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Jurgensen

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[54] **MULTI-MODE MICROWAVE CAVITY FEED SYSTEM**

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[51] **Int. Cl.²**........................ **H05B 9/06;** H01P 7/06
[58] **Field of Search**.................. 333/98 R, 83 R, 33; 219/10.55 R, 10.55 A, 10.55 F

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[57] **ABSTRACT**

A feed port arrangement for a multi-mode cavity is described. Such arrangement includes a plurality of waveguide extensions which project into the interior of the cavity. Each of such extensions includes an elbow within the interior of the cavity which angles an end stub on the extension obliquely with respect to the portion of such extension extending through the cavity wall. Each of the feed ports further includes an adjustable impedance matching iris at the free end of the waveguide extension for coupling energy from the extension into the multi-mode cavity.

14 Claims, 6 Drawing Figures

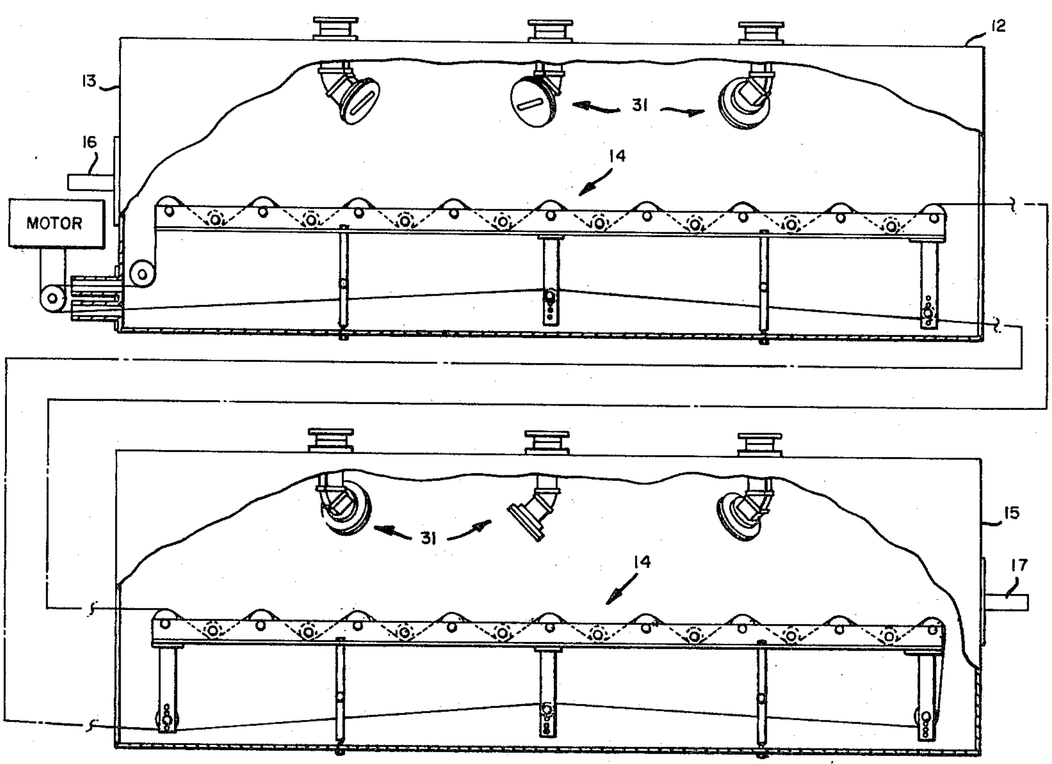
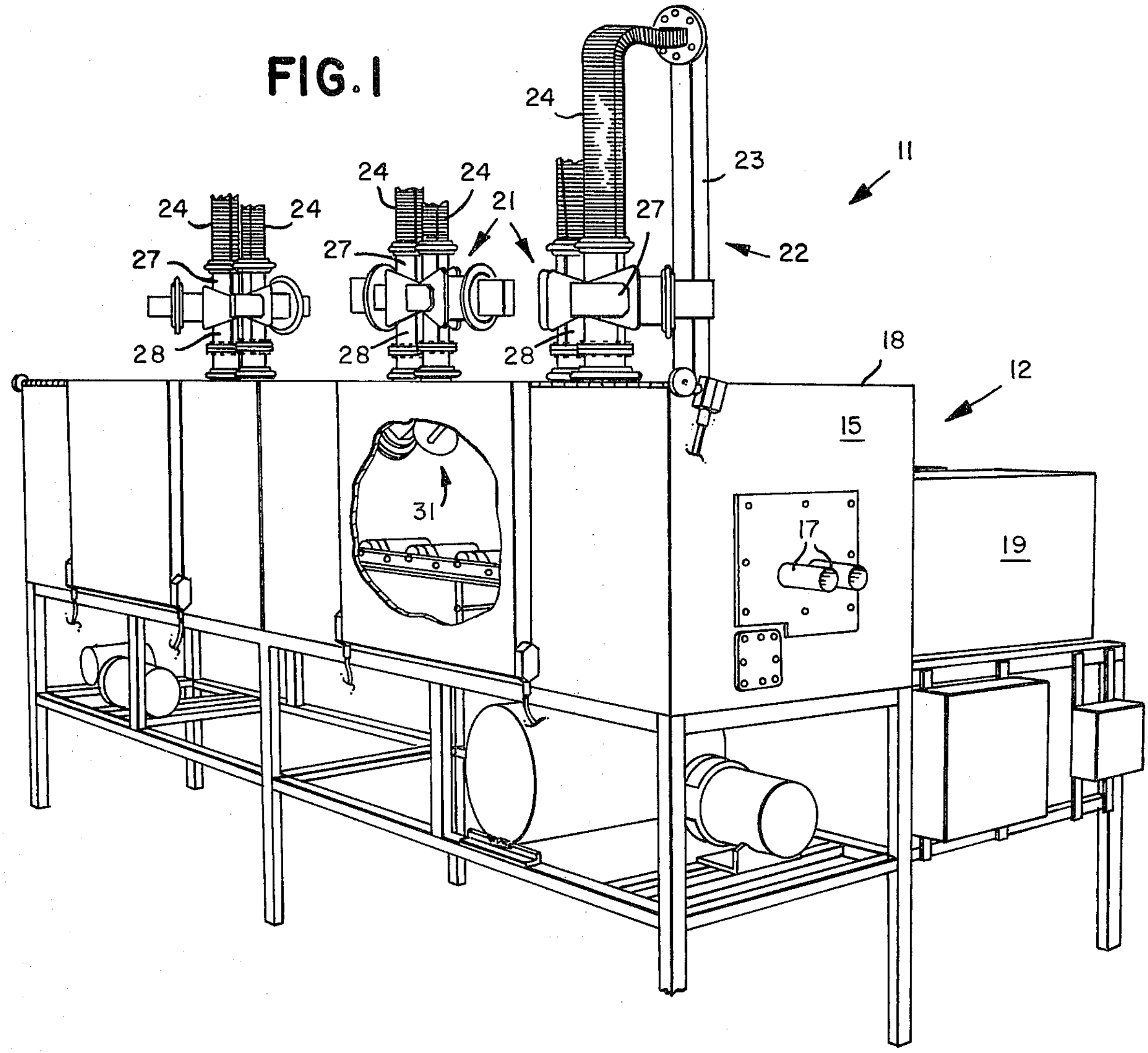


