

Oct. 2, 1956

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2,765,387

DIELECTRIC HEATING SYSTEM

Filed March 30, 1953

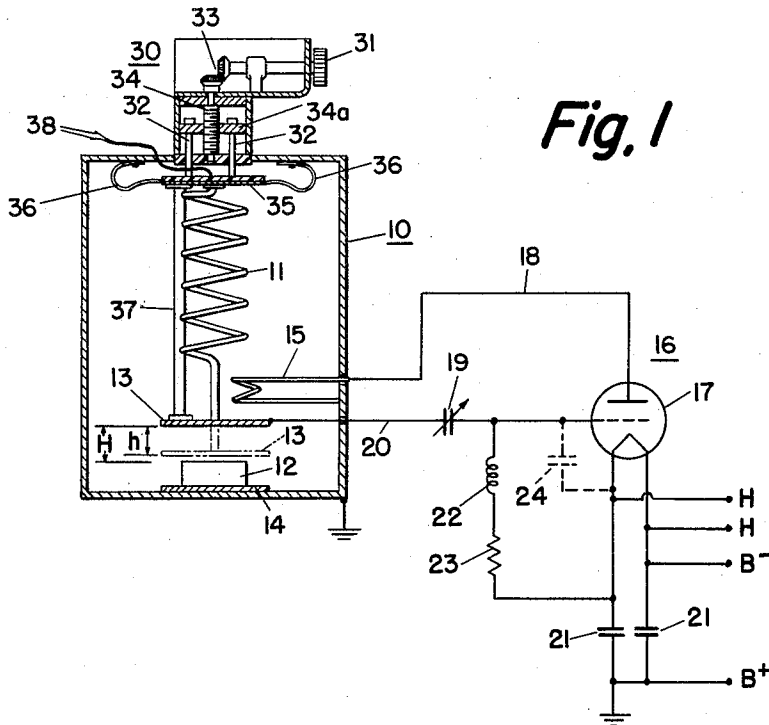
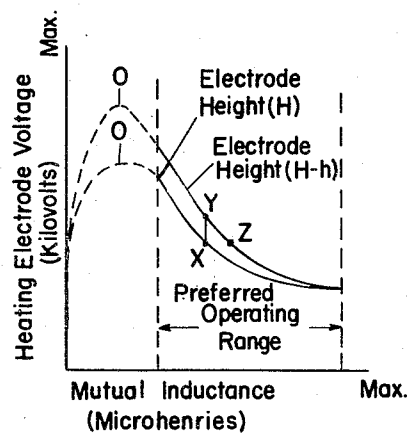


Fig. 2



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DIELECTRIC HEATING SYSTEM

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Application March 30, 1953, Serial No. 345,631

11 Claims. (Cl. 219—10.55)

This invention relates to high-frequency dielectric heating systems in which an oscillator supplies high-frequency power to a dielectric load disposed between spaced heating electrodes and particularly relates to arrangements for maintaining the voltage between the electrodes, and also the grid-excitation of the oscillator, substantially constant for different spacings of the heating electrodes.

In certain types of dielectric heating systems, including some disclosed in copending U. S. application, Warren, Serial No. 138,628, now abandoned in favor of U. S. continuation-in-part application, Warren, Serial No. 419,633, filed March 26, 1954, as the electrode spacing is changed to accommodate the physical or electrical characteristics of different loads, the electrode voltage changes. Depending upon the type of oscillator circuit driving the dielectric heating system, the variation in spacing between electrodes will increase or decrease the voltage therebetween. Therefore, where the grid-excitation is derived from electrode voltage, a variation in spacing between electrodes will cause a change in the amplitude of the voltage applied to the grid of the oscillator. The shift or change in amplitude of the grid-excitation may be of such extent and sense as to exceed the dissipation ratings of the grid and anode of the oscillator tube. In all such cases an inefficient operation of the heating system is the result.

