

March 13, 1951

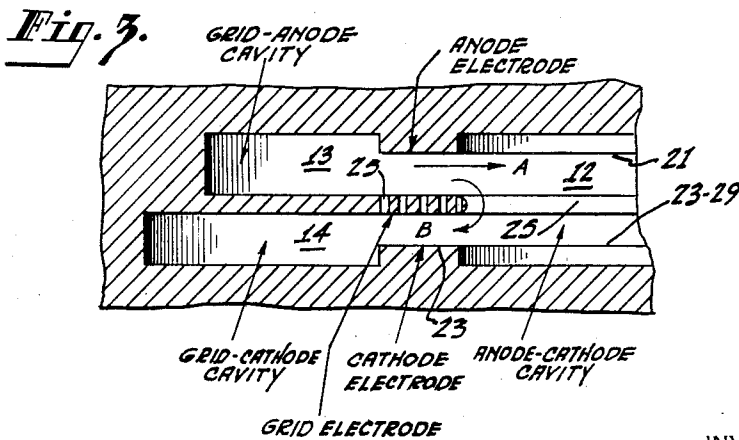
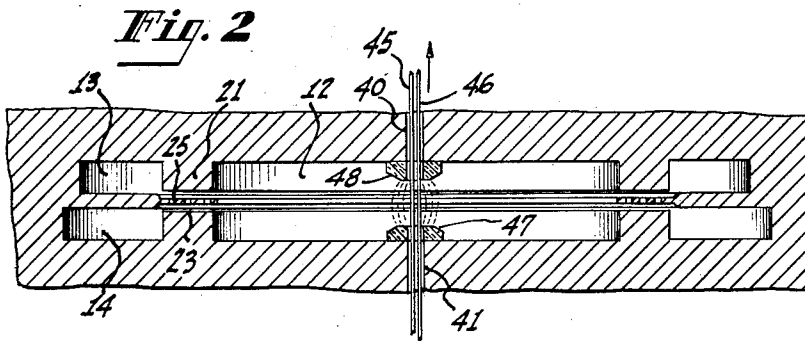
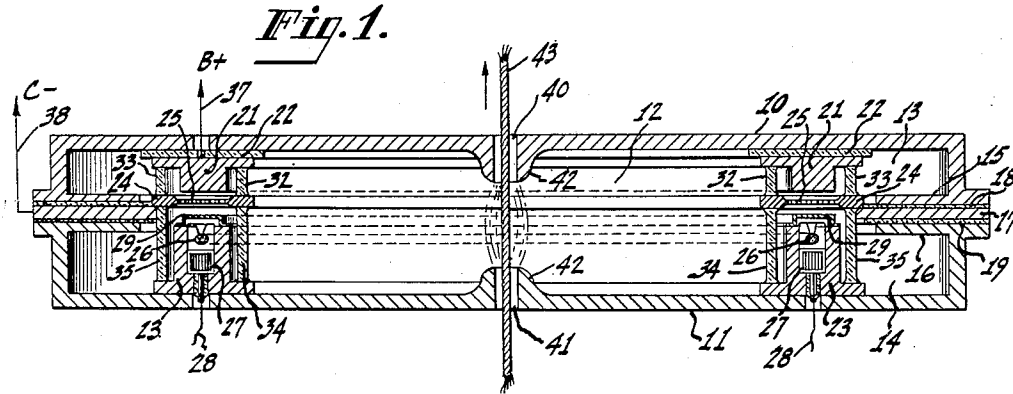
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2,545,106

