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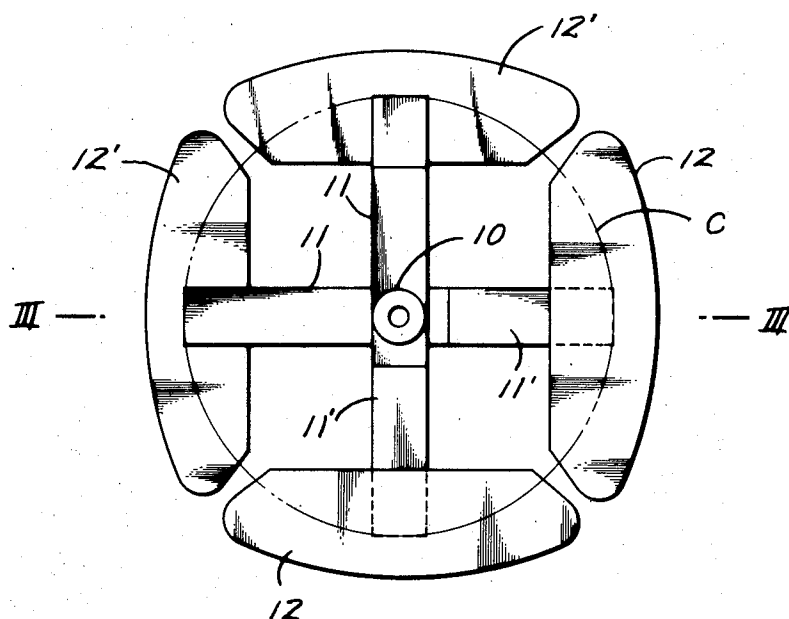
[54] **HIGH-FREQUENCY HEATING APPARATUS**
12 Claims, 5 Drawing Figs.

[52] U.S. Cl. **219/10.55,**
219/10.57
 [51] Int. Cl. **H05b 9/06,**
H05b 1/00
 [50] Field of Search **219/10.55**

[56] **References Cited**
UNITED STATES PATENTS

3,431,381	3/1969	Anderson	219/10.55
3,364,332	1/1968	Raftmark	219/10.55
2,813,185	11/1957	Smith	219/10.55

ABSTRACT: A high-frequency heating apparatus includes a supply source for supplying high-frequency energy into a conductive heating chamber. Two pairs of stirring blades mounted on a rotary shaft inside the chamber are positioned relatively to the supply source so that a substantial portion of the radiated energy is intercepted and reflected by the blades to afford more uniform heating of materials within the chamber. The generally elongated stirring blades are mounted tangentially of the circumference of an imaginary circle lying in a plane normal to the rotary shaft and concentric with the shaft axis. The blades of each pair lie in parallel planes inclined at an angle of 45° with respect to the plane of the imaginary circle and thus are oppositely inclined with respect to the axis of the rotary shaft. As the blades are rotated, high-frequency energy from the source, in a first mode, is reflected from the upper surface of one of the blades of the pair in a centrifugal direction and, in a second mode, from the upper surface of the other blade in a centripital direction toward the first blade of the pair and reflected downwardly from the lower surface of the latter. Continuous rotation of the shaft effects a continuously alternating sequence of the modes thus established by each pair of blades.



