Oct. 4, 1949. R. M. BAKER 2,483,569

HIGH-FREQUENCY DIELECTRIC HEATING

Filed Sept. 28, 1944 2 Sheets-Sheet 1

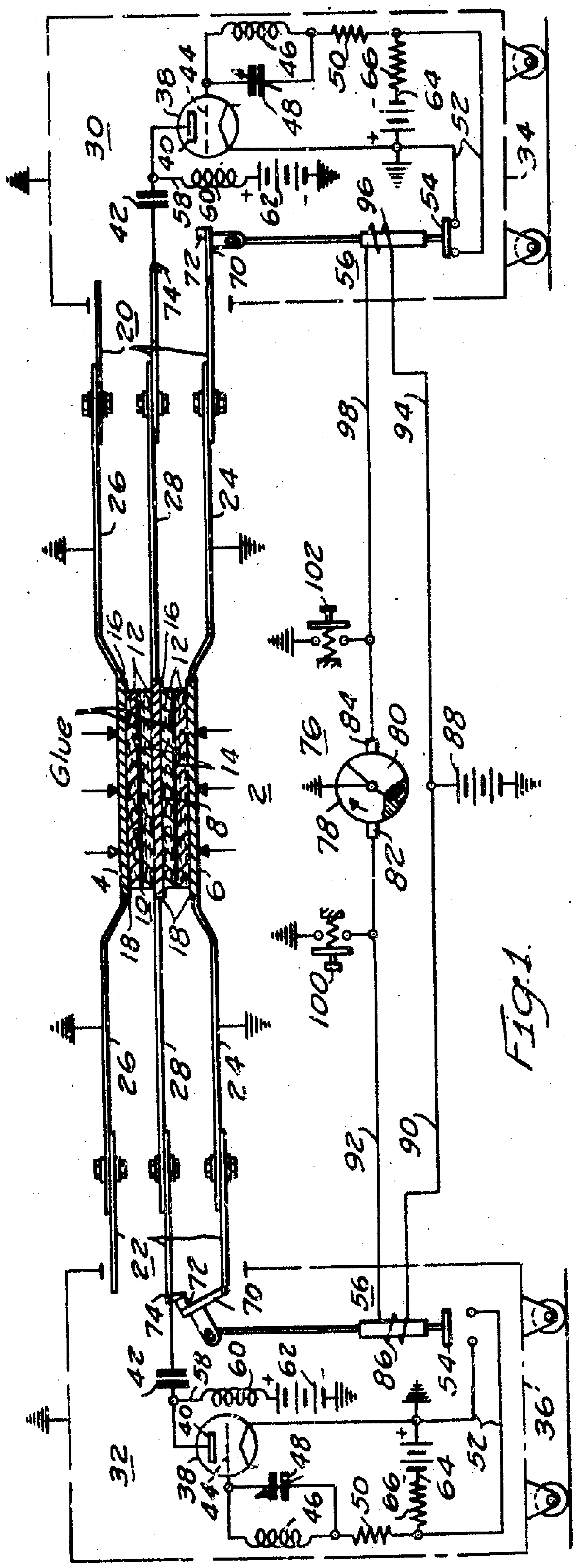


Fig. 1

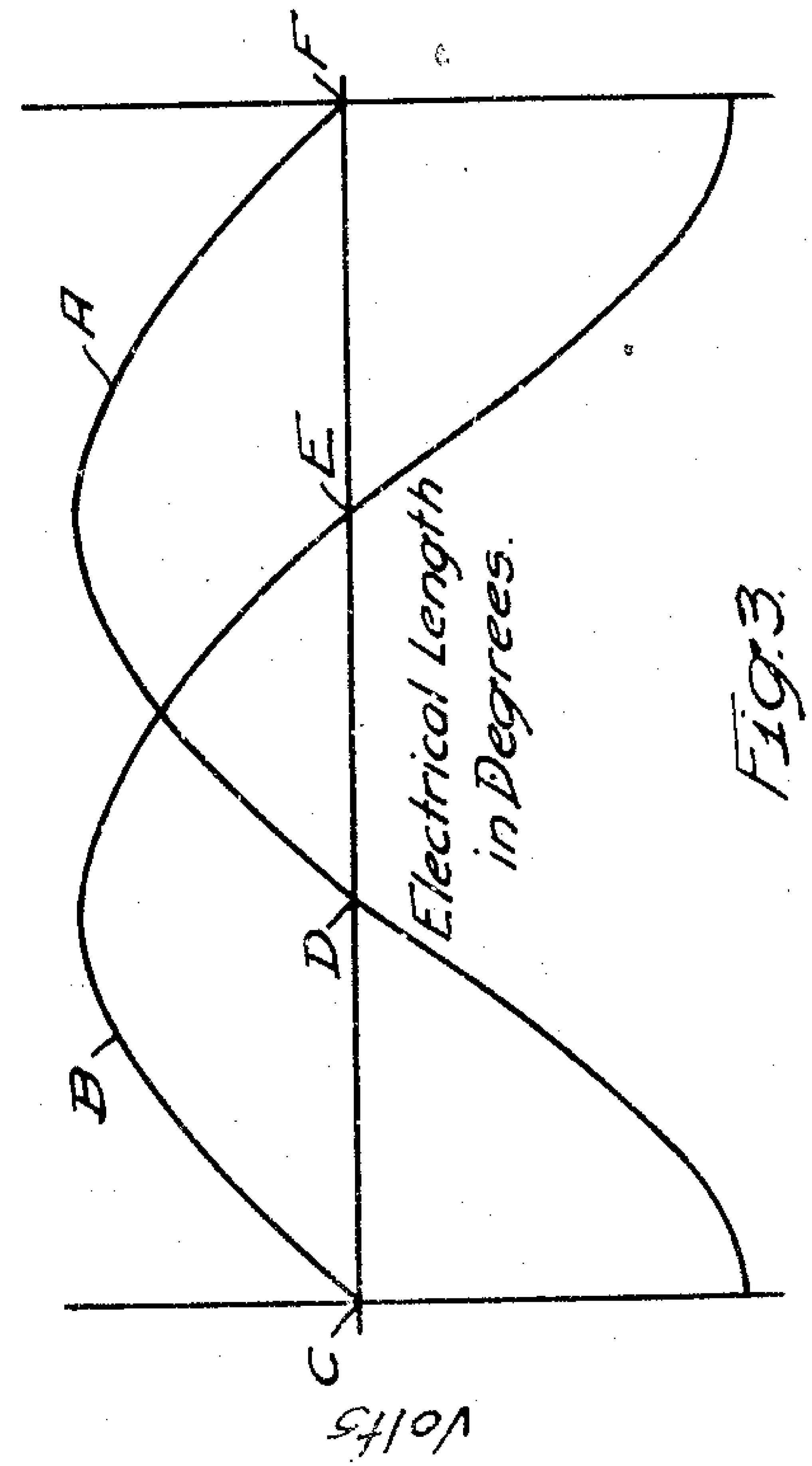


Fig. 3

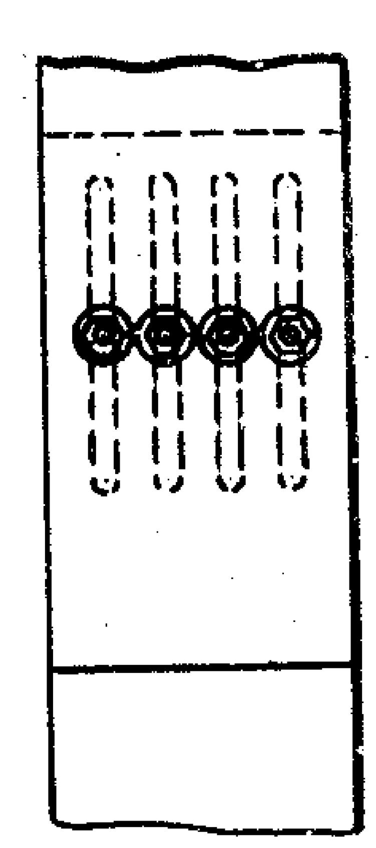