APPLICATOR FOR RADIO-FREQUENCY HEATING

Filed April 30, 1948

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

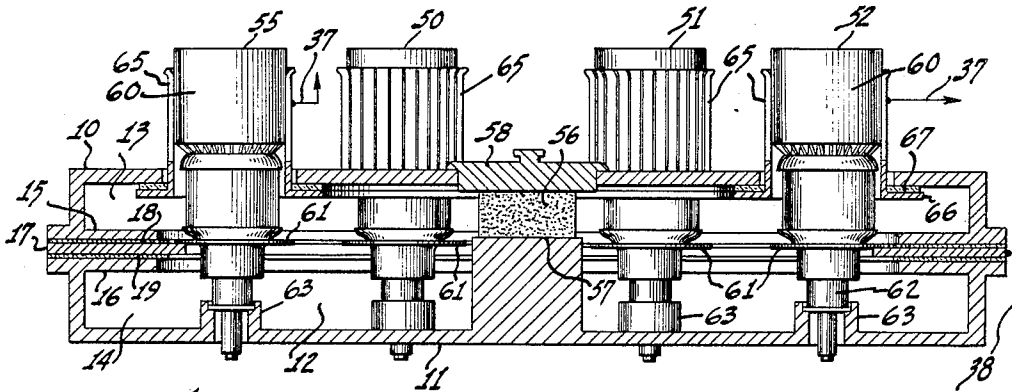
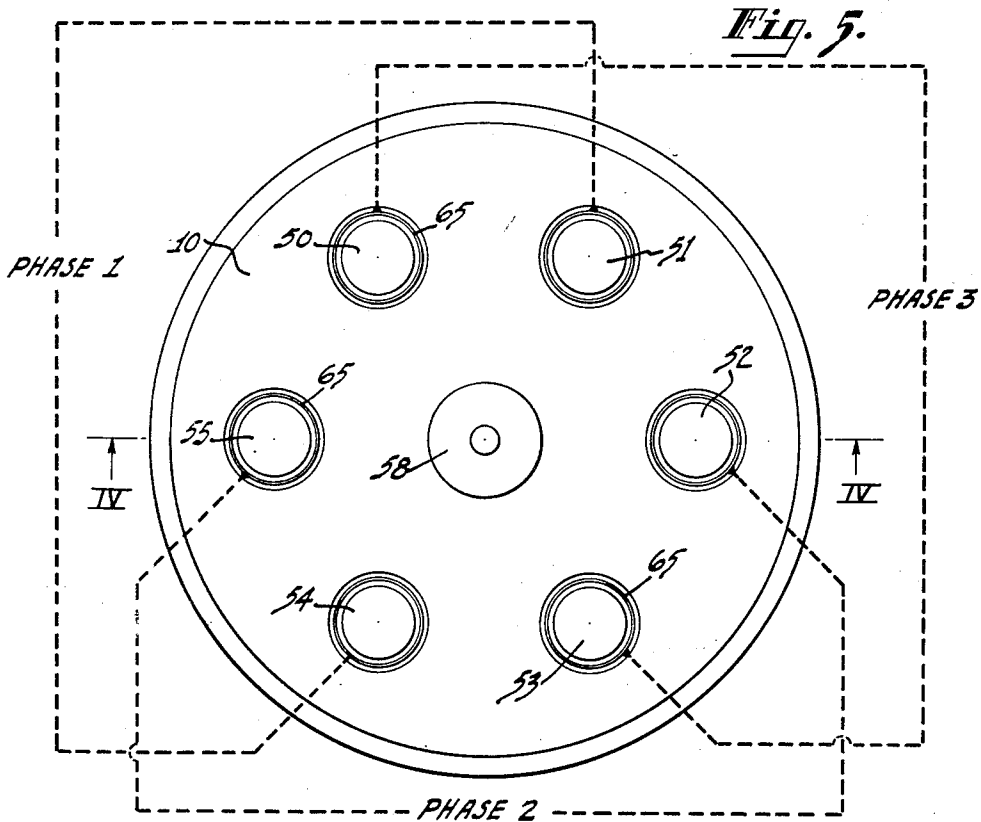


Fig. 4.



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APPLICATOR FOR RADIO-FREQUENCY
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The present invention relates to R.-F. heating applicators for bodies of dielectric material and the like, and more particularly to a radial cavity type of R.-F. heating applicator which is adapted to heat continuous long threads or cords of dielectric material, such as rayon yarn and the like.

Because of the relatively small cross sectional area and the filamentary nature of threads and cords of dielectric material, the application of R.-F. heating thereto in the manufacture or quantity production of such materials presents a difficult problem. High frequency power of the order of hundreds of megacycles must be generated and the work material must be passed through a highly concentrated electrical field. Such material can best be processed in a continuously moving cord or bundle of fibers; however, the slow rate of travel through the electric field heretofore available has involved considerable production time and cost.

It is, therefore, a primary object of this invention, to provide a simplified and effective method and means for heating filamentary bodies of dielectric material, such as rayon yarn, at a relatively high rate of speed in a highly concentrated electrical field through electrical means including an oscillator system which is highly stable in response to variation in load imposed upon it by the work, for example as the moisture content varies in the dielectric body being processed.