FIG. 1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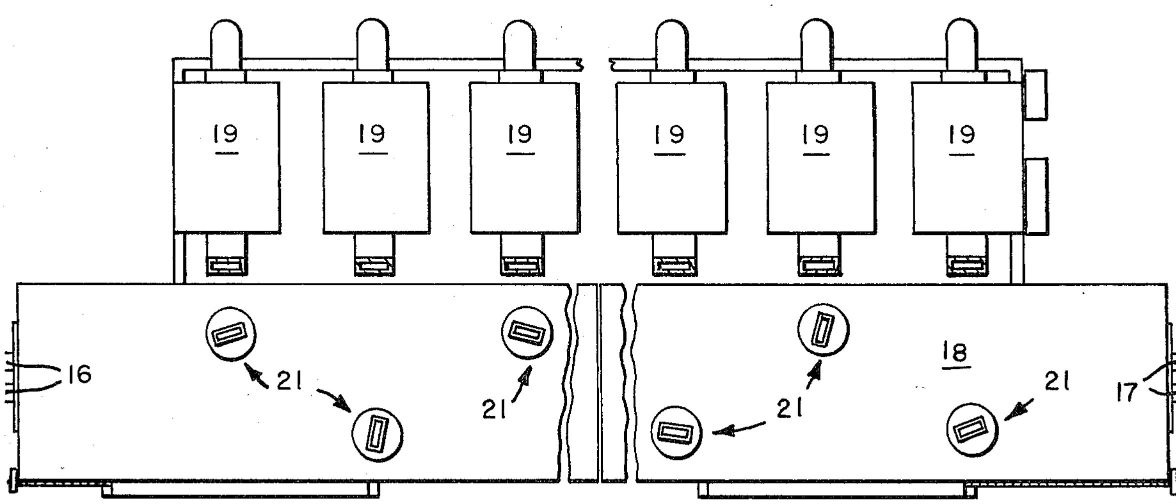
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FIG. 2

