end of said transmission line, means for combining these D. C. voltages to produce a single voltage, and means for impressing said single voltage on the grid of said amplifier.

3. In a system for the radio-frequency heating of dielectric material, an oscillator, a driver amplifier fed from said oscillator, a power amplifier fed from said driver amplifier, a variable load including said dielectric material, fed from said power amplifier, means for deriving a first D. C. voltage proportional to the radio frequency current to the load, means for deriving a second D. C. voltage proportional to the radio frequency voltage output of said power amplifier, means for combining said voltages to produce a single voltage, means for amplifying said single voltage, and cathode follower means for transferring the amplified voltage to the grid circuit of said driver amplifier whereby to vary the input voltage to the power amplifier and

thereby the output voltage to the load to maintain the load current substantially constant.

4. In a radio-frequency system, a radio frequency generator including a grid-modulated amplifier, a variable load connected to receive current from said generator, means for deriving a D. C. voltage proportional to the radio-frequency current to the load, means for deriving a D. C. voltage proportional to the radio-frequency voltage output of said generator, means for combining said D. C. voltages to produce a single voltage, and means for amplifying said single voltage and cathode follower means for transferring said amplified voltage to the grid circuit of said grid-modulated amplifier.

5. In a radio-frequency apparatus for heating dielectric material, a radio-frequency voltage generator, a valuable load including dielectric material, means for transferring current from said generator to said dielectric material, means for deriving a first D. C. voltage proportional to said current, means for deriving a second D. C. voltage proportional to the output voltage of said generator, means for subtracting said D. C. voltages to produce a single control voltage, and means responsive to said single control voltage for varying the output voltage of said generator to maintain substantially constant the current to said dielectric material.

6. In a sysem for controlling the transfer of radio-frequency energy from a generator to a load, the resistance of which is subject to random variation, means for picking up a voltage proportional to the output voltage of said generator, a load, means for picking up a voltage proportional to the current to said load, separate rectifying means for rectifying said voltages, means for selecting a portion of each of said rectified voltages, and means for subtracting said portion voltages to produce a single control voltage which is a function of said random variation of the load resistance.

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