It is a further object of the invention, to provide an improved R.-F. heating applicator system comprising a radial cavity resonator having means at the axis thereof for concentrating a high or strong electrical field in one or more filamentary bodies of dielectric material passed therethrough axially and to excite the cavity by electronic tube oscillator means of circular configuration placed about the periphery of the cavity, the electronic tube oscillator means having grid-anode and grid-cathode radial cavities coupled electrically to said radial cavity resonator which forms the anode-cathode circuit for the electronic tube.

In accordance with the invention, the radial length of the main cavity through the axis of which the material is passed, is substantially of the order of one half wavelength of the frequency to which the system is responsive and the grid-anode and grid-cathode cavities are located radially externally of the tube elements although being rigidly coupled so that the system oscillates as one circuit with a nearly constant feedback ratio. The resulting stability as the electronic tube or oscillator is loaded provides a distinct ad-

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vantage over the usual high frequency oscillator which depends upon feedback loops and relatively weak couplings by the resonant circuits.

It may also be considered to be an important object of the invention to provide a radial cavity high frequency R.-F. heating applicator for dielectric heating and the like of improved construction, comprising a closed radial cavity system operating in such a mode that a relatively high and concentrated electrical field is established at the center or axis through which the work is moved or located for treatment, together with active electronic tube oscillator elements symmetrically disposed in a disc-ring arrangement of relatively short radius about the axis of the cavity substantially at the periphery thereof and in a zone of electrical fields of the proper phase and amplitude for the generation of high frequency power, whereby such power may be applied directly to the work in the cavity.

More generally, also, it is an object of this invention, to provide an improved high frequency R.-F. heating applicator system for the heat treatment of moving bodies of dielectric material such as rayon thread and cords, either singly or in multiple, which utilizes a closed resonant cavity and a closely coupled electronic tube structure of the disc-ring type whereby the applicator structure is compact and simplified in construction and of low cost in manufacture.

A further and more specific object of the invention is to provide a totally enclosed high frequency R.-F. heating applicator comprising simple and improved means for generating and applying R.-F. energy to work being processed by dielectric heating, such as rayon yarn for example.

In carrying the invention into effect, the work to be heated is located at or passed through the center of a circular radial resonant cavity joined at its outer periphery with two other radial cavities in substantially parallel relation, in such a manner that the proper R.-F. voltages exist on a disc-ring active tube structure located substantially at the junction zone of the cavities, whereby the tube elements and the cavities coupled thereby operate as a single oscillatory system for applying high frequency R.-F. energy to the work at the center of the main cavity.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention, both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the follow-

ing description when read in connection with the accompanying drawings, in which

Figure 1 is a view in elevation and in cross section, of an R.-F. heating applicator embodying the invention,

Figures 2 and 3 are diagrammatic representations also in elevation and in cross section, on an enlarged scale, of portions of the structure shown in Figure 1, illustrating certain principles and modes of operation of an applicator system embodying the invention,

Figure 4 is a view in elevation and partly in cross section, of an R.-F. heating applicator embodying the invention, being a modification of the system shown in Figure 1, and

Figure 5 is a plan view of the embodiment of the invention shown in Figure 4.

Referring to Figures 1, 2 and 3 in which like parts throughout are indicated by like reference numerals, two cylindrical or circular flanges casing members 10 and 11 are mounted one on the other in registering face to face relation to provide a hollow interior comprising a central radial cavity 12 and two circular annular cavities 13 and 14 radially external to the central radial cavity 12. The external annular cavities 13 and 14 are separated by internal radial flanges 15 and 16 carried by each of the casing members 10 and 11 respectively, between which flanges is mounted a thin disc-ring of conducting material 17 separated and insulated from the casing flanges by thin radial rings 18 and 19 of dielectric insulating material. The flanges 15 and 16 are of short radial width, whereas the rings 17, 18 and 19 are of greater width, extending inwardly of the casing to a greater radial depth. The conducting ring 17 projects beyond the insulating rings 18 and 19 for the purpose of providing a connection with an annular electronic tube structure which is interposed between and coupled with the cavities 12, 13 and 14.

