

Feb. 26, 1957

H. R. WARREN

2,783,345

HIGH-FREQUENCY HEATING APPLICATORS

Filed March 26, 1954

2 Sheets-Sheet 1

Fig. 1

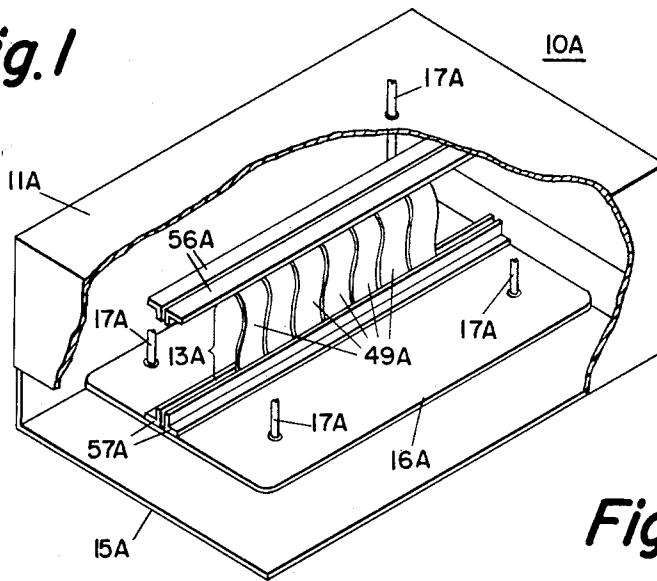


Fig. 2

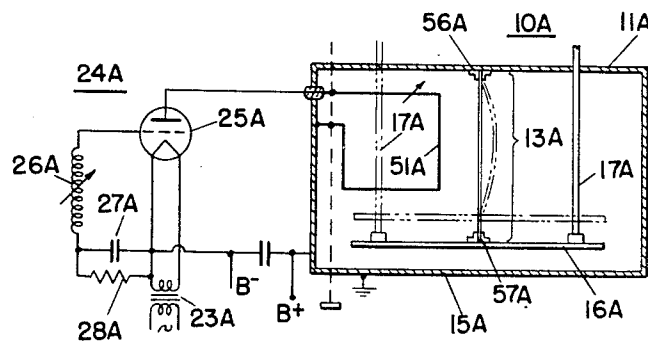
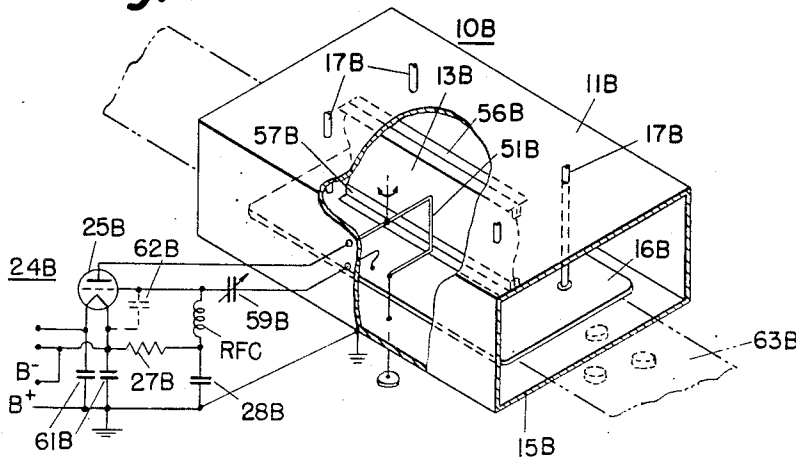


Fig. 3



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Fig. 4

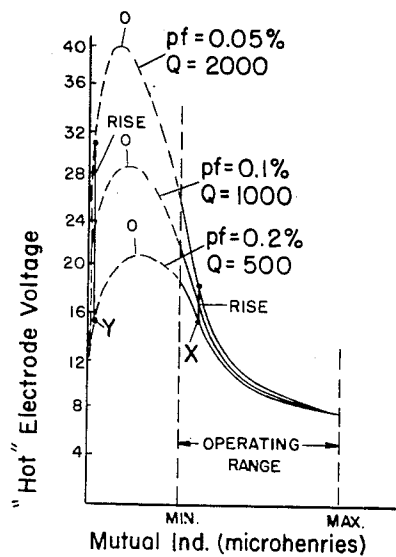


Fig. 5

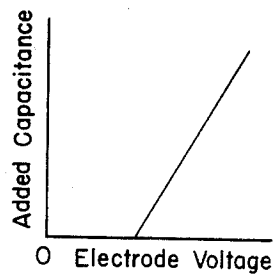


Fig. 6

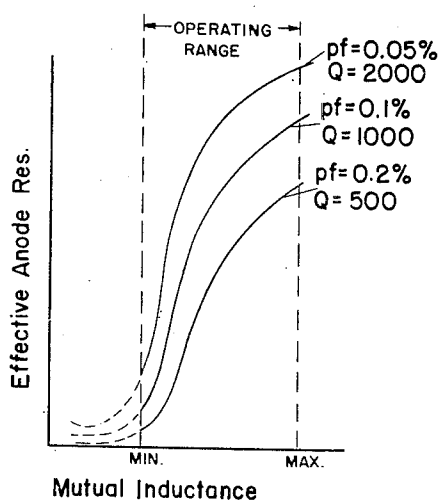
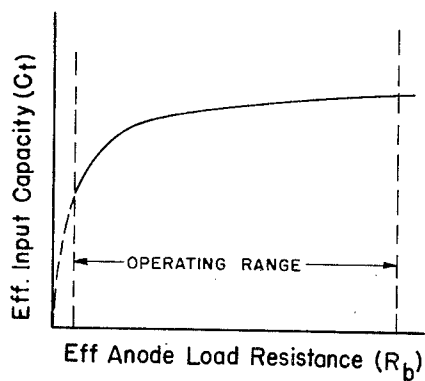