In accordance with the present invention, the movable heating electrode is supported from one end of a helix or coil whose other end is attached to a support adjustable to move the coil and electrode as a unit within a shielding enclosure concurrently to change the electrode spacing and to vary the coupling between the movable coil and a fixed coil in the oscillator circuit. The change in coupling between the coils is in sense compensating for the tendency of the electrode voltage to change with adjustment of the electrode spacing.

For a more detailed understanding of the invention and for an illustration of a preferred form thereof, reference may be had to the following description taken in conjunction with the accompanying drawings, in which:

Fig. 1 diagrammatically illustrates a dielectric heating system embodying the present invention; and

Fig. 2 is an explanatory figure referred to in the general discussion of the electrical operating characteristics of the system illustrated in Fig. 1.

Referring to Fig. 1 of the drawings, the invention in simplified schematic form is shown applied to a high-frequency dielectric heater system including an applicator 10 comprised of electrically conductive walls and enclosing the inductive and capacitive elements of a resonant heating circuit. The applicator is preferably substantially a complete enclosure to minimize the leakage of the intense magnetic and electric fields existing therein. However, it may be completely open at either or both ends.

Substantially all the inductance for the resonant heating circuit is provided by structure disposed within the applicator enclosure and including an electrically conduc-

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tive helix or coil 11 which is electrically connected to one of the walls of the applicator. In the particular embodiment illustrated, such coil is connected to the top wall and projects into the applicator enclosure in spaced relation to all other walls.

The heating of a load 12, such as plastic preforms and the like, subjected to the action of the heating system, takes place within an electric field produced between two electrodes 13 and 14. These electrodes provide a substantial part of the total capacitance for the applicator 10. The upper electrode 13 is adapted for movement toward and away from the lower electrode 14 which is represented as a platform surface raised above the lower wall of the applicator. Although not specifically disclosed in Fig. 1, a metallic conveyor may serve as the lower heating electrode so as to provide for the continuous processing of work, or the platform may be eliminated and the lower wall of the applicator 10 may serve as the lower electrode 14. The upper electrode 13, of preferred configuration, is secured or otherwise electrically connected at a portion intermediate the edges thereof to the free end of the coil 11.

The high-frequency magnetic field circulating through the coil 11 is created by an excitation afforded by a coupling loop 15. The loop 15 as illustrated may be in the output circuit of a high-frequency supply means for the tank circuit. As shown, the plate circuit of a high-frequency oscillator tube 17 whose resonant tank circuit is comprised of the coil 11 and the capacitor formed by the heating electrodes of the applicator 10. The coupling loop which may be formed of several turns of copper piping is adjustably supported in normally fixed position within applicator 10 adjacent a limit of travel of coil 11.

Many various types of oscillator circuits may be used for exciting the applicator 10 herein shown: the particular oscillator circuit 16 illustrated is generically similar to one described and claimed in the aforesaid Warren applications.

In the oscillator system 16, as used with the applicator 10, the fixed coil or loop 15 within the metallic enclosure inductively couples the heating circuit to the plate or anode circuit of the oscillator tube 17. In the particular circuit shown, one end of coupling coil 15 is conductively connected to the wall structure of applicator 10 and the other end of the coil is connected by conductor 18 to the anode of tube 17. The grid of tube 17 is connected to the heating electrode 13 by way of an external variable capacitor 19 and a lead 20 passing through an insulator in the side wall of the enclosure. Alternatively, as in copending U. S. application, Moore, Serial No. 345,663, filed March 30, 1953, the capacitor 19 may be within the applicator and adjustable concurrently with the movable heating electrode. The cathode of tube 17, so far as the operating frequency of the oscillator is concerned, is grounded through bypass capacitors 21. A direct current source of high voltage B+, B- is connected between ground and the cathode of tube 17; the positive end of that terminal being grounded as indicated. A direct-current path between the grid and cathode of tube 17 is provided by radio-frequency choke 22 and grid-leak resistor 23. Alternatively the negative terminal of the D. C. source of high voltage may be grounded: In such case, there may be employed a well known parallel feed arrangement which is not shown but which would include a blocking condenser in series with the coupling coil 15 and a radio frequency choke connected in series between the plate of the tube and the positive terminal of the high voltage supply.