The electronic tube structure is of the disc-ring type comprising an annular ring anode element 21 adjacent the casing element 10 and separated from the interior wall thereof by a suitable insulating dielectric plate 22 in the form of an annular flat ring, and annular ring-like cathode electrode structure 23 seated on and secured to the interior wall of the other casing element 11 in spaced opposed relation to the anode electrode, and a thin annular grid element 24 interposed in the space between the anode and cathode elements and having a thin walled perforated active grid section 25 directly between the anode and cathode elements.

The grid ring is seated on and connects with the annular ring 17 which forms the electrical output connection therefor, being uniformly symmetrical about the axis of the chamber 12 as are also the electron tube elements. The cathode structure 23 is trough-shaped in cross section, as indicated, and is closed hermetically and sealed by a glass seal 26 to enclose a primary toroidal winding 27 from which it is energized inductively. The active cathode element of the cathode structure is a thin heated annular channel member or ring 29 which completes the single turn secondary and forms the hot cathode surface adjacent to the grid electrode 25. Both windings are annular in form as shown, and the primary winding is energized from a suitable alternating current source through input leads indicated at 28. Any other suitable cathode structure, however, may be provided.

The active elements of the electron tube are

contained in an evacuated envelope which in the present example is provided by inner and outer annular ring walls or wall elements 32 and 33 coaxial with the chamber 12 and the active electrode elements, being spaced on opposite sides of the anode element 21 and between it and the grid ring 24. The tube casing or envelope is completed by a second pair of annular ring-like wall elements 34 and 35, positioned about and concentric with the annular cathode. The side wall elements of the tube structure may be of any suitable material providing high dielectric insulation between the tube elements and serving to seal the envelope. For example, the side wall of the tube may be of glass sealed to the cathode and anode which are flanged for the purpose and to the grid ring as shown in Figure 1.

With this arrangement, it will be seen that the cathode electrode is grounded to the casing 10-11 which is also of conducting material, while the anode electrode is insulated from the casing and provided with an input connection lead 37 through which positive operating potentials are applied. The tube structure receives a biasing potential through a connection lead 38 connected with the central annular ring 17 which in turn contacts with the grid ring 24 which is seated thereon.

The center of the high frequency applicator is provided with central registering openings or ports 40 and 41 in the casing elements 10 and 11 respectively, directly at the center of the resonant chamber 12, and the openings are internally provided with surrounding inwardly projecting bosses 42 which operate as electrodes between which high voltages are set up by operation of the tube, as will hereinafter be described to establish a concentrated electrical field at the center or axis of the cavity. The openings 40 and 41 are of sufficient size or diameter to permit the passage therethrough of the work to be heated, which in the present example is represented as a single enlarged cord of dielectric material or other work material, such as rayon, which is to be treated by heat as it passes in a continuous thread through the apparatus. The direction of movement is indicated by the arrow, although it is reversible.

The annular electron tube structure is arranged to lie at the periphery or boundary of the annular chamber 12 and separates the latter chamber from the annular chambers 13 and 14 at the outer periphery of the casing. The chamber 13 is so proportioned that it provides a resonant grid-anode cavity, while the chamber 14 is so proportioned that it provides a resonant grid-cathode cavity for the electronic tube, while the radial chamber 13 provides an anode-cathode cavity or load for the electronic tube.

The three cavities are coupled through the tube structure which lies at the junction of the three cavities, and the tube is operated or oscillates in operation, to provide zones of high potential or strong electrical fields at the electrodes 42 and within its tube structure, while the zones of weak electrical fields fall within the cavities 13 and 14 and midway radially within the cavity 12. This condition of operation is obtained by making the disc-rings 21, 25 and 23-29, or tube elements, of an average radius approximately equivalent to an electrical half wavelength in the radial cavity 12, which forms the anode-cathode load circuit as above noted. Under these conditions, the R.-F. oscillations in the cavity 12, when the tube is

energized, will set up zones of strong electrical field at the tube elements and near the axis of the annular structure. The field will tend to become considerably greater at the center due to the high surge impedance at this point, which is a desirable feature inherent in radial cavities which is used to advantage in the structure shown.

The moving rayon yarn cord 43 to be treated is thus exposed continuously to a strong electrical field and will, therefore, absorb a maximum of energy. Furthermore, this loading is uniformly distributed on the active tube elements due to the inherent symmetry of the structure.