Fig. 7



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2,783,345

HIGH-FREQUENCY HEATING APPLICATORS

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Application March 26, 1954, Serial No. 419,073

18 Claims. (Cl. 219—10.55)

This invention relates to high-frequency heating and particularly to resonant applicators especially suited for rapid dielectric heating of large area loads such as wallboard panels, foam-rubber mattresses, groups of sand cores or plastic preforms, and the like.

This application, a continuation-in-part of my application Serial No. 138,628, filed January 14, 1950, and now abandoned in favor of my continuation-in-part application Serial No. 419,633, filed March 26, 1954, has claims directed to subject matter divided from my parent application Serial No. 138,628. My aforesaid applications which contain a more detailed discussion, included herein by this reference, of the structural and operating characteristics of resonant applicators of the kind to which the present invention is particularly directed.

In general, such applicators comprise relatively large electrode structures electrically interconnected through conductive structure which at least in part has substantial inductance cooperative with capacity-means including the capacitance between said electrode structures to form a resonant circuit device, and a power transfer means, preferably a coupling loop disposed in position to be traversed by a high-frequency magnetic field encircling a part of said interconnecting conductive structure. More particularly, in the preferred form of such applicators, the interconnecting structure includes low resistance walls of a shielding enclosure which completes the resonant circuit of said device and serves to confine said magnetic field and also the electric field produced between said electrode structures, at least one of the electrode structures being spaced from all walls of the enclosure and electrically interconnected with wall structure thereof through a leg or fin element which reentrantly projects into the enclosure and in which a substantial part of the inductance of the resonant applicator is concentrated, and the said coupling loop being arranged to be traversed by the magnetic field encircling the inwardly projecting leg or fin element. Such loop may serve to provide for excitation of the applicator by inclusion in the anode or power delivery circuit of the high-frequency power-supply of the oscillator.

For reasons explained in detail in my aforesaid parent application, and which also will be more fully understood from the ensuing description, it frequently is necessary or desirable to provide for variation of the spacing between the electrode structures, particularly such parts of said structures as may be employed to accommodate therebetween the work to be heated. In accordance with the present invention, as the spacing between the electrode structures is varied, the mutual inductance between the coupling loop and the resonant applicator is concurrently varied, automatically to compensate for effects of the change in electrode spacing upon the loading of the oscillator and upon the electrode voltage. Preferably and with decided advantages, this feature is used in applicator-oscillator systems of the type claimed in my aforesaid parent applications and having either or both supraoptimum mutual inductance between the coupling

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loop and the applicator and a capacitive voltage-divider for deriving the grid-excitation of the oscillator from the electrode voltage.

The invention further resides in features of construction, combination and arrangement hereinafter described and claimed.

For a more detailed understanding of the invention and for illustration of embodiments thereof, reference is made to the accompanying drawings in which:

Fig. 1 is a perspective view, partly broken away, of a resonant applicator;

Fig. 2 is an elevational view, in section, of the applicator of Fig. 1 as included in an oscillator system schematically shown;

Fig. 3 is a perspective view, partly broken away, of a modification of the applicator of Fig. 1 as included in a second oscillator system schematically shown; and

Figs. 4 to 7 are explanatory figures referred to in general discussion of Figs. 1 to 3.

The resonant applicator 10A shown in Figs. 1 and 2 is particularly suited for dielectric heating of pulp wallboard panels, foam-rubber mattresses, and for like purposes requiring large heating electrodes and dissipation of relatively large amounts of high-frequency power in the dielectric load. The applicator housing or tunnel 11A may be of relatively thin sheet metal reinforced by frame members (not shown) to provide the strength and rigidity necessary when the work is subjected to pressure.

In the illustrated embodiment, all, or practically all, of the inductance of the reentrant resonant applicator is concentrated or lumped in the fin structure 13A extending inwardly, i. e., reentrantly, from the top wall of the applicator housing or tunnel and attached thereto as by bars 56A. The lower free end of the fin inductor 13A, or equivalent, is connected, as by bars 57A, to the upper face of the electrode 16A. The bottom of the tunnel 11A may serve as the lower electrode 15A. Alternatively, the lower electrode may be an auxiliary conductive member, movable or stationary, conductively connected or otherwise coupled to the tunnel wall structure. In such latter case, the connection or coupling of the lower electrode to the wall structure may be effected through a second fin inductor, or equivalent, as in certain of the constructions shown in my aforesaid parent applications. All, or practically all, of the capacitance of the applicator is concentrated or lumped in the capacity between the electrodes 15A, 16A. The conductive walls of the housing 11A serve as a path of very low resistance and of very low reactance for the circulating current between the lower electrode 15A and the upper end of the fin inductor 13A.