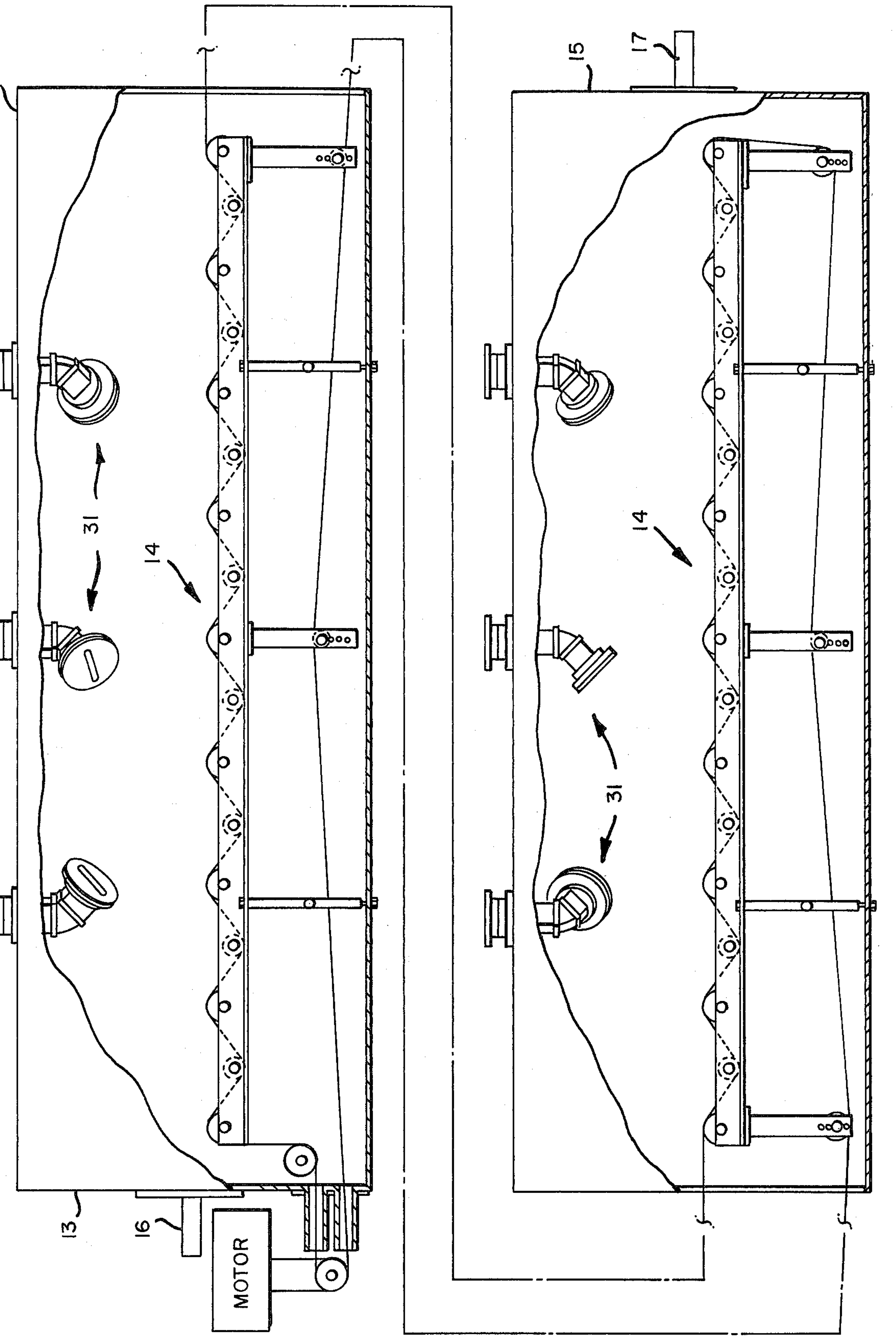


FIG. 3

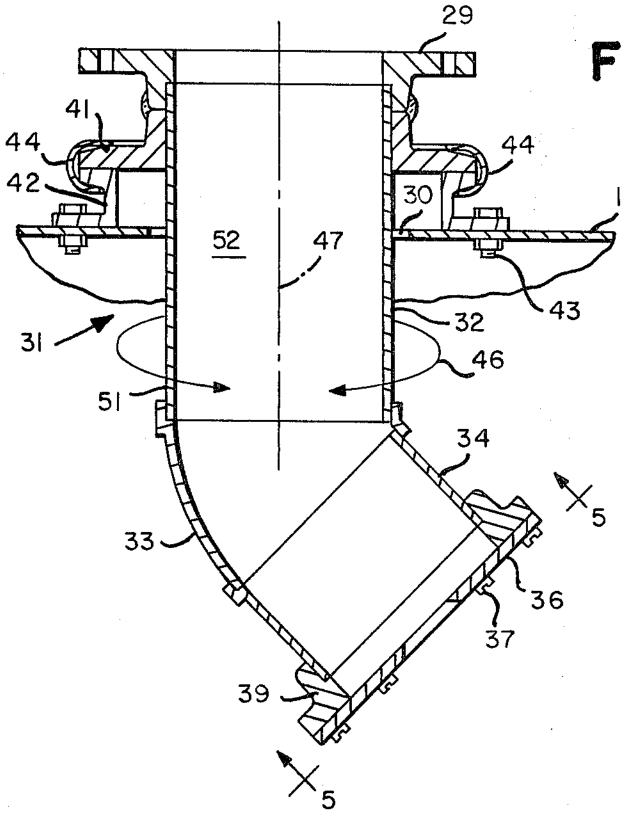
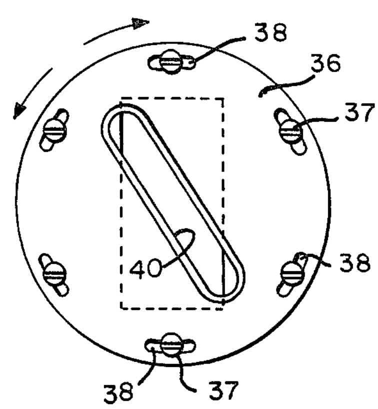


FIG. 4

FIG. 5



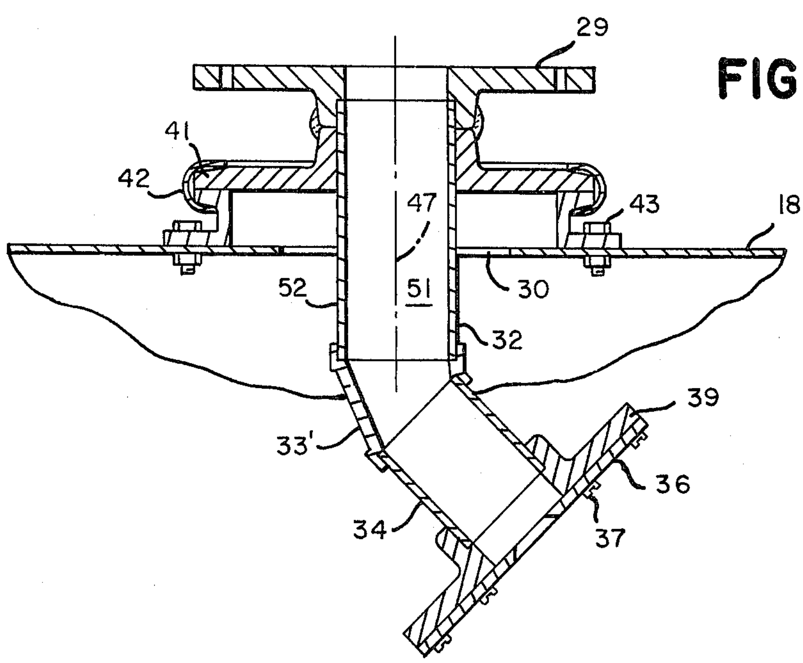


FIG. 6

MULTI-MODE MICROWAVE CAVITY FEED SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates to an applicator for treating a product with electromagnetic energy and, more particularly, to a multi-mode cavity having an energy feed port arrangement especially adapted to excite the cavity with a plurality of randomly selected different standing wave patterns.

Multi-mode microwave cavities are now commonly used to heat or otherwise treat a dielectric material, particularly when it is important that thermal energy be delivered to the interior of the material without such necessarily having to be conducted inwardly from the surface of such material. For example, multi-mode microwave cavities are used to both foam and vulcanize rubber and synthetic rubber products during the manufacture of such products.