Fig. 2

WITNESSES:

E. A. McCloskey.

James F. Young

INVENTOR

Robert M. Baker.

BY

B. L. Zangwill

ATTORNEY

HIGH-FREQUENCY DIELECTRIC HEATING

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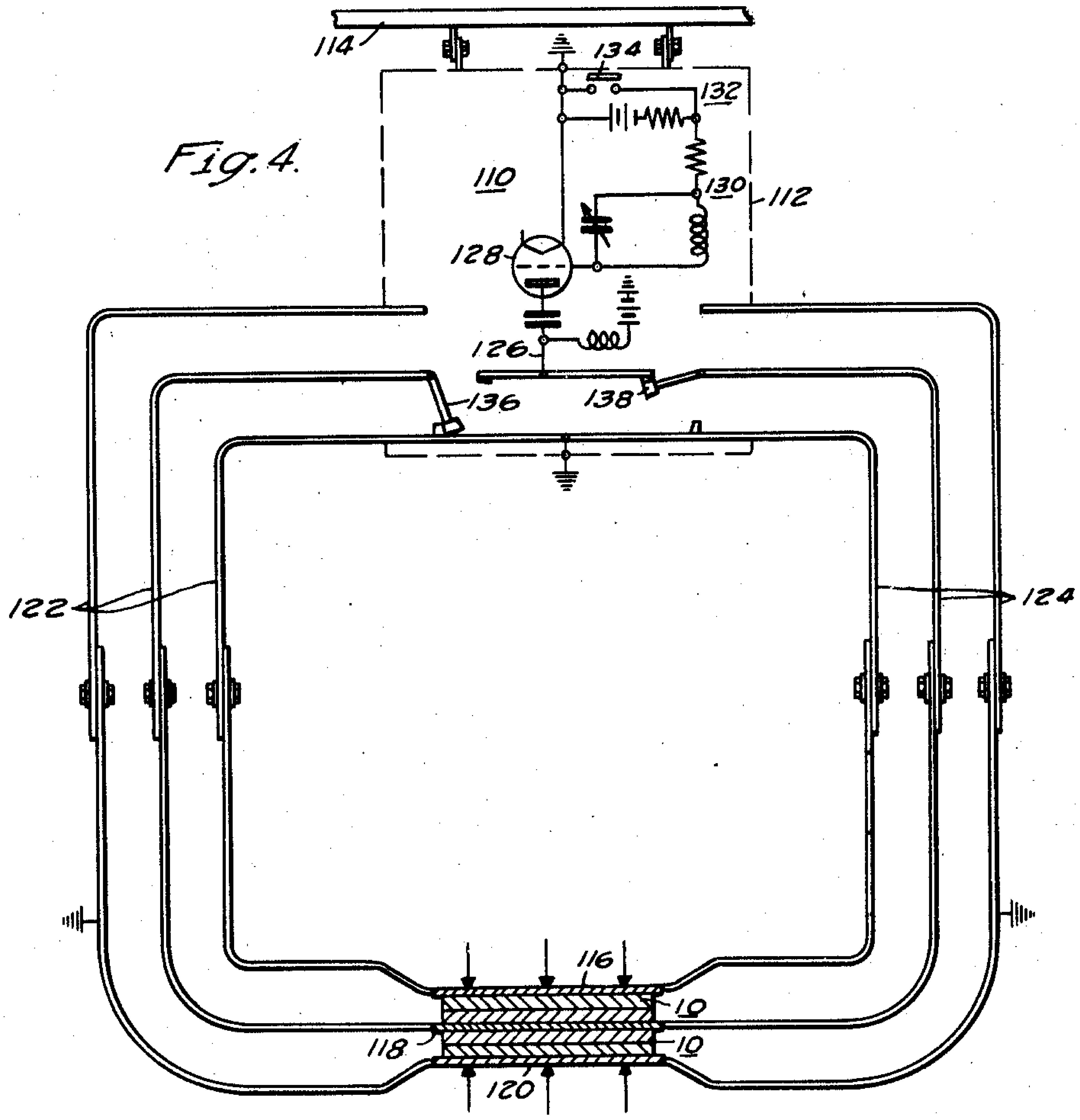
Fig. 4.