The resistance of the fin inductor 13A and of the electrode 16A is very low and, as above stated, the resistance of the remainder of the current path afforded by the wall structure is also very low so that the Q of the applicator is very high despite the low ratio of inductance to capacity. Because of their high-frequency, the circulating currents are practically confined to the inner surfaces of the applicator housing and consequently all external surfaces are at ground potential and serve as a radio-frequency shield for the internal components which are at high radio-frequency potential.

Therefore, the radiation losses of the applicator are low, thus minimizing radio interference and further contributing to its high Q which makes it uniquely suited for dielectric load materials having very low power-factor, such as foam rubber, pure gum rubber, extruded rubber hose and gaskets as well as for materials having high power-factor, such as wood.

The ends of the housing 11A may be left open (Fig. 3) or at least partially open (Fig. 1) for insertion, removal or passage through the applicator of the objects

or material to be heated. For batch operation, one or both ends of the housing may be provided with doors or removable panels, further to minimize radiation from the tunnel during heating. Partial end closures (Fig. 1), leaving an unobstructed path for insertion or removal of the work from either end of the tunnel, or for continuous flow of the work, may be provided. When the ends of the applicator housing are closed, or partially closed, the edges of the fin inductor 13A should be spaced therefrom leaving an unobstructed path around the fin for its high-frequency magnetic field.

The resonant power-receiving load circuit formed by the applicator 10A (Figs. 1, 2) is inductively coupled to the anode circuit of the oscillator tube 25A by the power-transfer loop 51A which is disposed within the tunnel and threaded by the high-frequency magnetic field encircling the fin inductor 13A. The effective area of the loop may be adjustable, as by rotation of the loop about a vertical or horizontal axis, to effect smooth variation of the mutual inductance (of the applicator and the anode-circuit loop) for adjusting or presetting of the high-frequency voltage of the "hot" electrode. The mutual inductance of the applicator and anode circuits may, however, be preset or adjusted by many other arrangements including those shown in my parent applications. For reasons later herein more fully discussed, the range of adjustment of mutual inductance, either manually or automatically, should preferably be entirely in the supra-optimum range as broadly taught and claimed in said parent applications.

The high-frequency power-supply means or oscillator system 24A of Fig. 2 is of the so-called "T. N. T." type (Tuned-anode, Non-tuned grid) in which the grid-anode capacity of tube 25A provides the feedback coupling required for generation of oscillations. The high-Q resonant applicator 10A, coupled by loop 51A to the anode circuit of tube 25A, is the tank or frequency-determining circuit of the oscillator. One terminal of the grid coil or inductance 26A is connected to the grid of tube 25A and the other terminal thereof is connected, for high frequencies, to the cathode of the tube by the grid by-pass condenser 27A. The grid-leak resistor 28A in shunt to condenser 27A is traversed by the rectified grid-current of the tube to derive the direct-current bias for the grid from the generated oscillations. One terminal (B+) of the anode power-supply is connected to the grounded terminal of coupling loop 51A and the other terminal (B-) to the cathode of tube 25A which is supplied with heating current from an isolating power-transformer 23A. Thus the applicator housing 11A is at ground potential for both the high radio-frequency and high direct-current voltages involved in dielectric heating.

A press applicator similar in construction to Fig. 1 having height, length and width approximately of 3, 12 and 8 feet respectively, with an electrode 16A having length and width respectively of 10 and 5 feet, has been in operation at frequencies of from about 12 to 16 megacycles for dielectric heating of pulp wallboard requiring dissipation in the load of radio-frequency power of the order of 125 kilowatts and radio-frequency potentials between the heating electrodes of the order of 25,000 volts. The pressure applied as through insulated rods 17A, was light but sufficient to prevent warping of the wallboard during the dielectric heating. In this applicator, as generally in all tunnel applicators of the kind herein described, the resonant wavelength of the applicator is predominantly determined by the small lumped inductance of an inductor comprising the fin and the large capacitance between the electrodes. In most cases, the length of the fin inductance of the tunnel-type resonator is short compared to a quarter-wavelength, and usually less than an eight-wavelength, and the capacitance between the electrodes is very large.

The perimeter of the illustrated fin, which in certain

respects is of the type more particularly described and broadly claimed in my copending application Serial No. 419,071, filed March 26, 1954, and the connection of the fin to the "hot" electrode are such that the distances from the fin to the adjacent edges of the electrode are less than a quarter-wavelength and usually are less than an eighth-wavelength. With such construction, the "hot" electrode, though of large area to accommodate work loads of large rectangular shape, neither enforces use of frequencies which are too low for satisfactory dielectric heating nor requires the use of stubs to minimize standing waves or excessive voltage gradients along the electrodes.