The essential elements of the structure of Figure 1 are diagrammatically indicated in Figure 2, wherein the simplified outline of the structure may provide a better understanding of the relation of the cavities and the coupling provided therebetween by the tube structure. Referring to Figure 2 along with Figure 1, it will be seen that the cathode, grid, and anode elements of the tube in annular form, are interposed between the radial central chamber 12 and the annular chambers 13 and 14. The disc-ring type of tube structure shown is thus combined with a closed radial cavity type of applicator in such a manner as to provide a self-exciting oscillator and to provide a concentrated electrical field at the center of the structure through which the work material passes radially.

As indicated further in Figure 2, the work material may comprise a plurality of threads 45 and 46 of dielectric material as indicated, arranged in any suitable manner to pass through the openings 40 and 41 which likewise may be made of a size to suit the number of threads forming the work to be heated.

The zone of high electrical stress at the center of the cavity 12 may further be confined to the area about the moving work by electrode elements 47 and 48 of dielectric material arranged as inwardly projecting tapered rings surrounding the work material and registering with the openings 40 and 41. The electrode tips 47 and 48 may be of high dielectric constant ceramic material, and further prevent arcing of the high voltage areas to the work material as it moves.

Referring now to Figure 3, in which a portion of the structure of Figure 2 is shown in a further diagrammatical manner with enlarged spaces between the grid electrode and the anode and the cathode, in order to maintain an efficient oscillating condition, it is necessary that the cathode-grid voltage be a certain fraction of the cathode-anode voltage and substantially 180° out of phase with it. This condition is insured by proper tuning of the grid-anode and the grid-cathode cavities located outside the annular or disc-ring tube elements. Figure 3 shows the junction of the three resonant cavities 12, 13 and 14 taking place at the free end or inner edge of the grid electrode. The three resonant circuits are effectively connected in series so that the sum of the three junction voltages must be zero.

In order that the cathode-grid and cathode-anode voltages may be out of phase, the impedances at A and B, which the anode-grid cavity looks into, must have the same kind of reactance, and a ratio A/B equal to the desired feedback voltage ratio. If A and B are made capacitive by making the grid-cathode and anode-cathode cavities appropriate electrical lengths, the operation will be similar to the usual well known Colpitts oscillator circuit. The grid-anode cavity must in this case act as the tank inductance. If

desired, A and B may be made inductive and the grid-anode cavity capacitive.

Since all three cavities are rigidly coupled together, they oscillate effectively as one circuit at the frequency determined approximately by the radial length of the cavity 12, with a nearly constant feedback ratio, similar to a lumped constant Colpitts circuit. The resulting stability as the oscillator is loaded by the presence of work material passing through the cavity with varying degrees of moisture content, gives the device of the present invention a considerable advantage over known high frequency oscillators which depend upon feedback loops and relatively weak couplings between the resonant circuits.

It is to be further understood that radial cavity 12 may be operated at higher order modes and still fulfill the condition of strong axial electric fields at the center and at the electronically active elements 21, 23 and 25. In this case the radius of cavity 12 is chosen to be substantially an integral number of electrical half-waves in accordance with well known radial cavity design procedure. Likewise, cavities such as 13 and 14 for providing feedback may be operated at higher modes as long as the respective input impedances at the junction of the various cavities fulfill the conditions for self-oscillation as previously discussed.

The work load may best be exposed to the most central region of high electric field. However, any of the concentric high electric field regions may be used for this purpose. Furthermore, the positions relative to the axis of cavities 13 and 14 and cavity 12 may be interchanged within the scope of the invention.

In the actual tube structure as shown in Figure 1, it will be noted that not only must the active tube elements be enclosed in an evacuated chamber, but also certain blocking capacitors must be inserted to maintain the proper D.-C. voltages on the grid and the anode with respect to the cathode. In the present example, suitable plate and cathode blocking capacitors are provided by the presence of the dielectric material 22 between the anode 21 and the casing wall, and likewise the desired grid blocking capacitor is provided by means of the ceramic rings 18 and 19 interposed between the casing and the grid supporting ring 17.