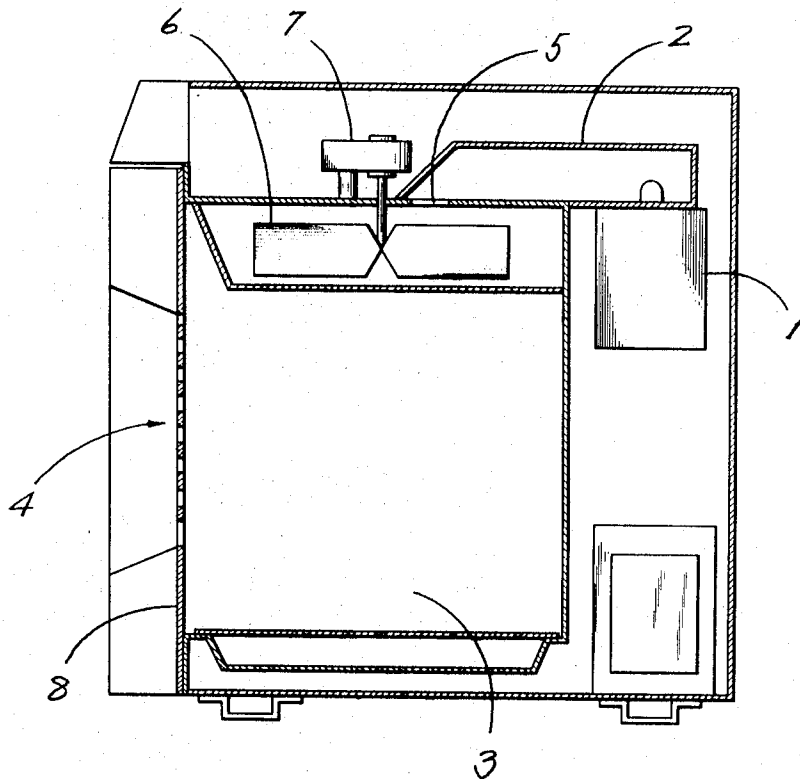


Fig. 1
PRIOR ART

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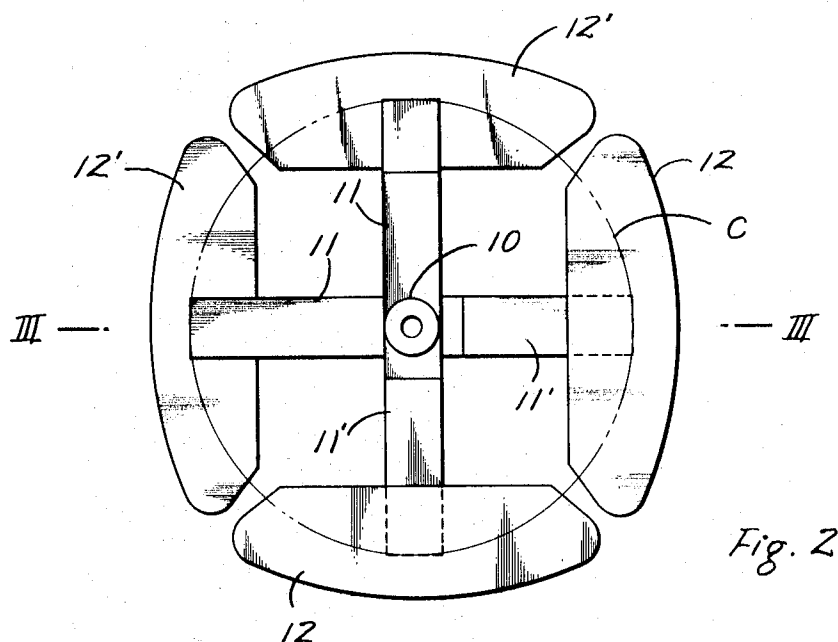


Fig. 2

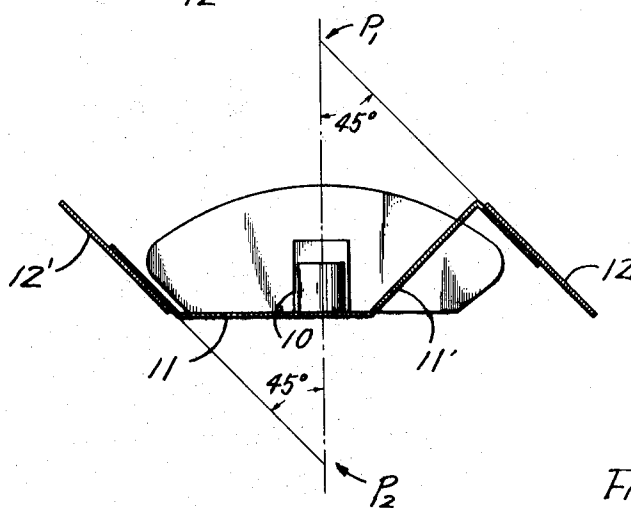


Fig. 3

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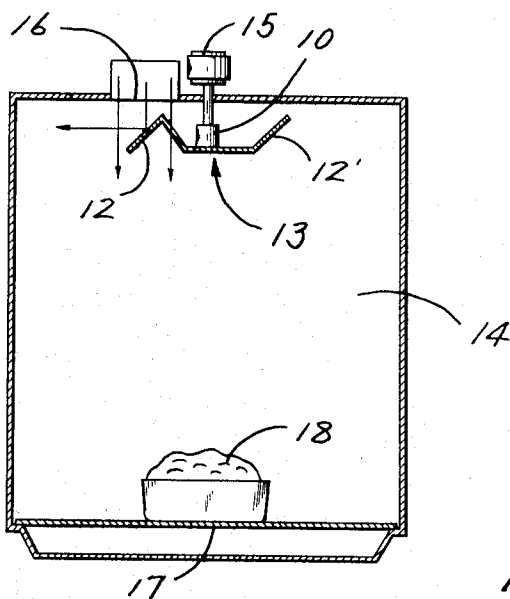