In Fig. 1, the fin inductor 13A electrically connecting the "hot" electrode 16A to the upper tunnel wall may be comprised of a plurality of flexible straps 49A of metal having high conductance and some or all of which may be of beryllium-copper or other metal also having substantial resiliency. As shown in Fig. 2 by the full and dotted line positions of the fin 13A and "hot" electrode 16A, as the electrode spacing is changed the flux area between the fin and the tunnel wall is varied in the vicinity of the loop 51A. This changes the ratio between the effective area of the loop and the tunnel flux space in which the loop is disposed, so as to change the mutual inductance concurrently with the change in electrode spacing. The tunnel flux space in which the loop is disposed extends between the fin structure and the opposing wall structure with upper and lower limits corresponding with those of the loop. That tunnel flux space may also be considered as the area subtended by the loop between the inductance element 13A and the opposing wall of the housing. The effect of changing the ratio between the effective area enclosed by the loop and traversed by the magnetic field and the area subtended by the loop between the inductance element 13A and the opposing wall of the housing is used to compensate for the change in electrode voltage occurring with change in electrode spacing.

As shown by any of the curves of Fig. 4, for any given loading the "hot" electrode voltage is maximum at a point "O" for which the mutual inductance is of "optimum" value. For the range of values of mutual inductance below optimum, the electrode voltage changes in the same sense as the mutual inductance; whereas for the range of values of mutual inductance above optimum, the electrode voltage and mutual inductance change in opposite senses.

If as in the system of Fig. 2, the electrode voltage tends to decrease with increase of spacing between the heating electrodes, the concurrent change in mutual inductance should be a decrease, if in the supraoptimum range; or an increase, if in the infra-optimum range, in order to obtain compensation. If, on the other hand, the system is one in which the electrode voltage tends to increase with increase of spacing between the heating electrodes, the mutual inductance should be concurrently increased, if in the supraoptimum range; or concurrently decreased, if in the infra-optimum range.

Specifically in Fig. 2, with the mutual inductance in the supraoptimum range for load-compensation reasons later discussed, the fin 13A is made to approach the loop 51A as the electrode spacing is decreased so as to compensate for the tendency of the electrode voltage to rise with decreased spacing. By way of explanation, the decrease in capacitance incident to removal of load causes a decrease in electrode voltage, Fig. 5.

The arrangement of Fig. 2 is exemplary of arrangements in which the operation of the electrode-raising mechanism effects both relative movement of the heating electrodes and movement of structure associated with the coupling loop so as concurrently to change the spacing between the electrodes and the mutual inductance of the loop and applicator.

The resonant applicator 10B of Fig. 3 is similar to that of Fig. 1 except that the elongated fin inductor 13B

is a continuous web or sheet of flexible conductor. As the electrode spacing is varied, the fin flexes or bows, as in Fig. 2, concurrently to change the mutual inductance or inductive coupling between the resonant applicator 10B and coupling loop 51B. The applicator 10B need not be further described as the discussion of applicator 10A of Figs. 1 and 2 is generally applicable thereto and since the corresponding elements are identified by corresponding reference numbers differing only in letter suffix.

The preferred oscillator system 24B of Fig. 3 may be used with either of the applicators 10A, 10B, or any other equivalent applicator arrangement which provides change in mutual inductance concurrently with change in electrode spacing.

In oscillator system 24B, the grid-excitation voltage is derived from the "hot" electrode voltage by a capacity voltage-divider arrangement which automatically changes the ratio of these voltages with change of loading. Specifically, the excitation means in the arrangement shown includes the connection of the grid of oscillator tube 25B to heating electrode 16B by capacitor 59B. The cathode of tube 25B, so far as the generated oscillations are concerned, is grounded through by-pass condensers 61B. As graphically shown in Fig. 4, the radio-frequency potential difference between heating electrodes 15B, 16B, or their equivalent, may be adjusted to any desired value within a wide range by selection or adjustment of the mutual inductance between the anode loop 51B and the resonant applicator 10B. Since the grid-excitation is derived from the heating electrode 16B, the potential-difference between the heating electrodes must have a minimum value sufficient for proper grid-excitation. As the mutual inductance is varied in direction to increase the potential-difference of the heating electrodes, the capacitor 59B should be varied in sense to prevent excessive grid-excitation.

The radio-frequency potential of the "hot" electrode may be, and usually is, many times the radio-frequency grid potential and hence the capacity of capacitor 59B is of magnitude much less than the effective input capacity (62B) of the oscillator tube. The radio-frequency potential of the grid of the oscillator tube is always a fraction of the radio-frequency potential-difference between the heating electrodes and is inversely proportional to the ratio of the total reactance of the series-connected capacitors 59B, 62B to the reactance of the effective input capacity 62B of the oscillator tube. (Capacitor 62B represents the grid-cathode capacity alone or additive to an external shunt condenser.) With low power-factor loads, the radio-frequency potential of the grid may be one-twentieth of the "hot" electrode potential.

With the mutual inductance preset, as by adjustment of the coupling loop 51B, to provide the desired radio-frequency voltage of the "hot" electrode 16B, and with capacitor 59B preset for proper grid-excitation, the capacity 62B has an effective value which, as now explained, inherently varies with the tunnel load so that the ratio of the two reactances of voltage-divider 59B, 62B varies automatically with load and in proper sense to stabilize the grid current.