A capacitor 24, in whole or in the main provided by the effective input capacitance of tube 17, together with capacitor 19 provides a capacitive potential divider which is utilized in the automatic stabilization of grid-excitation

compensating for the effect of changes in power factor of the load as fully set forth and claimed in the aforesaid Warren applications.

In order to avoid unduly large shifts or changes in the amplitude of electrode voltage as conditions within the heater vary, it has been found desirable, as set forth in aforesaid Warren applications, to couple the loop 15 and coil 11 beyond the optimum point so as to provide supra-optimum mutual inductance coupling.

The effect of the supraoptimum coupling as a factor in reducing the extent of variations in electrode voltage is illustrated by the curves in Fig. 2. The first curve (H) may be produced by setting the electrode 13 at a predetermined height H above a given work load, as in the low range shown by the broken-line position of the electrode 13, Fig. 1, and varying the mutual inductance of the coil 11 and the loop 15, and observing the variations in heating electrode voltage resulting therefrom.

The second curve (H-h) may be likewise produced by shifting the electrode to a new position (H-h) illustrated by the dotted lines in Fig. 1 for which the spacing between the given load and the upper electrode is decreased.

The operating range of the applicator is preferably selected to lie entirely to the right or above the optimum coupling point of the coils as indicated by point O (Fig. 2). It is apparent from these curves, which are representative of a family of curves, that change in electrode voltage occasioned by variations in the height of the movable electrode is much less, when within the selected operating range, than it would be if operations were conducted at or below optimum coupling. However, the present invention permits operation of dielectric heaters or applicators within ranges at either side of the optimum coupling point O. With the operating range to the right or the left of the optimum point, it will be observed the electrode voltage will increase as the spacing between electrodes is decreased. However, to compensate for the otherwise occurring change in electrode voltage, in one case the mutual inductance should be increased and in the other case, it should be decreased.

Although the extent of the variations in electrode voltage is materially reduced by operating within the supra-optimum coupling range, the present invention provides for a still further reduction in electrode voltage change to such an extent that the electrode voltage may be considered as substantially constant over a wide range of variations in electrode height. This control of the electrode voltage is effected by automatically varying the coupling between the coil 11 and the coupling loop 15 with change in electrode spacing. The increase in electrode voltage occasioned by decreasing the spacing of the electrodes is illustrated as an example of operation in Fig. 2, as where the electrode voltage is increased from a point X to a higher point Y. The electrode voltage, automatically decreased by increasing the coupling or mutual inductance of the coil and coupling loop 15, is reduced to a point Z which is of the same magnitude of electrode voltage as point X. Although the correction of electrode voltage is illustrated to take place in two distinct steps, it will be understood that since the change in mutual inductance takes place simultaneously with variations in electrode spacing, the electrode voltage will remain substantially constant as the mutual inductance is increased from X to Z.

It is apparent from the above disclosure that where operations take place in an infraoptimum range, the operational analogy will be similar. Of course, the position of the coupling loop will need be changed so that as the distance between the electrodes is decreased, tending to cause an increase in electrode voltage, the coupling will be decreased. To produce the desired relationship between electrode spacing and mutual inductive coupling, it is only necessary to locate the coupling loop 15 at a position above the coil 11, instead of below the coil as presently illustrated.

When the electrode height is substantial and the voltage change, which occurs with change in electrode height, is predominantly due to change in power factor within the space defined by the electrodes, the electrode voltage may decrease with decreased spacing.

The coil 11 and the heating electrode 13 affixed at one end thereof may be adjusted in height by means of a lifting mechanism 30 mounted on the upper wall of the applicator. The mechanism may be of any well known type which will elevate and lower the coil 11 and electrode 13 without rotating them. It is apparent that the presence of any rotational component during movement of the coil 11 and electrode 13 would effect the operational characteristics of the applicator by changing the values of capacitance and mutual inductance coupling other than desired.