Fig. 4

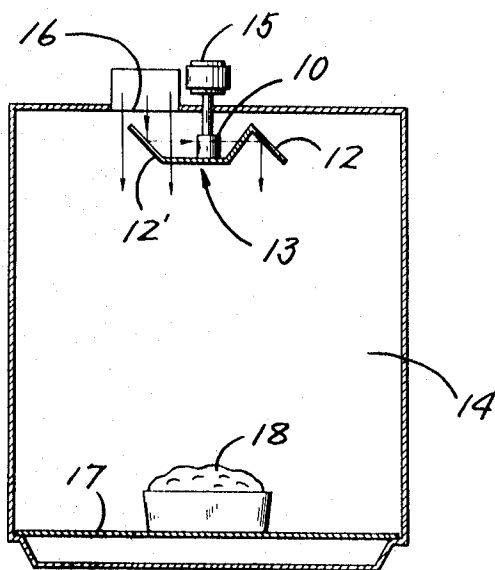


Fig. 5

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HIGH-FREQUENCY HEATING APPARATUS

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to high-frequency heating apparatus and more specifically to means for improving the high-frequency electromagnetic field distribution or mode pattern by stirrer means which produce a continuously alternating sequence of different mode patterns to achieve more uniform heating.

Description of the Prior Art

In high-frequency heating apparatus, which has now found wide use, materials are heated or cooked by applying high-frequency energy to the materials. The heating or cooking is achieved due to the dielectric loss presented by the materials to the high-frequency energy, as is well known. The heating apparatus of this type includes a cubiform cavity or oven of conductive, typically metallic, material, and a supply source for supplying high-frequency energy into the cavity. One of the walls of the oven defining the cubic cavity is constructed as a door providing access to the cavity and which, when shut, effects a suitable seal of the cavity.

In such high-frequency heating apparatus, the oven is considered as defining a high Q resonant cavity. As is well known, the higher the Q of the resonant cavity, the more well defined are the modes of the fields established within the cavity resulting in a more uneven heating within the cavity with respect to its spatial dimensions. When only a small heating load is presented to the oven, such as when only a small amount of material is placed in the oven for heating, the effective Q of the resonant cavity remains relatively high resulting in uneven heating. The smaller the heating load, therefore, the less uniform the heating becomes. On the contrary, as the heating load is increased, the number of high-frequency electromagnetic field modes generated within the oven are correspondingly increased, and more uniform heating of the materials is achieved.

Since control of the number of electromagnetic field modes cannot be achieved in a practical sense by always supplying a high heating load to the oven and further since it is desirable to improve the uniformity of heating even in the presence of high heating loads, there have been provided and proposed heretofore in the prior art various types of movable devices for increasing the number of electromagnetic field modes within such heating apparatus. Such mode changing devices, in addition to exciting different modes, also serve to redirect the radiated energy by reflection to effect more uniform heating, a matter of greater importance in the high load situation.

One such prior art device comprises a propeller-type fan comprising a plurality of radially extending blades of conductive or metallic materials, inclined relatively to the axis of rotation much like the blades of a conventional airplane propeller. The propeller is positioned such that the blades are opposite to a high-frequency energy source for intercepting and reflecting the energy propagated into the oven, the fan being continuously rotated by a suitable motor. As the fan is rotated, the high-frequency energy is reflected from each blade in succession as it is advanced into position opposite the energy source, producing a larger number of modes within the cavity of the oven. Such a propeller-type fan, however, provides for reflection of the high-frequency energy only in a predetermined direction and in a predetermined cycle, and therefore has not been capable of providing the desired effect of uniform heating to a sufficient extent.