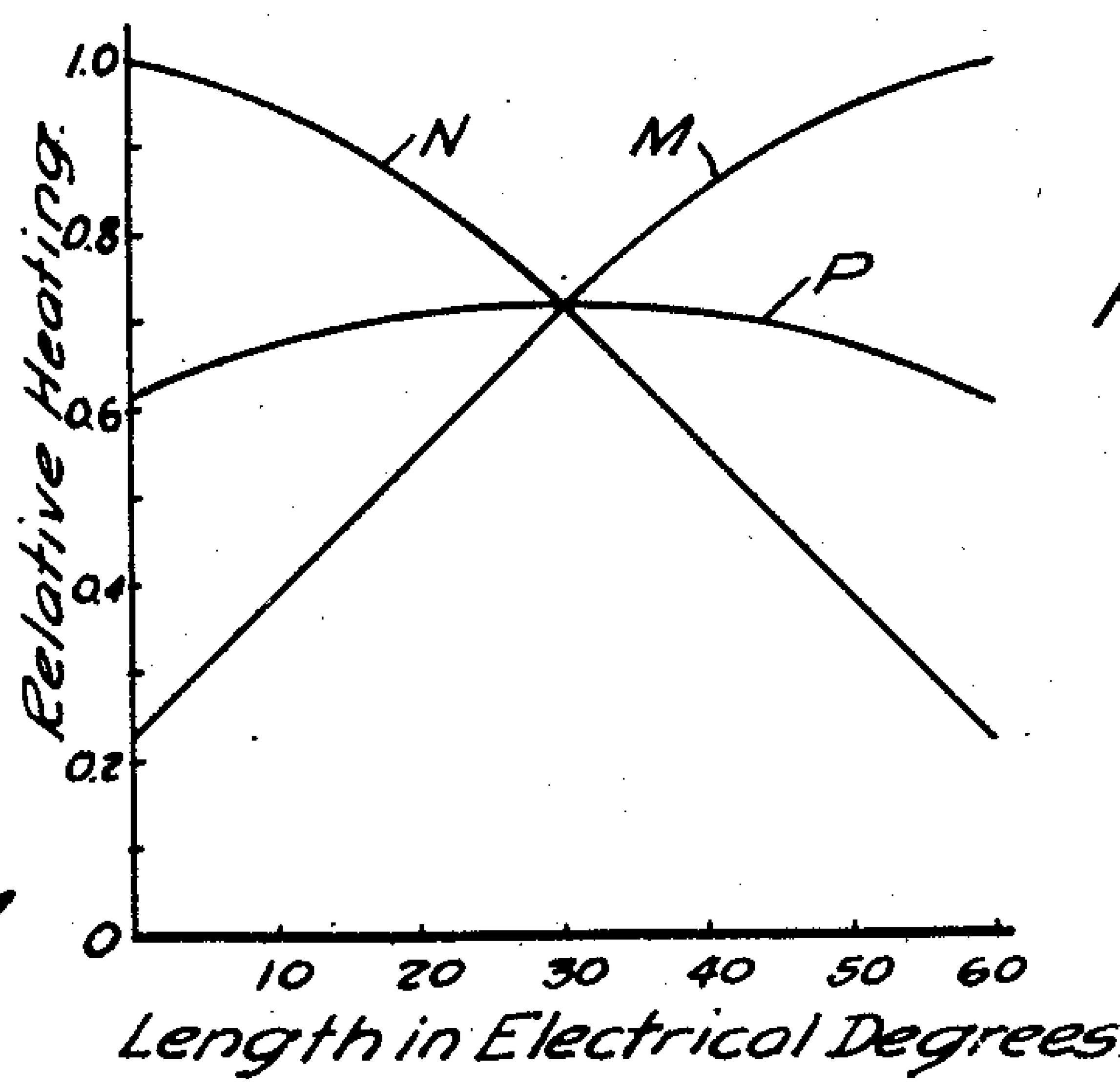




Fig. 5.