Likewise, it will be seen that at the center of the cavity the projections or electrode tips 42 of Figure 1 and the electrode tips 47 and 48 of Figure 2 of high dielectric constant low loss insulating material, serve to concentrate the electrical field in the moving work being treated. For the same reason that a high voltage or strong electrical field exists at the tube element, the body of the tube structure comprising the side walls 32, 33, 34 and 35 should be of low loss insulating material.

From the foregoing description, it will be seen that a structure in accordance with the invention provides a simple and improved means for generating and applying R.-F. energy to work being processed by dielectric heating, such as rayon yarn or any long, continuous filamentary body, and that the work to be heated may be located at or passed axially through the center of a simple circular radial cavity. It is essential, however, that the cavity be coupled at its outer periphery to two other radial cavities in such a manner that the proper R.-F. voltages exist in the disc-ring oscillator tube elements located substantially at the junction zone of the cavities.

As will be seen with reference to Figure 3 particularly, the grid-anode cavity may be electrically short in order to operate as the tank inductance and is coupled to the radial cavity 12 at A, while feedback at B is provided between the grid-anode cavity and the grid-cathode cavity.

The closed radial cavity system provided, operates in such a mode that a relatively high dielectric field is set up at the center of the radial cavity where the work is located and wholly enclosed, thereby minimizing radiation and loss of power. Furthermore, direct coupling is provided with the active tube elements which are symmetrically disposed about the axis of the cavity at the periphery thereof and located in a zone of strong electric fields of the proper phase and amplitude for the generation of high frequency power. Accordingly this power is applied without appreciable loss directly to the work as it passes through the central cavity.

Referring now to Figures 4 and 5, wherein like reference numerals are applied to similar parts as in Figures 1-3, the annular casing comprising the two complementary sections 10 and 11, provide a grid supporting annular flat ring 17 located between annular internally extending flanges 15 and 16 and separated therefrom by suitable ceramic insulating annular discs 18 and 19 as in the preceding embodiment.

The casing is likewise provided with an internal central radial chamber 12 and outer peripheral annular chambers 13 and 14 constituting respectively the anode-cathode tuning cavity, the grid-anode tank circuit cavity and the grid-cathode cavity for a series of electron tubes 50-55 inclusive, arranged in a circular configuration and equally spaced about the center of the structure. The tubes are located at the boundary of the junction of the cavities 13 and 14 with the cavity 12 as in the preceding embodiment, and function in a similar manner to apply high frequency energy to a work load comprising, in the present example, a body 56 of ceramic material to be treated located on a pedestal 57 within the chamber 12 at the center thereof. A removable cover plate 58 in the casing section 10 directly in registration with the pedestal 57 is provided for the removal and placement of the material to be treated.

The electronic tubes 50-55 may be of the triode type having an anode sleeve 60, a grid ring 61 and a cathode terminal end 62, the latter being seated in suitable socket element 63 connected to or integral with the casing section 11 for providing a direct ground connection therewith. The grid rings 61 are arranged to engage the inner edge of the grid connecting ring 17 for receiving controlling D.-C. potentials therefrom, and the grid blocking capacitors are provided as before through the medium of the ceramic rings 18 and 19 interposed between the ring 17 and the internal flanges 15 and 16.

The anode terminals 60 of the tubes are seated in split cylindrical contact sleeves 65 which in turn pass through the top of the casing 10 and are joined to an annular flat ring 66 supported from the casing. In this arrangement, the sleeves 65 are spaced from the casing to prevent grounding thereto and are electrically insulated therefrom through the medium of an annular flat ring of insulating material 67 located between the rings 66 and the inner wall of the casing section 10. This provides an anode blocking capacitor as in the preceding example, and D.-C. anode operating potentials are applied to the

anodes through connections leads 37, which are connected with each of the sleeves 65.

In the arrangement shown, the electronic tubes are of a more conventional disc-seal type of triode, and as shown, several of such triodes may be mounted in a circle about the central axis of the radial cavity for high frequency operation, and may be operated in parallel or may be connected to operate from any suitable alternating current source. In the case illustrated in Fig. 5, the tubes 51 and 54, for example, may operate on phase 1, tubes 52 and 55 may operate on phase 2, and tubes 50 and 53 may operate on phase 3 of a 3 phase power supply as indicated by the dotted connections in Figure 5.