In U.S. Pat. No. 2,813,185 entitled "Heating Device" and issued to R. V. Smith in 1957, there is disclosed high-frequency heating apparatus including a movable device positioned to provide an increased number of modes to afford more uniform heating. The movable device therein disclosed includes a propeller-type fan comprising a plurality of similar blades mounted on a rotary shaft and extending radially from the shaft. A motor rotates the fan for continuously advancing the blades to a position opposite to a high-frequency energy

source, thereby to intercept and reflect the propagated energy. A first set of blades are inclined to a plane normal to the axis of the shaft at a first angle and a second set of blades are of the opposite or reversed inclination with respect to that same plane relative to the first set of blades. Thus, as the blades are rotated into position for intercepting the energy, the first set reflects the energy in a corresponding first direction and the blades of the other set reflect the energy in a corresponding, opposite direction. By alternating the blades of opposite inclination, the rotation of the propeller-type device effects a continuous, periodic reflection of the energy in the noted opposite directions. Although the device of the referenced patent affords some improvement over the other prior art devices, it provides an insufficient degree of uniform heating since the energy is only reflected in the noted two opposite directions.

Thus, the prior art has failed to provide a device of relatively simple construction capable of producing a large number of electromagnetic field modes for attaining uniform heating in resonant cavity-type heating ovens. The invention disclosed herein accomplishes this purpose.

SUMMARY OF THE INVENTION

The invention comprises a movable device to be mounted within the resonant cavity of a heating chamber to effect reflection of high frequency energy propagated into the cavity and to establish an increased number of electromagnetic field modes to assure uniform heating of materials within the cavity. The device comprises at least one pair of blades mounted on a rotary shaft, the generally elongated blades thereby being positioned tangentially of the circumference of an imaginary circle lying on a plane normal to the rotary shaft and concentric with the shaft axis. The blades of each pair lie in parallel planes inclined at an angle of 45° with respect to the plane of the imaginary circle and thus are oppositely inclined with respect to the axis of the rotary shaft. Thus, the plane of one blade intersects the axis at a point above the plane of the imaginary circle whereas the plane of the other blade intersects the axis at a point below the plane of the imaginary circle. A prime mover such as a suitable motor is attached to the shaft to rotate it and the blades mounted on it, the blade positions being selected relatively to the source of electromagnetic energy propagated into the chamber such that the blades successively are rotated into position opposite the source to intercept and reflect the energy propagated into the chamber.

Assuming that the energy is directed into the cavity from above and in a direction parallel to the axis of the rotary shaft, one of the blades of the pair, as above described, reflects the energy from an upper surface thereof in a centrifugal direction and thus radially outwardly with respect to the shaft. As the other blade of the pair is advanced into position, high-frequency energy is reflected from the upper surface thereof in a centripetal direction or radially inward direction toward the lower surface of the first-mentioned blade positioned on the diametrically opposite side of the shaft. A certain amount of the high-frequency energy then is reflected from that lower surface of the first-mentioned blade in a vertically downward direction again parallel to the axis of the shaft.

Thus, in the first mode of operation, the high-frequency energy is reflected in the centrifugal direction with respect to the rotary shaft of the movable device, whereas in the second mode of operation, the high-frequency energy is reflected in the centripetal direction of the shaft of the movable device and a certain amount of the high-frequency energy is reflected downward (or upward depending on the design) or in parallel to the rotary shaft. This diversified transmitting route of the high-frequency energy results in a larger number of electromagnetic field modes and more uniform heating as compared with any of the conventional type devices.

Therefore, an object of this invention is to provide a high-frequency heating apparatus including a movable device which provides improved heating patterns.

Another object of this invention is to provide a movable device in a high-frequency heating apparatus for creating an increased number of diversified electromagnetic field modes.

A further object of this invention is to ultimately direct high-frequency energy in centrifugal and centripetal directions from the circumference of an imaginary circle coaxial with the axis of a shaft supporting the movable device.

Still a further object of this invention is to provide a movable device in a high-frequency heating apparatus to ultimately direct high-frequency energy introduced into the apparatus in centrifugal and centripetal directions with respect to a rotary shaft of the movable device and to further direct the high-frequency energy directed to the centripetal direction in a direction parallel to the axis of the rotary shaft.

Still a further object of this invention is to provide a movable device in a high-frequency heating apparatus having blades extending tangentially of the circumference of an imaginary circle coaxial with the axis of the rotary shaft supporting the device.