WITNESSES:
E. A. McCloskey
James T. Young

INVENTOR
Robert M. Baker.
BY
B. L. Zangwill
ATTORNEY

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# UNITED STATES PATENT OFFICE

2,483,569

## HIGH-FREQUENCY DIELECTRIC HEATING

Robert M. Baker, Pittsburgh, Pa., assignor to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

Application September 28, 1944, Serial No. 556,140

10 Claims. (Cl. 219—47)

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This invention relates, generally, to dielectric heating in which a dielectric material is heat treated between a plurality of spaced heating-electrodes having a high frequency voltage there across.

In dielectric heating, such as can be used in the manufacture of large pieces of plastic products, plywood and the like, it is preferable, and generally necessary, to use high frequencies of several megacycles or more in order to keep the voltage required across the heating-electrodes down to reasonable and practicable magnitudes. In many instances, the heating-electrodes must be long enough to receive material several feet in length, perhaps as much as twenty feet or more. At the operating frequencies, standing-wave voltage patterns are likely to exist along the heating-electrodes and also on the lines conveying or transmitting power to them. If there is enough difference between the maximum and minimum values of the standing-wave patterns on the heating-electrodes, serious variations occur in the manner in which different parts of the material are heat treated. Such non-uniformity of heat treatment may be further aggravated if the power delivered per increment of electrode length or surface is large so as to cause an attenuation of the standing-wave pattern on the heating-electrodes from the point at which the power is delivered. For production on a commercial scale, the troublesome problem arises of providing a tube-oscillator generator having a tunable resonant plate circuit or tank circuit which can supply the power required.

An object of my invention is to improve the manner in which heat is dielectrically introduced into a material which is dielectrically heated between heating-electrodes having a part of a standing-wave pattern therein.

A further general object of my invention is to provide a dielectric heating system of a type described in which the standing wave-pattern on the heating-electrodes can be adjusted so as to provide a desired part of a wave length therealong.

A particular object of my invention is to provide a dielectric heating system having heating-electrodes of an electrical length which encompasses an appreciable part of a standing wave, but which will heat the dielectric material with satisfactory uniformity although the standing wave has widely different maximum and minimum values on the heating-electrodes.

Another object of my invention is to provide a high-frequency dielectric heating system by means of which considerable energy can be quickly and substantially uniformly put into a large piece of material.

An important object of my invention is to provide a voltage distribution over the heating-electrodes which is intermittently changed during a heat-treatment cycle of the material being heat treated. The voltage distribution is changed in a manner to cause the square of the different voltages across substantially opposite parts of the electrodes to be substantially the same, or within close variations, when averaged over the heat-treatment cycle for the material.

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A feature of my invention resides in providing a dielectric heating system having one or more tube--oscillator power supplies in which the customary tank circuit is replaced by a power transmission line comprising a frequency-determining circuit.

Other features, objects, methods, innovations and combinations of my invention will be discernible from the following description thereof, which is to be taken in conjunction with the accompanying drawings illustrating forms of my invention at present preferred. In the drawings,

Figure 1 is a diagrammatic view of an embodiment of my invention with parts in elevation;

Fig. 2 is a top plan view of a portion thereof illustrating plate-like conductors used in the power transmitting lines;

Fig. 3 is a curve illustrating a standing-wave voltage pattern established on the power lines and heating-electrodes under different conditions of operation of the embodiment of my invention which is shown in Fig. 1, the ordinates representing the voltage-magnitudes and the abscissae representing electrical lengths in degrees;

Fig. 4 is a diagrammatic view of a second embodiment of my invention; and

Fig. 5 is a curve illustrating the relative heating along the heating-electrodes of the embodiment of Fig. 4, under different conditions of operation.

In carrying out my invention, I provide a dielectric heating equipment comprising heating-electrodes to the opposite ends of which sets of similar conductors are electrically associated or connected. The other far ends of the conductors are alternately energized with high-frequency power or short-circuited, the far ends of one set of conductors being short-circuited when the other is delivering power to the heating-electrodes, so that each set of conductors functions as a power transmission line, and is so designated herein. In the embodiment shown in Fig. 1, the heating-electrodes and transmission lines are co-extending and a separate tube-oscillator generator is provided for each of the transmission lines; while in that shown in Fig. 4 the transmission line conductors extend upwardly so as to save floor space and to permit a single tube-oscillator to be selectively connected to each of the transmission lines.

Referring to Fig. 1, a dielectric heating means is indicated in its entirety by the reference numeral **2**. It comprises a plurality of substantially equally spaced rectangular heating-electrodes including outer grounded plates or platens 4 and 6, and an intermediate plate 8, all of substantially the same dimensions. The outer heating-electrodes are pressed toward each other and toward the intermediate electrode, as indicated by the arrows shown, for applying pressure to dielectric material 10 which is to be treated under heat and pressure. In the particular instance, this material comprises a plurality of alternating layers of veneer 12 and glue 14 for making plywood.