As illustrated, the preferred mechanism is of the type which translates rotational movement of a knob 31 to a linear movement of rods 32 by way of bevel gears 33, screw 34, and captive nut 34a. The rods 32 are secured to a plate 35 mounted on one end of the coil 11 and pass through their respective apertures in the top wall of the applicator 10 to hold the nut 34a against rotation. The rods 32 are shielded from the magnetic field by flexible straps 36 of conductive metal which extend the length of the applicator.

The coil 11 is rigidly held against extension or compression by a shaft 37, formed of insulating material and spaced from the coil and secured at opposite ends to the supporting plate 35 and the electrode 13.

The coil 11 may be formed of a solid conductor but is preferably a hollow conductor, particularly when, as now described, the upper electrode has internal heating means.

In those cases where excessive vapor is produced during the work cycle, it may be desired to provide an auxiliary device to heat the electrode and thereby raise the temperature of the work apparatus in such a manner as to prevent condensation of vapor thereon which might cause arcing or otherwise damage the work. This heating device may be comprised of a series of resistors (not shown) mounted on the upper side of or within the heating electrode 13. The resistors derive excitation from an external source, not shown, by way of leads 38 that extend through the hollow conductor of the coil 11. The leads 38 enter the applicator 10 in the area shielded by the flexible straps 36.

What is claimed is:

1. A dielectric heating system comprising heating electrodes variably spaced to accommodate different work loads, a heating circuit coil bodily movable with one of said heating electrodes and resonated by capacity between said heating electrodes, said coil having a plurality of turns, and an oscillator having a plate coil positioned adjacent the path of movement of said heating circuit coil, the distance between said heating circuit coil and said plate coil varying with change in the spacing of said electrodes to change the coupling between said coils in sense compensatory of the tendency of the electrode voltage to vary with change in electrode spacing.

2. A dielectric heating system as in claim 1 in which the electrode voltage tends to decrease with increase of electrode spacing, in which the mutual inductance of said coils is supraoptimum throughout a range of spacing of said electrodes, and in which said plate coil is so positioned that the coupling decreases with increase of electrode spacing.

3. A dielectric heating system as in claim 1 in which the electrode voltage tends to increase with increase of electrode spacing, in which the mutual inductance of said coils is supraoptimum throughout a range of spacing of said electrodes, and in which said plate coil is so positioned that the coupling increases with increase of electrode spacing.

4. A dielectric heating system as in claim 1 in which the electrode voltage tends to decrease with increase of

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electrode spacing, in which the mutual inductance of said coils is infraoptimum throughout a range of spacing of said electrodes, and in which said plate coil is so positioned that the coupling increases with increase of electrode spacing.

5. A dielectric heating system as in claim 1 in which the electrode voltage tends to increase with increase of electrode spacing, in which the mutual inductance of said coils is infraoptimum throughout a range of spacing of said electrodes, and in which said plate coil is so positioned that the coupling decreases with increase of electrode spacing.

6. A dielectric heating applicator comprising a metallic enclosure, a movable heating electrode within said enclosure, a coil bodily movable with said electrode and electrically connected at its opposite ends respectively to said electrode and to said enclosure, said coils having a plurality of turns, and means including an exciting coil positioned within said enclosure adjacent said movable coil for variation of the coupling between said coils concurrently with movement of said movable heating electrode and said movable coil to maintain the electrode voltage constant.

7. A dielectric heating applicator comprising a metallic enclosure, a heating electrode within said enclosure, a conductive supporting member mounted for linear movement within said enclosure and electrically connected thereto, rigid insulation means extending between and attached to said heating electrode and said supporting member, a heating circuit coil attached at its opposite ends respectively to said electrode and support for movement bodily therewith, said coil having a plurality of turns, and means including a normally stationary exciting coil positioned within said enclosure adjacent said movable coil for variation of the coupling between said coils concurrently with movement of said movable heating electrode to maintain the electrode voltage constant.