The effective input capacity C_i of the oscillator tube 25B may be expressed by the following equation:

$$(1) \quad C_i = C_{gk} + C_{gp} \left(1 + \frac{\mu R_b}{R_p + R_b} \right)$$

Where

C_{gk} = grid to cathode capacity of tube
 C_{gp} = grid to anode capacity of tube
 μ = effective amplification factor of tube
 R_p = effective anode-resistance of tube
 R_b = effective anode load resistance

As shown by Equation 1, the effective input capacity of tube 25B is proportional to the effective anode load resistance R_b which, in the applicators herein described,

is determined substantially entirely by the load being heated because of the high "Q" of the applicator itself. Specifically and by way of example, the unloaded "Q" of various tunnels used has been in the range of from 1000 to over 3000. A decrease in loaded tunnel power-factor, as occurs upon removal of part or all of the work, results in an increase in the effective anode load resistance R_b , generally as indicated in Fig. 6, and causes a corresponding increase in the effective input capacity of the tube, generally as graphically shown in Fig. 7. The increase of the effective anode load resistance R_b (Equation 1) automatically increases the capacitance and thus reduces the reactance of capacitor 62B of the potential-divider network with corresponding automatic reduction of the grid voltage to a still smaller fraction of the "hot" electrode voltage.

Since the change in mutual inductance concurrently with change in electrode spacing can, as above described, be made to compensate for change in electrode voltage due to change in spacing, and since the grid-excitation which is derived from the electrode voltage can be compensated by the voltage-divider for changes in load, the combination of these two features automatically provides corrective change of grid drive in accordance with changes in load and changes in electrode spacing.

As generally shown by the group of curves of Fig. 4, the maximum "hot" electrode voltage for a given loading occurs at a point "O" termed the point of "optimum" coupling at which the effective resistance R_b , reflected into the anode circuit of the oscillator tube from the resonant applicator, is equal to the effective anode resistance R_p . The corresponding "optimum" mutual inductance M_o is given by the equation:

$$(2) \quad M_o = \frac{\sqrt{R_p R_s}}{2\pi f_o}$$

where

f_o = operating frequency

R_s = effective series-resistance of applicator

As more fully described and broadly claimed in my aforesaid parent application Serial No. 419,633, the coupling loops of the applicators of Figs. 2, 3, or their equivalent, are preferably of dimensions and disposition insuring that the mutual inductance of the anode and resonator circuits is supraoptimum, i. e., greater than "optimum" as above defined. With these tunnel applicator constructions, supraoptimum coupling is readily obtained since essentially all of the high-frequency magnetic flux encircling the current in the fin inductor must pass through the space between the fin inductor and the walls of the tunnel.

Since the anode loop may be dimensioned and disposed to intercept a large percentage of the total flux, supraoptimum coupling is readily obtainable even with a single-turn loop, which may be a wide strap, of low inductance, facilitating satisfaction of the requirement that the anode circuit frequency for many dielectric heating applications must be substantially higher than the tunnel frequency. In all cases, the anode circuit frequency should be non-harmonically related to the resonator frequency.

With supraoptimum coupling, the electrode-voltage does not substantially vary with change in the loaded "Q" of the applicator as would occur, for example, upon change of the electrical characteristics of a dielectric load during its heating or, in a conveyor-fed applicator, upon change in the number of load objects, such as sand cores, moving between the heating electrodes. For example, referring to Fig. 4, it is assumed that the work to be heated normally causes the tunnel applicator to have an apparent power-factor of 0.002 or 0.2% and that an electrode potential of 15,000 volts is required to heat that load at the desired rate. Accordingly, the mutual inductance may be set, as by adjustment of the coupling loop at the corresponding value X, Fig. 4, prior to or during

the early stages of heating. Should, for any reason, the apparent power-factor of the applicator drop to 0.05%, the "hot" electrode potential rises only to about 17,200 volts (as indicated by "Rise" on the right-hand side of Fig. 4).

This is in marked contrast to the excessively high rise in "hot" electrode voltage occurring if, in accord with prior practice, the mutual inductance was of value Y (below optimum coupling), to obtain the initially required 15,000 volts on the "hot" electrode. Now upon reduction of the apparent power-factor of the heating circuit to 0.05%, the "hot" electrode voltage rises to over 29,000 volts (as indicated by "Rise" on the left-hand side of Fig. 4), an increase in "hot" electrode voltage of more than 90%.

With the preferred oscillator circuit 24B using supra-optimum coupling, the voltage change incident to change in dielectric constant is opposite in sense to that due to change in power-factor and consequently the net rise is less than the "X" rise, Fig. 4. By way of explanation, a decrease in capacitance between the heating electrodes causes a decrease in electrode voltage (Fig. 5) whereas a decrease in power-factor causes an increase in electrode voltage (Fig. 4).

Substantial constancy of the "hot" electrode voltage for a selected value of mutual inductance is of great advantage when, as indicated in Fig. 3, the objects to be heated are transported through the applicator by a conveyor belt 63B, or equivalent. This is so because the apparent power-factor of the applicator may vary from a very low value corresponding with the power-factor of the lightly loaded tunnel, which may be as low as 0.02%, for example, to a substantially higher value corresponding with the power factor of the heavily loaded tunnel, which may be 1.0%, for example, a variation of 50 to 1. Otherwise stated, at times the conveyor may be practically covered with load objects whereas at other times there may be only a few objects, or none, between the heating electrodes. Both the number and size of the work objects and the power-factor of the work material, as disposed between the heating electrodes, determine the apparent power-factor of the tunnel for any given electrode spacing. With the preferred circuit arrangement 24B, there is substantially uniform heating despite large variations in the load density.