The heating-electrodes 4, 6 and 8, have opposite end sides, 16 and 18, to which a transmission line, 20 and 22, respectively, is conductively connected in any suitable manner. Each transmission line comprises a pair of grounded outer conductors 24 and 26 and an intermediate insulated conductor 28, in parallel relation. The conductors are of sheet copper and substantially flat, having a width in the preferred embodiment equal to about the width of the heating-electrodes. Although not absolutely essential, it is preferable to keep the conductors uniformly spaced a distance which is related directly to the spacing of the heating-electrodes, and inversely to the square root of the dielectric constant of the material between the heating-electrodes.

Power is established on the transmission lines 20 and 22 by tube-oscillator generators 30 and 32, respectively, located in grounded metallic cages 34 and 36, respectively, at the far ends of the transmission lines which are away from the heating-electrodes. Each cage is provided with an open window for the associated insulated conductor 28 of the associated transmission line. The other grounded conductors are grounded to the corresponding cage. Each of the tube-oscillator generators is shown schematically as comprising an oscillator tube 38 having an anode or plate-electrode 40 electrically connected or associated, through a coupling means comprising a blocking capacitor 42, to the insulated conductor 28.

With a dielectric material 10 between the heating electrodes, by dielectric meaning one having a loss factor in the order of .1 or less, or even more under some circumstances, the impedance characteristics between the conductor 28 and the grounded conductors 24 and 26 usually will be the primary factor in determining the frequency at which the tube 38 oscillates. The tube 38 includes a control electrode or grid 44 to which a tunable grid circuit is connected so that a tuned plate circuit, tuned grid circuit form of oscillator is provided.

The grid circuit includes an inductor 46 connected in parallel with a variable capacitor 48, the parallel circuit having one side series connected to one end of a biasing resistor 50, the other end of which is connected to a low resistance branch-circuit 52 which includes a movable contact 54 of a relay means 56. When the movable contact 54 is in its back or closed position, it completes the low resistance branch-circuit 52 and permits the tube 38 to oscillate and deliver a high power derived from the D. C. plate energizing circuit 58 which includes a high frequency choke 60 and a plate battery 62. When the contact 54 is in its front or open postion, the circuit 52 is interrupted and a negative biasing branch-circuit 64 is effective on the grid circuit for applying a sufficiently high negative bias to the grid 44 of the tube 38 for preventing oscillations. A protective resistor 66 is included in the branch-circuit 64 for preventing excessive current when the branch-circuit 52 is closed at the contact 54. Accordingly, it is obvious that when a contact 54 is in back closed position, the associated tube-oscillator generator 30 or 32 is conditioned for generating high frequency power for application to the transmission line-section 20 or 22, and when it is in the front position oscillations are prevented because of the high negative bias applied to the grid.

In accordance with my invention, it is desired to short-circuit each end of the transmission lines 20 and 22 at suitable times. For short-circuiting purposes, one of the grounded conductors 24 of each transmission line is provided with a hinged conductor section 70 having a contact 72 adapted to engage a contact 74 at the end of the insulated conductor 28 when the relay means 56 associated therewith is energized for placing its contact 54 in front or open position.

In order to control the sequence of operations of the apparatus, I provide a timer 76 adapted to rotate once every twenty or thirty seconds, although the time period is variable over a wide range. The timer 76 comprises a grounded conducting segment 78 of somewhat more than a half circle and an insulating segment 80 for the balance of the circle. Brushes 82 and 84 are provided on diametrically opposite sides of the timer. During rotation of the timer, a circuit is alternately completed to the relay means 56 of the tube-oscallator generator 30 and to the relay means 56 of the tube-oscillator generator 32.

The operation is as follows: Assuming the apparatus in the position shown, a circuit is completed to the operating coil 86 of the relay means 56 of the tube-oscillator generator 32. This circuit starts from one end of a battery 88, continues through a conductor 90 to the coil 86, through a conductor 92, the brush 82 and conducting segment 78, to the other grounded end of the battery 88. Inasmuch as the brush 84 is on the insulating segment 80, the circuit from the battery 80 through the conductor 94, the operating coil 96 of the relay means 56 of the tube-oscillator generator 30, the conductor 98, and the brush 84, is interrupted so that this relay means is deenergized.

With the operating coil 86 energized, the grounded hinged conductor section 70 is in raised position short-circuiting the transmission line 22, and the associated contact 54 is in open position permitting the large negative bias to be applied to the grid of its associated tube 38 so that the tube-oscillator generator 32 is not in oscillating power-delivering condition. On the other hand, the tube-oscillator generator 30 is in oscillating condition because its operating coil 96 is deenergized so that its associated contact 54 is in closed position permitting its associated tube 38 to oscillate, and the hinged conductor section 70 for the transmission line 20 is in down position, with contacts 72 and 74 separated, so that the high frequency power is sent along the transmission line 20.