Yet a further object of this invention is to provide a movable device in a high-frequency heating apparatus having a plurality of stirring blades extending tangentially of the circumference of the imaginary circle normal to and coaxial with the axis of a rotary shaft supporting the device and having selected ones of the blades inclined in a first direction and the other blades inclined in an opposite direction with respect to the plane of the imaginary circle as the blades are rotated about the circumference of that circle into position for intercepting the high-frequency energy propagated into the apparatus.

These objects and other objects and features of the invention will be apparent and more fully understood from the following description of the invention made with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS:

FIG. 1 is a cross-sectional view of high-frequency heating apparatus to which this invention is applied;

FIG. 2 is a top view of a movable high-frequency reflecting device in accordance with this invention;

FIG. 3 is a sectional view of the device shown in FIG. 2 along the line III—III;

FIG. 4 is a diagrammatic, cross-sectional view of the cavity of the high-frequency heating apparatus, employed for explaining the first mode of operation of the apparatus of this invention; and

FIG. 5 is a view similar to FIG. 4 in which the reflecting device has been rotated to a different position than in FIG. 4 for explanation of the second mode of operation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS:

FIG. 1 is a sectional view of a typical example of the high-frequency heating apparatus to which this invention is applied. Referring to FIG. 1, the high-frequency energy generated at a magnetron 1 is transmitted through a waveguide 2 to the cubic or cubiform heating chamber 3, or cavity, made of a conductive material. The heating chamber 3 includes an inlet or opening 4 for inserting materials to be heated or cooked into the chamber. The inlet 4 is provided with a door 8, which can be opened or closed freely, and which when closed provides a perfect seal with respect to the high-frequency energy generated within the chamber 3.

Considering merely the chamber 3 with means for introducing high frequency energy into that chamber such as from waveguide 2 and in the absence of any further energy controlling device, a substantially uneven or nonuniform distribution of the electromagnetic field would be established in the heating chamber 3. Any materials placed within the chamber 3 would be heated very unevenly, the degree of the uneven heating increasing, the smaller the heating load or materials provided.

As generally recognized heretofore in the prior art, to provide more even heating, a stirring blade 6 made of conductive

material is provided in the vicinity of an outlet 5 of waveguide 2. The blade 6 is rotated by means of a motor 7 disposed outside the heating chamber 3. The high-frequency energy is reflected and dispersed by the stirring blade and the distribution of high-frequency energy impinging upon the materials to be heated is thus made more even. In other words, the number of electromagnetic field modes of the high-frequency energy in the heating chamber 3 or cavity is increased.

The present invention provides for a stirring blades of improved construction which increases the stirring or distribution effect of the blade to provide increased reflections and an increased number of electromagnetic field modes thereby to afford more uniform distribution of the field and more uniform heating. The details of the blades are illustrated in FIGS. 2 and 3. FIG. 2 is a top view of an electromagnetic field stirring blade of an embodiment constructed in accordance with this invention. FIG. 3 is a sectional view of the blade of FIG. 2 along the line III—III.

With reference to FIG. 2, the movable device or electromagnetic field fan of the invention includes a boss 10 by which the fan is affixed to a rotary shaft and to which are secured arms 11, such as by spot welding, extending radially of the boss 10 and thus of the axis of the rotary shaft. As shown, the arms 11 extend diametrically of that axis and at right angles to one another. Mounted on the opposite ends of each arm 11 are blades 12 and 12' which extend tangentially of the circumference of an imaginary circle C lying in a plane normal to the axis and coaxial with the axis. The blades 12 and 12' may be affixed to the ends of the respective arms 11 by spot welding or other suitable technique.

The pair of blades 12 and 12' associated with each arm 11, as best shown in FIG. 3, are generally parallel to one another, that is, the blades 12 and 12' generally lie in planes which are parallel to one another and which are thus oppositely inclined with respect to the axis of the fan. This is illustrated by the representation of the plane in which the blade 12 generally lies, intersecting the axis at the point P1 above the plane of the imaginary circle and by the plane in which the blade 12' generally lies, intersecting that same axis at the point P2 below the plane of the imaginary circle, the angles defined by the intersections of the axis and the plane in each instance being approximately 45°. In thus defining the inclination of the blades 12 and 12', of course, there is no intent to limit the specific configuration of the blades to precisely planar form although generally they may be considered as lying within mutually parallel planes. The arm 11 may conveniently be provided with a bent terminal portion or end to which the blade 12' is mounted at one end thereof, and with an inverse V-shaped bent portion 11' at the diametrically opposite end thereof for supporting the blade 12 whereby the blades 12 and 12' are supported generally in the vicinity of the plane of the imaginary circle C as illustrated in FIG. 2.