When the work is of substantially higher power-factor, such as above 2% and of area comparable to that of the "hot" electrode, the interelectrode spacing should be adjusted to provide an air gap so to decrease the apparent power-factor of the tunnel. Otherwise, the power-factor of the heavily loaded tunnel might, in extreme cases, be so high that the anode current could not be reduced to safe value by adjustment of the coupling loop.

Supraoptimum coupling is advantageously used with applicators in which, as above described in connection with Figs. 1 to 3, the mutual inductance is increased concurrently with decrease of electrode spacing to compensate for the tendency of the voltage of the "hot" electrode to rise with decrease of electrode spacing. Lowering the electrode increases the capacity between the heating electrodes and causes the electrode voltage to rise (Fig. 5). However, as the electrode is lowered, the position of the fin inductor, or other conductive structure movable with the electrode, may be made to change relative to the coupling loop in manner as to increase the mutual inductance between the anode circuit and the resonant applicator. Such increase, in the constructions of Figs. 1 to 3, results due to the flexible fin inductor approaching more closely to the loop. As indicated in Fig. 4, with supra-optimum coupling, an increase in mutual inductance reduces the electrode voltage. Hence the two concurrent effects are compensatory and tend to hold the electrode voltage constant.

The bowed fin structure, or equivalent arrangement for varying the mutual inductance concurrently with

change of electrode spacing, is also of advantage in oscillator systems, such as the T. N. T. circuit of Fig. 2, having supraoptimum coupling but not using the capacity divider 59B, 62B.

Particularly, as above pointed out in the general discussion, the tendency of the electrode voltage to rise with decrease of electrode spacing is offset by the tendency of the electrode voltage to fall with increase of mutual inductance.

Since, as hereinbefore pointed out, stabilization of grid drive can be advantageously effected by combination of the capacitive voltage-divider arrangement with an arrangement for effecting change in mutual inductance concurrently with change in electrode spacing and since, as also pointed out hereinbefore, stabilization of heating electrode voltage can be advantageously effected by combination of supraoptimum coupling with such mutual-inductance changing arrangement, it follows that effective stabilization of the dielectric heating operation can be most advantageously accomplished by such mutual-inductance changing arrangement in combination with the capacity voltage-divider arrangement and supraoptimum coupling.

What is claimed is:

1. In a high-frequency dielectric heating system, the combination of a power-receiving circuit comprising a reentrant resonant applicator having conductive wall structure forming an electrically conductive housing and having therein an inductance-capacitance assembly including spaced electrodes of extended area for the heating of dielectric work disposed in the electric field between the electrodes and an inductance element reentrantly projecting into the interior of said housing in spaced relation with said wall structure to provide for the magnetic field encircling said inductance element an unobstructed path around and lengthwise thereof, one of said electrodes being formed by or electrically connected to adjacent wall structure of said housing, a second of said electrodes being disposed at and electrically connected to the inwardly projecting end of said inductance element in spaced relation to all wall structure of said housing and being electrically connected with said wall structure through said inductance element, and means including at least portions of said wall structure electrically interconnecting said inductance-capacitance assembly to complete said power-receiving circuit and affording a high unloaded Q thereof; high-frequency power-supply means having a power-delivery circuit and excitation means energized from said power-receiving circuit so that the operating frequency of the system is primarily determined by said inductance-capacitance assembly included in said power-receiving circuit; a power-transfer loop included in said power-delivery circuit and disposed within the unobstructed path of said magnetic field encircling said inductance element to provide an effective loop area, enclosed by the loop and traversed by the magnetic field, which is of lesser size than the area of the flux space subtended by the loop between said inductance element and opposing wall structure of said housing, and means for varying the ratio between said effective loop area and said subtended flux space area for varying the mutual inductance coupling between said power-delivery circuit and said power-receiving circuit.

2. The system of claim 1 in which said last-named means comprises an element of said inductance-capacitance assembly movable relative to said power-transfer loop.

3. In a high-frequency dielectric heating system, the combination of a power-receiving circuit comprising a reentrant resonant applicator having conductive wall structure forming an electrically conductive housing and having therein an inductance-capacitance assembly including spaced electrodes of extended area for the heating of dielectric work disposed in the electric field between the electrodes and an inductance element reentrantly projecting into the interior of said housing in spaced relation with said wall structure to provide for the magnetic field encircling said inductance element an unobstructed path around and lengthwise thereof, one of said electrodes being formed by or electrically connected to adjacent wall structure of said housing, a second of said electrodes being disposed at and electrically connected to the inwardly projecting end of said inductance element in spaced relation to all wall structure of said housing and being electrically connected with said wall structure through said inductance element, and means including at least portions of said wall structure electrically interconnecting said inductance-capacitance assembly to complete said power-receiving circuit and affording a high unloaded Q thereof; high-frequency power-supply means having a power-delivery circuit and excitation means energized from said power-receiving circuit so that the operating frequency of the system is primarily determined by said inductance-capacitance assembly included in said power-receiving circuit; a power-transfer loop included in said power-delivery circuit and disposed within the unobstructed path of said magnetic field encircling said inductance element to provide an effective loop area, enclosed by the loop and traversed by the magnetic field, which is of lesser size than the area of the flux space subtended by the loop between said inductance element and opposing wall structure of said housing, and means for varying the ratio between said effective loop area and said subtended flux space area for varying the mutual inductance coupling between said power-delivery circuit and said power-receiving circuit.