When the timer moves in the direction of the arrow, the brush 84 first engages the conducting segment 78 before the brush 82 leaves this segment. Accordingly, the operating coil 96 of the tube-oscillator generator 30 is energized, and its contact 54 is first moved to open position and then its grounded movable conductor-section 70 is connected to the insulated conductor 28 of the transmission line 20. Both tube-oscillator generators 30 and 32 are in non-oscillating condition for a short time while the brushes are both in contact with the conducting segment 78. When the timer moves so that the insulated segment 80 is under the brush 82, the operating coil 86 of the tube-oscillator generator 32 becomes deenergized, causing, first, a separation of the contacts 72 and 74 of the transmission line 22 by lowering the hinged conductor-section 70 thereof, and, then, a movement of the associated contact 54 to closed position, thereby placing the tube-oscillator generator 32 in oscillating power-delivering condition. The latter will deliver power until the conducting segment 78 reaches the brush 82 whereupon its oscillations will be stopped and the conductor-section 70 of the transmission line 22 placed in short-circuiting position. Substantially immediately thereafter, the brush 84 will leave the conducting segment 78 so that the operating coil 96 of the tube-oscillator generator 30 is deenergized, thereby first causing a separation of the contacts 72 and 74 of the transmission line 20, and then moving its contact 54 to closed position so that high-frequency power is applied to the transmission line 20.

From the foregoing, it is evident that with the timer rotating at a constant speed, energy will be applied first to one transmission line and then to the other transmission line for alternating repeating intervals, both lines being deenergized for short times during switching. It is also evident that when one transmission line has power delivered to one of its ends, the far end of the other transmission line is short-circuited so that there is no voltage across its conductors thereat. For manual control switches 100 and 102 can be used in the place of the timer.

In accordance with the described form of my invention, the two transmission lines have substantially the same electrical length and, under ideal conditions, each should be a quarter of a wave length at the frequency at which the tube-oscillator means 30 and 32 oscillate, the frequencies being preferably the same for both generators. The electrical length of the heating-electrodes with the material 10 therebetween is also preferably a quarter of a wave length at the supplied frequency. This means that the total electrical length of the serially-connected transmission lines 20 and 22, with the dielectric heating means 2 therebetween, is three-fourths of a wave length.

With the generator end of a transmission line short-circuited and the generator end of the other transmission line receiving power, standing-wave voltage patterns will be present along the power transmitting and power consuming system, as represented by curve A of Fig. 3 when the tube-oscillator generator 32 is supplying the power, and by curve B when the tube-oscillator generator 30 is supplying the power, the abscissae being electrical lengths. The point C represents the point of the transmission line 22 at which the tube-oscillator generator 32 can deliver power thereto. The points D and E represent the ends 18 and 16, respectively, of the heating-electrodes. The point F represents the point of the transmission line 20 at which the tube-oscillator generator 30 can deliver power thereto.

Each part of the curves A and B between the points C and D, between the points D and E and between the points F and E, is approximately a quarter of a sine wave cycle, or a quarter of a wave length. The portions of the two curves A and B between the points D and E represent the standing-wave voltage patterns along the heating-electrodes, and are 90 electrical degrees out of phase. The successive voltages at each point across the material 10 can, accordingly, be represented as a function of the sine and cosine of the same angle. The heating or power input to the dielectric material depends on the square of the voltage. Consequently, that part of the curves A and B along the heating-electrodes must be squared for obtaining the heating along each point of the material. If the curve A between the points D and E is represented by the sine and the curve B between the same points by the cosine, the squares are, respectively, $\sin^2$ and $\cos^2$. From elementary trigonometry, the $\sin^2$ plus the $\cos^2$ is equal to one, so that the average heating between the points D and E will, under the conditions assumed, be uniform along all points if the standing wave on the heating-electrodes is intermittently repeatedly changed from curve A to curve B and back at regular intervals.

In actual practice, a heat-treatment can vary from several minutes to several hours as a rule. During each heat-treatment the wave-pattern changes cyclically in accordance with the speed of the timer. The speed of the timer 76 can obviously be controlled as desired, to give as many alterations of the standing-wave pattern on the heating-electrodes as desired during a heat-treatment.

The dielectric constant of the material being heat treated will generally vary not only for different batches of the material, but also for a given batch during a heat treatment thereof, so that ideal conditions are not generally obtained. However satisfactory uniformity is usually obtained with variations in the heating voltage on the different points along the electrodes of as much as 2 to 5%, and sometimes more. Also many materials can tolerate somewhat higher temperatures above the minimum required for heat-treatment. By making the minimum temperature occur at the minimum voltage-point, the material can be relatively quickly heat-treated without being adversely affected by the higher temperatures present at the points of higher voltage.

In order to heat materials of varying dielectric properties with a single heating apparatus, it is desirable to adjust the supply frequency so as to provide a suitable standing wave pattern on the heating-electrodes. The electrical length of the transmission lines can be changed by adjusting their physical lengths and the tube-oscillator means moved in accordance therewith. To this end, each conductor of the transmission lines comprises a pair of co-extending conductor-sections having overlapping portions slidable on each other so that the total physical length of the transmission lines can be altered as indicated schematically in Figs. 1 and 2. Such overlapping portions may be provided with elongated slots permitting them to be bolted together in various different positions. When the length of a transmission line 20 or 22 is changed, the cage containing the associated tube and oscillator means 30 or 32 is correspondingly moved. To permit this to be conveniently done, the cages 34 and 36 are supported on wheels.