The modes of operation of the electromagnetic field stirring by the stirring blades of this invention may be understood more fully with reference to FIGS. 4 and 5. By connecting the boss 10 of the fan 13 of this invention to the prime mover 15 such as a suitable motor, placed outside the heating chamber 14, rotation is effected in such a way that each stirring blade 12 or 12' is brought, in succession, to a position opposite the output opening 16 of the waveguide.

FIG. 4 shows the position of the blade in the cavity 14 at a time when the blade 12, the plane of which intersects the axis of rotation above the plane of the imaginary circle C as illustrated in FIG. 3, is positioned opposite the output opening 16 of the waveguide. In this context, the waveguide is such as that diagrammatically illustrated in FIG. 1 identified by the numeral 2. A material 18 to be heated is shown placed in the cavity 14, supported above the bottom by means of the bed plate 17 of a material transparent to the high-frequency energy, such as glass. As readily seen from FIG. 4, the high-frequency energy from the output opening 16 of the waveguide is reflected from the upper surface of the blade 12 and is directed radially or in the centrifugal direction with

respect to the axis of the rotary shaft. The geometry and overall dimensions of the stirring blades 12 and 12' are preferably selected in relation to the dimensions of the output opening 16 of the waveguide such that the length of the blade 12 in the dimension disposed tangentially of the imaginary circle C is somewhat less than that of the opening 16. By this technique, a portion of the high-frequency energy radiated from the output opening 16 of the waveguide is not intercepted by the waveguide but rather propagates in a downward direction generally parallel to the axis of rotation for directly heating the material 18.

FIG. 5 is a diagrammatic illustration of the heating apparatus substantially identical to that of FIG. 4 but in which the fan 13 has been rotated substantially 180° to position the blade 12' opposite the output opening 16 of the waveguide and thus in position for intercepting and reflecting energy propagated therethrough. The blade 12' as defined in FIG. 3 lies in a plane which intersects the axis of rotation at a point below the plane of the imaginary circle. As readily seen from FIG. 5, a portion of the high-frequency energy radiated from the output opening 16 of the waveguide is reflected from the upper surface of this stirring blade 12' in the centripetal direction with respect to the rotary shaft, or axis of rotation, and is further reflected downward from the lower surface of the stirring blade 12 which is diametrically opposite to the blade 12' and thus toward the material 18 to be heated. In this instance, it is understood that the relatively narrow arm connecting the blade 12 to the boss 10 presents only a minimal surface relative to the surface of the blade 12 and thus permits a substantial portion of the high-frequency energy thus reflected from the upper surface of the blade 12' to be directed to and reflected downwardly from the lower surface of the blade 12. In addition, a portion of the high-frequency energy transmitted through the opening 16, as in the case of the blade 12 discussed in FIG. 4, is not intercepted by the blade 12' and travels directly downwardly and thus in a direction generally parallel to the axis of rotation; further, a portion of the energy reflected from the blade 12' is not intercepted and reflected by the lower surface of blade 12, but rather continues in a straight path and thus in a radial direction relative to the rotary shaft.

The apparatus of the invention, due to the continuous rotation of the device 13, effects a continuously repeating alternating sequence of the modes of operation described in reference to FIGS. 4 and 5 and in addition produces intermediate modes in the transitions from either of the two major modes as described. As a result, a substantial diversification of the electromagnetic field modes is generated in the cavity. The diversification of the modes and the reflections of the energy thus provided contributes to a substantial improvement in the degree of uniformity of the electromagnetic field produced within the heating chamber and thus to more uniform heating of materials placed therein.

This effect was substantiated by experimental data obtained by the inventor in comparing the uniformity of heating achieved in an electromagnetic heating apparatus employing the movable device, or stirring blades, of the invention with that achieved in such apparatus employing conventional electromagnetic field stirring blades such as those described above in relation to the prior art. The data was obtained in accordance with the following procedure.