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trantly projecting into the interior of said housing in spaced relation with said wall structure to provide for the magnetic field encircling said inductance element an unobstructed path around and lengthwise thereof, one of said electrodes being formed by or electrically connected to adjacent wall structure of said housing, a second of said electrodes being disposed at, electrically connected to, and extending outwardly from, the inwardly projecting end of said inductance element in spaced relation to all wall structure of said housing and being electrically connected with said wall structure through said inductance element, and means including at least portions of said wall structure electrically interconnecting said inductance-capacitance assembly to complete said power-receiving circuit and affording a high unloaded Q thereof; high-frequency power-supply means having a power-delivery circuit; a power-transfer loop included in said power-delivery circuit and disposed within the unobstructed path of said magnetic field encircling said inductance element to provide an effective loop area, enclosed by the loop and traversed by the magnetic field, which is of lesser size than the area of the flux space subtended by the loop between said inductance element and opposing wall structure of said housing, and means for varying the ratio between said effective loop area and said subtended flux space area for varying the mutual inductance coupling between said power-delivery circuit and said power-receiving circuit.

4. The system of claim 3 in which said last-named means comprises an element of said inductance-capacitance assembly movable relative to said power-transfer loop.

5. The system of claim 4 in which said last-named means comprises a movable portion of said inductance element.

6. In a high-frequency dielectric heating system, the combination of a power-receiving circuit comprising a reentrant resonant applicator having conductive wall structure forming an electrically conductive housing and having therein an inductance-capacitance assembly including spaced electrodes of extended area for the heating of dielectric work disposed in the electric field between the electrodes and an inductance element reentrantly projecting into the interior of said housing in spaced relation with said wall structure to provide for the magnetic field encircling said inductance element an unobstructed path around and lengthwise thereof, one of said electrodes being formed by or electrically connected to adjacent wall structure of said housing, a second of said electrodes being disposed at and electrically connected to the inwardly projecting end of said inductance element in spaced relation to all wall structure of said housing and being electrically connected with said wall structure through said inductance element, and means including at least portions of said wall structure electrically interconnecting said inductance-capacitance assembly to complete said power-receiving circuit and affording a high unloaded Q thereof; high-frequency power-supply means having a power-delivery circuit; a power-transfer loop included in said power-delivery circuit and disposed within the unobstructed path of said magnetic field encircling said inductance element to provide an effective loop area, enclosed by the loop and traversed by the magnetic field, which is of lesser size than the area of the flux space subtended by the loop between said inductance element and opposing wall structure of said housing, and means for varying the area of said subtended flux space to change the ratio between said flux space area and said effective loop area for adjustment of the mutual inductance coupling between said power-delivery circuit and said power-receiving circuit.

7. The system of claim 1 in which said high-frequency power-supply means includes an oscillator tube and in which the said excitation means deriving the grid excitation for said tube from said power-receiving circuit com-

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prises a potential-divider including the effective input capacitance of said tube in series with capacitance means, and connections for applying to said potential-divider a potential-difference varying with change in the potential-difference between said heating electrodes, said excitation means and said ratio-varying means automatically providing corrective change of grid-excitation with changes in load and changes in electrode spacing.

8. The system of claim 1 in which said mutual inductance coupling is predetermined so as to be maintained in the supraoptimum range and in which, upon change of electrode spacing, said ratio is adjusted in sense compensatory of the effect of variation in spacing between said electrodes upon the potential-difference between them.

9. The system of claim 1 in which said high-frequency power-supply means includes an oscillator tube and in which said mutual inductance coupling is predetermined so as to be maintained in the supraoptimum range and is adjusted in sense compensatory of the effect of variation of the spacing between said electrodes upon the potential-difference between them, and in which said excitation means deriving the grid-excitation of the oscillator tube from the applicator comprises a potential-divider including the effective input capacitance of said tube in series with capacitance means, and connections for applying to said potential-divider a potential-difference varying with change in the potential-difference between said electrodes, said excitation means and said ratio-varying means effectively stabilizing the electrode voltage and the grid-excitation for changes in apparent power-factor of the applicator and for changes in spacing between the electrodes.

10. An applicator for a dielectric heating system comprising an electrically conductive housing, inductance structure therein comprising a fin inductor projecting into the interior of said housing, spaced electrode structures cooperative to provide electric field space within the housing, one of said electrode structures being disposed at the inwardly projecting end of said fin inductor in spaced relation to walls of the housing and electrically connected with wall structure of the housing through said fin inductor, said wall structure providing a low resistance, low reactance path completing 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 inductance structure and the capacitance between said electrode structures, a coupling loop within said housing in the space between a wall of said housing and said fin inductor for traverse by a magnetic field circulating about said fin inductor, said fin inductor having at least a portion thereof movable with movement of said one of said electrodes and in a direction toward and away from said loop in control of the potential between said electrode structures.