A somewhat different embodiment is shown in Fig. 4. In this embodiment, a single tube-oscillator means 110 is supported inside grounded metal cage 112 which is vertically adjustably supported from ceiling 114. Heating-electrodes 116, 118 and 120 are provided for heating dielectric material 10 therebetween. Three-conductor transmission lines 122 and 124 are provided respectively connected to opposite ends of the heating-electrodes. The natural resonance frequency of the transmission lines and heating-electrodes can be adjusted by changing the amount of overlapping of the conductor sections thereof. The outer conductors are grounded and the inner insulated conductors pass through opposite open windows in the cage 112 for selective connection to the output side 126 of an oscillator tube 128 of the tube-oscillator generator 110. A suitable grid circuit 130 similar to that of the tube-oscillator generators 30 and 32 is connected to the tube 128. The bias control circuit 132 for the grid includes a contact 134 controlled by a suitable timer either to short-circuit, in effect, the negative bias or to permit a high negative bias to be applied to the grid of the tube. Hinged sections 136 and 138 on the insulated inner conductors of the transmission lines are operable by the timer to short-circuit the transmission line 122 while power is being delivered to the transmission line 124, and for short-circuiting the transmission line 124 while power is being delivered to the transmission line 122. The contact 134 and the hinged sections 136 and 138 are operated in suitable sequence so as to first stop the power delivery of the tube-oscillator generator 110 before the positions of the hinged sections 132 and 134 are reversed.

In many cases, it is not especially essential to have quarter wave lengths of standing waves across the dielectric material, and in Fig. 5 I show the heating which obtains with heating-electrodes of an electrical length, in operation, of 60° at the supplied frequency. Curve M indicates the standing-wave voltage pattern when one transmission line is energized and curve N the pattern when the other transmission line is energized. Curve P is the average of the sum of the squares of the curves M and N. This curve P is fairly flat and indicates the marked improvement in heating over that obtainable through operation with a single standing-wave pattern, bearing in mind that the square of the voltage is an indication of the heating.

The difficulty of generating high power at very high frequencies makes it desirable to keep the loaded length of the line, that is the length of the heating-electrodes between the transmission lines, down to about one quarter of the effective wave length. This wave length, λ, in feet, is given by the expression

$$\frac{\lambda}{4}=\frac{2.46\times10^8}{f\sqrt{K}}$$

where

$f$=frequency (cycles per second)
K=dielectric constant of load.

With a block of plywood 4′ wide by 8′ long by 6″ thick, having a dielectric constant of 4, between rectangular heating-electrodes of about the same dimensions, the frequency, from the foregoing equation, will be 15.4 megacycles if 8 feet of heating electrodes are required for a quarter wave length. The length of the unloaded lines, that is the transmission lines 20 and 22, for example, to make up the other quarter wave lengths will each be approximately 16 feet, making a total length of about 40 feet for the power transmitting and consuming means.

The flat plate-like conductors need not be very thick, but should be not less than twice the "depth of current penetration." At high frequencies the conductors actually can be very thin. The flat plate-like conductors can store considerable reactive or circulating k. v. a. and are included in the tank circuit for the tube-oscillator generators. In general, the capacitance between the conductors makes the use of a tuning capacitor unnecessary or infeasible. Improved tuning is satisfactorily obtained by changing the length of the transmission lines and changing the tuning of the tunable grid circuit to correspond.



While I have described my invention in forms which are now preferred, it is obvious that the principles and teachings of my invention have broader application and can be readily utilized by those skilled in the art for other embodiments involving high-frequency heating.

I claim as my invention:

1. Dielectric heating apparatus for the high-frequency heating of dielectric material, comprising, in combination, a plurality of spaced heating-electrodes for receiving dielectric material therebetween, a plurality of high-frequency transmission lines, a first of said transmission lines being connected to a first point on said heating-electrodes and a second of said transmission lines being connected to a second point on said heating-electrodes, said first and second points being spaced apart on said heating-electrodes, generator means for delivering a high-frequency voltage to each transmission line at a place removed from said heating electrodes, the frequency of the voltage being sufficiently high to establish a standing-wave pattern along said transmission lines and said heating-electrodes, during a heating operation, said generator means comprising tube-oscillator means having an oscillator tube and a frequency-determining circuit therefor comprising said transmission lines, control means operable for causing power from said tube-oscillator means to be delivered to each of said transmission lines, means operable for short-circuiting each of said transmission lines, and means for separately intermittently operating said control means and said short-circuiting means in a predetermined sequence during a heating operation.

2. High-frequency heating equipment comprising relatively insulated spaced heating-electrodes providing a spacial field of energy for heating dielectric material within said field, said heating electrodes having a plurality of separate spaced places to each of which high-frequency power can be established, and power applying means for causing such power to be sequentially established at said places in a predetermined sequence, the frequency of said power and the distance between said places being such as to provide different curved voltage wave patterns on said heating-electrodes, during a heating operation, with magnitudes of said standing wave-patterns such that the average of their squares is approximately uniform.