Twelve glass cups each containing 100 cc. of water were placed in the heating chamber, the cups being disposed in three columns and in four lines. These cups were subjected to the high-frequency energy for two minutes in the chamber. Then, the temperature of the water in each cup was measured. The results were as follows:

For this apparatus of the prior art the maximum temperature was 21.7° C. and the minimum temperature 8.7° C. and the difference between the two was 13° C. while for the apparatus of this invention the maximum temperature was 16.8° C. and the minimum temperatures was 11.0° C. and the difference between the two was 5.8° C. These results clearly

demonstrate that the uniformity of the field and resultant uniform heating achieved when employing the device of the invention provides a substantial improvement over that obtained with the conventional prior art devices.

While specific preferred embodiments of the invention have been described, it will be apparent that obvious variations and modifications of the invention will occur to those of ordinary skill in the art from a consideration of the foregoing description. It is therefore desired that the present invention be limited only by the appended claims.

What is claimed is:

1. A device for use in a high-frequency heating apparatus having an enclosure made of conductive material into which high-frequency energy is supplied for heating material placed within the enclosure comprising:

a pair of blades of conductive material,

means for mounting said blades within said enclosure for rotation about a predetermined axis of rotation, said blades being rotatable in succession into position to intercept a portion of the high-frequency energy supplied into the enclosure,

one of said blades being positioned by said mounting means to direct high-frequency energy intercepted thereby in a centrifugal direction with respect to said axis of rotation, the other of said pair of blades being positioned by said mounting means to direct high-frequency energy intercepted thereby in the centripetal direction with respect to said axis of rotation, and

said one of said blades furthermore is positioned for intercepting energy directed centripetally from said other of said blades and directing a portion of said centripetally directed energy parallel to the axis of rotation.

2. A device as recited in claim 1 wherein said blades of said pair thereof are mounted at diametrically opposite positions relative to the axis of rotation and tangentially of the circumference of an imaginary circle concentric with the axis of rotation and in a plane normal thereto, and

said pair of blades are oppositely inclined with respect to the plane of the imaginary circle relative to the axis of rotation.

3. The device as recited in claim 2 wherein said blades lie in substantially parallel planes inclined to the plane of the imaginary circle at an angle of approximately 45°.

4. A device as recited in claim 2 wherein said blades define planes intersecting the axis of rotation on opposite sides of the plane of the imaginary circle at angles of approximately 45°.

5. A device as recited in claim 2 wherein said blades are each of elongated configuration and are positioned along a given dimension thereof tangentially of the circumference of the imaginary circle.

6. A device as recited in claim 1 wherein there is further provided at least one additional pair of said blades mounted on said rotary shaft with the blades of each pair diametrically disposed about said shaft and with said pairs of blades equian-gularly disposed about said shaft.

7. A high-frequency heating apparatus comprising:

an enclosure made of a conductive material,

means for supplying high-frequency energy to said enclosure,

means for placing a heating load within said enclosure to be heated by the high-frequency energy,

a movable device and means including a rotary shaft to which said device is mounted for rotating said device within said enclosure,

said movable device includes a pair of conductive blades rotatable in succession into position to intercept a portion of high-frequency energy supplied to the enclosure, one of said pair of blades directing high-frequency energy intercepted thereby in a centrifugal direction with respect to said rotary shaft and the other of said pair of blades directing high-frequency intercepted thereby in a centripetal direction with respect to the rotary shaft, and

said one of said blades furthermore is positioned for intercepting energy directed centripetally from said other of said blades and directing a portion of said centripetally directed energy parallel to the axis of rotation.

8. Apparatus as recited in claim 7 wherein said blades of said pair thereof are mounted at diametrically opposite positions relative to said rotary shaft and tangentially of the circumference of an imaginary circle concentric with the axis of rotation of said shaft and in a plane normal thereto, and said pair of blades are oppositely inclined with respect to the plane of the imaginary circle and axis of rotation.

9. Apparatus as recited in claim 8 wherein said blades are mounted by said mounting means to lie in substantially parallel planes inclined to the plane of the imaginary circle at an

angle of approximately 45°.

10. Apparatus as recited in claim 8 wherein said blades define planes intersecting the axis of rotation of said rotary shaft on opposite sides of the plane of the imaginary circle at angles of approximately 45°.

11. Apparatus as recited in claim 8 wherein said blades are positioned above a given dimensions thereof tangentially of the circumference of the imaginary circle.

12. Apparatus as recited in claim 7 wherein said movable device further includes at least one additional pair of said blades mounted on said rotary shaft with the blades of each pair diametrically disposed about said shaft and with said pairs of blades equiangularly disposed about said shaft.

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