11. A high-frequency heating system comprising a generator for supplying high-frequency power to work between spaced heating electrodes, means providing a resonant applicator comprising an enclosure for the heating space between said electrodes, at least one of said heating electrodes being spaced from walls of said enclosure and electrically connected to wall structure of said enclosure by an inductor, a power-transfer coupling loop disposed in said enclosure for traverse by high-frequency magnetic flux around said inductor, and means for varying the ratio between the effective area of said loop and the cross-sectional area of the magnetic flux path about said inductor in the vicinity of said loop, thereby to control the high-frequency potential-difference of said heating electrodes of said resonant applicator, said means comprising at least a portion of said inductor which is movable toward and away from said loop.

12. A high-frequency heating system comprising an applicator having a conductive shielding enclosure and having electrodes variably spaced therein to receive dielec-

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tric material to be heated, and conductive structure within said enclosure and cooperating with wall structure thereof electrically to interconnect said electrodes, a power-transfer circuit including a loop disposed in the space between said conductive structure and the wall structure of said enclosure for traverse by the high-frequency field about said conductive structure, mechanism operable to vary the spacing between said electrodes, and structure operable concurrently with change of said spacing between said electrodes to vary the ratio between the effective area enclosed by said loop and traversed by said field and the area of said space subtended by said loop between said conductive structure and said wall structure of said enclosure.

13. The system of claim 12 in which said loop is in the anode circuit of an oscillator tube, and in which potential-divider means derives the grid-excitation of said tube from said applicator, said potential-divider means including the effective input capacitance of said tube and capacitance in series therewith, and connections for applying to said potential-divider a potential-difference varying with change in the potential-difference between said electrodes.

14. The system of claim 12 in which said loop is in the anode circuit of an oscillator tube and is dimensioned relative to said space to obtain supraoptimum coupling, and in which a potential-divider deriving the grid-excitation of said oscillator tube from said applicator comprises the effective input capacitance of said tube and capacitance in series therewith, and connections for applying to said potential-divider a potential-difference varying with change in the potential-difference between said electrodes.

15. The system of claim 12 in which the applicator is resonant at a frequency predominantly determined by the inductance of said conductive structure and the capacitance between said electrodes, in which said loop is in the anode circuit of an oscillator tube whose frequency is determined by said resonant frequency of said applicator and in which the mutual inductance between said loop and said conductive structure is in the supraoptimum range, and which additionally includes potential-divider means for deriving the grid-excitation of the oscillator from said applicator, said potential-divider means comprising the effective input-capacitance of the oscillator tube and a capacitance in series therewith, and connections for applying to said potential-divider means a potential-difference corresponding with the potential-difference between said electrodes.

16. The system of claim 12 in which said conductive structure is at least in part flexible and is movable by said mechanism toward and away from said loop.

17. A high-frequency heating applicator of the re-entrant resonant type comprising electrodes variably spaced to receive dielectric material to be heated, a shielding enclosure having conductive wall structure, conductive

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structure reentrantly extending into said enclosure and cooperating with said wall structure electrically to interconnect said electrodes, a power-transfer circuit including a loop disposed in the space between said conductive structure and the wall structure of said enclosure for traverse by the high-frequency magnetic field about said conductive structure, mechanism operable to vary the spacing between said electrodes, and structure operable concurrently with change of said spacing between said electrodes to vary the area of said space subtended by said loop between said conductive structure and said enclosure to change the ratio between said area and the effective area enclosed by said loop and traversed by said field.

18. An applicator for a dielectric heating system, comprising an electrically conductive housing, inductance structure therein comprising a fin inductor projecting into the interior of said housing, spaced electrode structures cooperative to provide electric field space within the housing, one of said electrode structures being disposed at the inwardly projecting end of said fin inductor in spaced relation to walls of said housing and electrically connected with wall structure of said housing through said fin inductor, said wall structure providing a low-resistance, low-reactance path completing 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 inductance structure and the capacitance between said electrode structures, and a high-frequency power-supply circuit including a coupling loop within said housing for traverse by a magnetic field produced by current flow through said fin inductor and affording mutual inductance coupling between said resonant circuit and said power-supply circuit, said fin inductor having at least a portion thereof movable with movement of said one of said electrodes and in a direction toward and away from said loop to vary said mutual inductance coupling in control of the potential between said electrode structures.

References Cited in the file of this patent

UNITED STATES PATENTS

2,215,582	Goldstine	Sept. 24, 1940
2,218,223	Usselman et al.	Oct. 15, 1940
2,292,798	Roberts	Aug. 11, 1942
2,342,897	Goldstine	Feb. 29, 1944
2,465,102	Joy	Mar. 22, 1949
2,467,782	Schuman	Apr. 19, 1949
2,504,109	Dakin et al.	Apr. 18, 1950
2,504,956	Atwood	Apr. 25, 1950
2,504,969	Ellsworth	Apr. 25, 1950
2,506,626	Zottu	May 9, 1950

FOREIGN PATENTS

55	556,292	Great Britain	Sept. 28, 1943
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