8. A dielectric heating system having an oscillator tank circuit including heating electrodes variably spaced to accommodate different loads to be heated, an oscillator tube having a grid and a cathode, the excitation voltage for the grid of said oscillator being derived from the potential-difference of said heating electrodes, and means for maintaining the electrode voltage constant despite variations in spacing between the electrodes and changes in power factor of the load being heated, said means comprising a coil bodily movable with one of said heating electrodes, said coil being in said tank circuit with said electrodes and having a plurality of turns, a coupling loop connected in the plate circuit of said oscillator and disposed in normally fixed position relative to the other of said electrodes, the tendency of the electrode voltage to vary with variation in electrode spacing being compensated by the concurrent change of coupling between said coil and loop with change in electrode spacing, and a grid feedback capacitor connected to form with the effective input capacitance of said oscillator tube a capacitive voltage-divider which compensates for variations in power factor of a load being heated by changing the percentage of electrode voltage applied to the grid of said oscillator.

9. A dielectric heating system having an oscillator tank circuit including heating electrodes variably spaced to accommodate different loads to be heated, an oscillator having a grid and a cathode, the excitation voltage for the grid of said oscillator being derived from the potential-difference of said heating electrodes, and means for maintaining said electrode potential-difference and grid excitation constant despite variations in spacing between said electrodes, said means comprising a coil with a plurality of turns bodily movable with one of said heating electrodes and a loop in the plate circuit of said oscillator coupled to said coil and disposed in fixed position relative to the other of said electrodes, the coupling of said coils being variable concurrently with the spacing of said heating electrodes.

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10. A dielectric heating system for the heating of dielectric work comprising an electrically conductive housing, an oscillator tank circuit including a coil having a plurality of turns projecting into the interior of said housing and also including spaced electrode structures cooperative to provide electric field space within said housing for receiving therein the material to be heated by the electric field between said electrode structures, at least one of said electrode structures being electrically attached to the inwardly projecting end of said coil and in spaced relation to walls of the housing, connecting means electrically interconnecting wall structure of said housing and the end of said coil adjacent wall structure of said housing to complete a resonant circuit which includes said inductance structure and said electrode structures and the frequency of which is predominantly determined by the inductance of said coil and the capacitance between said electrode structures, means for bodily moving said coil and said one electrode structure to change the spacing between said electrode structures, and high-frequency supply means having an output circuit including an output loop disposed adjacent an end portion of said first-mentioned coil for supplying high-frequency energy to said resonant circuit through magnetic coupling therewith, said supply means also including an excitation circuit excited from said resonant circuit in determination of the operating frequency of said supply means, relative movement between said loop and said first-mentioned coil automatically varying the mutual inductance coupling between said output circuit and said resonant circuit with change in electrode spacing in a direction to compensate for the effect upon the electrode voltage of said change in spacing, said loop and said coil being disposed within said housing in positions such that the magnetic fields extending longitudinally respectively of said coil and of said loop intersect each other.

11. A dielectric heating system comprising spaced electrode structures adapted to accommodate therebetween dielectric material to be heated by an electric field between said structures, an inductance coil having a plurality of turns and electrically connected at one end to one of said electrode structures, means electrically interconnecting the other end of said coil with the other of said electrodes to complete a resonant circuit which includes said coil and said electrode structures and the frequency of which is predominantly determined by the inductance of said coil and the capacitance between said electrode structures, said one electrode structure being movable relative to the other electrode structure for variation of the spacing and the voltage between said structures, high frequency power generating means for delivering high frequency power to said electrode structures and having an output circuit including a coupling loop disposed adjacent said coil in such position that the magnetic fields of said coil and said loop intersect each other for mutual inductance coupling between said output circuit and said resonant circuit, and means for effecting bodily movement of said coil with movement of said one electrode structure and relative to said loop so as to automatically vary said mutual inductance coupling with change in electrode spacing and in a direction to compensate for the effect of such change in spacing upon the voltage between said electrode structures.

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