3. Dielectric heating apparatus comprising, in combination, a plurality of spaced substantially rectangular heating-electrodes for receiving dielectric material therebetween, two high-frequency transmission lines, an end of each of said transmission lines being associated with a separate one of a pair of opposite sides of said heating-electrodes, and means coupled to each of the other ends of said transmission lines, for selectively applying high-frequency energy to each transmission line in a predetermined sequence,

the sequence for a first for said transmission lines being other than that for sequence for the other of said transmission lines, the frequency of the energy supplied to said transmission lines being such as to provide curved voltage wave patterns on said heating-electrodes.

4. Dielectric heating apparatus comprising a plurality of spaced heating-electrodes for receiving dielectric material for heat-treatment therebetween, two generally similar high-frequency transmission lines each comprising a plurality of spaced facing conductors, an oscillator tube-means adapted to be electrically connected to either of said transmission lines, said heating-electrodes being electrically connected to one end portion of each of said transmission lines, and means for causing said tube-means selectively to deliver power to the other end portions of said transmission lines in a predetermined sequence.

5. Dielectric heating apparatus comprising a plurality of spaced heating-electrodes for receiving dielectric material for heat-treatment therebetween, two generally similar transmission lines each comprising a plurality of spaced facing plate-like conductors, an oscillator tube-means adapted to be electrically connected to either of said transmission lines at a frequency determined primarily by said transmission line, said heating-electrodes being electrically associated with one end of each of said transmission lines, and said tube-means being electrically connectible to their other ends, means operable for short-circuiting each of said other ends, and timing means for intermittently alternately electrically connecting said tube-means with said transmission lines, and for operating said short-circuiting means for the transmission line which is not electrically connected to said tube-means.

6. The invention of claim 2 characterized by said power-applying means comprising means for causing the wave patterns established on said heating-electrodes to consist of substantially an odd number of quarter-waves substantially following a sine and cosine form from a point on said heating-electrodes, said power-applying means for applying power producing each of said sine and cosine forms alternately for substantially the same time periods.

7. A method of giving a dielectric material of some length a single dielectric heat-treatment between a pair of spaced heating-electrodes, the method comprising heating the material by applying high-frequency power to the heating-electrodes in a manner to establish a voltage wave-pattern thereon of varying magnitudes, and repeatedly cyclically changing the voltage wave-pattern by cyclically changing the network system connected to the heating electrodes.

8. A method of giving a dielectric material of some length a dielectric heat-treatment between spaced heating-electrodes, the method comprising alternately energizing the heating-electrodes, for successive substantially equal time-periods, with high-frequency power providing a standing-wave voltage pattern along the heating-electrodes, the wave having, in alternate periods, a sine function embracing a quarter-wave along a predetermined physical portion of the electrodes, and having, in the other alternate periods, a cosine function embracing a quarter-wave length along substantially the identical portion of the heating-electrodes.

9. A method of dielectrically heating a material of some length between a pair of spaced heating-electrodes, which method comprises successively energizing the heating-electrodes with high-frequency electrical power so as to establish first a high-frequency standing-wave voltage pattern along said heating-electrodes, the pattern having an envelope which is a sine function of the frequency, and then, before the material has cooled, energizing the heating-electrodes with high-frequency electrical power so as to establish a standing-wave voltage pattern along said heating-electrodes having an envelope which is a cosine function of the frequency, that corresponds otherwise to the sine function.

10. Dielectric heating apparatus for the high-frequency heating of dielectric material, comprising, in combination, a plurality of spaced heating-electrodes for receiving dielectric material therebetween, a plurality of high-frequency transmission lines, a first of said transmission lines being connected to a first point on said heating-electrodes and a second of said transmission lines being connected to a second point on said heating-electrodes, said first and second points being spaced apart on said heating-electrodes, generator means adapted to deliver a high-frequency voltage to each of said transmission lines at a place removed from said heating-electrodes, the frequency being sufficiently high to establish a standing wave pattern along said transmission lines and said heating-electrodes, during heating operations, and means comprising a timer for sequentially causing said generator means to apply energy to said transmission lines, with the sequence associated with said first transmission lines being other than that associated with said second of said transmission lines.

ROBERT M. BAKER.


## REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

| Number | Name | Date |
|---|---|---|
| 1,972,050 | Davis | Aug. 28, 1934 |
| 2,159,782 | Conklin et al. | May 23, 1939 |
| 2,293,533 | Denneen et al. | Aug. 18, 1942 |
| 2,304,958 | Rouy | Dec. 15, 1942 |
| 2,308,043 | Bierwirth | Jan. 12, 1943 |
| 2,308,204 | Parry | Jan. 12, 1943 |
| 2,370,423 | Roberts | Feb. 27, 1945 |
| 2,433,067 | Russell | Dec. 23, 1947 |

FOREIGN PATENTS

| Number | Country | Date |
|---|---|---|
| 118,453 | Australia | May 11, 1944 |

OTHER REFERENCES

Bierwirth et al.: "Radio-frequency heating applied to wood gluing," Proceedings of the Institute of Radio Engineers, October 1943, pages 529–537 (particularly pages 534 and 535). Copy in Scientific Library.

Batcher et al.: "The Electronic Engineering Handbook" (1944), Electronic Development Associates, 125 East 46th Street, New York 17, New York, pages 222 and 224. Copy in Division 60.