In this modification, while the work 56 remains fixed inside the cavity until processed, it is obvious that a central aperture may be provided for the passage of a continuous body of work material in the same manner as shown in Figures 1 and 2, for example, and that the operation is otherwise similar to that as described in connection with Figures 1, 2 and 3.

In any case, the three cavity close-coupled arrangement as described and as used in the embodiment shown in Figures 4 and 5, provides a relatively higher output and the enclosed type of circuit prevents a considerable loss of power by radiation. Furthermore, as in the preceding embodiment, the resonant cavities are directly coupled by the tube structure located between them at the cavity junction which is arranged to be in a zone of high electrical stress, and the resultant radio frequency power is directly applied to the work within the cavity.

While the arrangement shown in Figure 1 is at present preferred in practical applications of the invention, a series of tubes arranged in circular formation as shown in Figures 4 and 5 may be provided, with the results approximating those of the complete disc-ring structure of Figure 1. In any case, however, all three cavities are rigidly coupled so that they oscillate as one circuit with nearly constant feedback ratio, resulting in oscillator stability with variations in load.

The disc-ring type of tube structure of the tube arrangement of Figures 4 and 5 combined with a closed radial cavity type of application wherein the cavity radius is of the order of one half wavelength, provides a self-excited oscillator and a concentrated field in the center for the processing of any work material located or passed through axially. It should be noted that in this embodiment, the disc-ring elements are relatively short radially and that the load provided by the work is uniformly distributed over the active tube elements due to the inherent symmetry of the structure.

Because of the advantages of the simple applicator arrangement in accordance with the invention, the problem of applying effective R.-F. heating to a moving body of ceramic or other material to be heated has been greatly simplified, and the invention is of present extensive usefulness in the heat treatment of long lengths of rayon yarn and the like in a continuously moving production line. Because of the high heat concentration the speed of production or movement of the yarn through the applicator may be greatly increased and a plurality of threads may be heated simultaneously.

I claim as my invention:

1. An R.-F. heating applicator comprising a casing having a central radial cavity joined at

its outer periphery by two substantially parallel radial cavities of annular form, an annular disc-ring electronic tube oscillator located at the junction of said cavities, said central cavity being of a radial length of substantially an integral number of half wavelengths, whereby said cavities are resonated to provide a concentration of R.-F. power at the center of said structure and of said central cavity, and means providing electrodes at the center of said central cavity for applying R.-F. energy to a work load.

2. An R.-F. heating applicator as defined in claim 1 wherein means are provided for passing a continuous body of dielectric material axially through the axis of said central chamber between said electrodes.

3. An R.-F. heating applicator system comprising in combination, a radial cavity resonator having electrodoal means at the axis thereof for providing a concentrated electrical field, means for passing work material to be treated axially through said cavity resonator between said electrodoal means, electronic tube oscillator means of circular configuration located about the periphery of said cavity resonator, and means providing grid-anode and grid-cathode cavities radially externally of said electronic tube oscillator means and coupled therethrough to said first named radial cavity resonator.

4. An R.-F. heating applicator system as defined in claim 3 wherein the radial cavity resonator has a radius substantially of the order of one half wavelength of the frequency to which the system is responsive, and the electronic tube oscillator means is of the disc-ring type, of relatively short radial length.

5. An R.-F. heating applicator for dielectric heating and the like, comprising a substantially closed casing providing a central radial cavity and an annular disc-ring electronic tube having grid anode and grid cathode coupling means defining the outer periphery of said central radial cavity for establishing a relatively high and concentrated electrical field substantially at the axis of said cavity and at the active elements of said electronic tube, and means substantially at

the axis of said cavity for receiving dielectric material and the like to be processed by R.-F. heating within said casing.

6. A high frequency R.-F. heating applicator comprising in combination, a cylindrical casing, an annular electronic tube structure of the disc-ring type in said casing spaced substantially one half wavelength from the center thereof to define a central resonant radial cavity, said tube structure having anode and cathode elements coupled to said cavity, means providing substantially parallel grid-cathode and grid-anode cavities in said casing radially externally of said tube structure, said last named cavities being annular in form and coupled to said radial cavity through the medium of said tube structure, whereby an enclosed oscillatory system is provided for applying R.-F. heat directly to the center of said structure, and means for passing a body of dielectric material axially through the center of said structure to apply concentrated high frequency energy thereto within the casing.

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