In most processes utilizing microwave energy for treating, it is important that the treating be uniform. That is, it is important that all parts of the material or product being treated receive generally the same amount of microwave energy. For a most effective use of the energy, it is most desirable that the energy be coupled into the product by placing the product within a so-called standing wave cavity which resonantly supports the energy. The problem with this type of applicator, though, is that the field strength within the cavity is generally not uniform throughout the cavity since standing waves represent both space and time variations in such field strength. To overcome this, it has generally been the practice to attempt to excite the cavity with a plurality of different standing wave patterns to smooth out the time-average electrical field strength throughout the cavity. Although various approaches have been taken for this purpose, most rely on the use of a rotating mode stirrer or the like positioned within the cavity to intercept radiation introduced therein and reflect the same at various angles into the remainder of the cavity. Although mode stirrers do increase uniformity sufficiently for many purposes, they have several disadvantages. For one, it will be recognized that a rotating mode stirrer will not allow, as a practical matter, control of the various modes which are excited. Rather, it relies more or less on a continually changing, random generation of modes to obtain the plurality of modes. The result is that it is not unusual for positions of inordinately high or low electrical field strengths to develop at various times and places within the cavity, resulting in overtreating or undertreating of material. Also, mode stirrers are relatively costly, and there is often a problem of radiation leakage at the bearing where the shaft of the mode stirrer enters the cavity.

SUMMARY OF THE INVENTION

The present invention is an electromagnetic energy applicator which includes a feed port arrangement for a multi-mode cavity that provides a desired plurality of modes within such cavity without the necessity of a mode stirrer. In its basic aspects, the applicator includes a source of electromagnetic energy and a waveguide for conveying energy from the same to a multi-mode cavity. It also has at least one feed port connected with the waveguide for introducing the electromagnetic energy into the cavity. As a particularly salient feature of the instant invention, the feed port includes a waveguide extension which projects obliquely into the interior of the cavity for directing energy emanating therefrom angularly toward a stationary reflecting surface. The result will be that the energy reflected from the surface into the cavity will set up a plurality of standing wave modes within the cavity. Because the reflecting surface is stationary, the modes excited within the cavity will tend to be the same, rather than continually changing ones as would be the case if the reflecting surface was continually changing its angle with respect to impinging radiation as is the case with mode stirrers.

Most desirably, the waveguide which conveys electromagnetic energy from the source to the feed port is twistable in the direction of wave propagation therethrough, and the waveguide extension of the feed port is mounted on the wall of the cavity for rotation in a plane transverse to such direction at the wall so that the angular orientation of the same with respect to the reflecting surface can be adjusted. There are instances in which it is desirable to adjust the direction from which energy is introduced into a cavity for other purposes and the rotatable mounting is also usable for such purposes.

For best results, an impedance matching iris is provided on the free end of the waveguide extension to provide coupling of energy therefrom into the cavity. Preferably, the position of the iris is adjustable in a plane transverse to the direction of propagation of the radiation for changing the impedance match to that at which the iris provides optimum coupling between the waveguide extension and the cavity.

To increase the number of modes which are excited and, hence, the uniformity of the field within the cavity, a plurality of such feed ports are preferably provided, spacially distributed along at least one wall of the cavity. Each of such feed ports includes a waveguide extension as previously described, as well as an adjustable iris on its free end. Not only will such a plurality of feed ports provide a desired uniformity in the cavity, but by appropriately adjusting the angle of each with respect to another, as well as the relative positioning of the coupling irises, "cross talk", i.e., power reflected into one feed port from another feed port, can be minimized.

The invention includes other features and advantages which will become apparent from the following more detailed description of a preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

With reference to the accompanying three sheets of drawings:

FIG. 1 is an overall isometric view with portions broken away of a multi-mode cavity applicator incorporating the present invention;

FIG. 2 is a partial and broken away plan view of the applicator of FIG. 1;

FIG. 3 is an enlarged elevational view of the multi-mode cavity of the applicator of FIG. 1, having a wall portion thereof broken away to illustrate in more detail the feed port arrangement of the instant invention;

FIG. 4 is an enlarged cross-sectional view of a feed port of the invention;

FIG. 5 is a view looking from the plane indicated by the lines 5—5 in FIG. 4 of the free end of the extension of the feed port illustrating an impedance matching iris thereon; and

FIG. 6 is a sectional view of another feed port of the invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

WIth reference to FIG. 1, a microwave applicator incorporating the invention is generally referred to by the reference number **11.** Such applicator includes a rectangular, multi-mode standing wave cavity **12** which is dimensioned relative to the frequency of the energy to be introduced therein to support a plurality of modes of such energy.

Product to be treated with the microwave energy enters the cavity through an end wall **13** thereof (FIG. **3**), transported therethrough on a roller conveyor system **14,** and then exits from the cavity through end wall **15.** The particular applicator illustrated in the drawings is designed for foaming and vulcanizing rubber hose parts and, in this connection, includes entrance waveguides beyond-cutoff **16** defining an opening at wall **13** through which the product can enter into the cavity. Similarly, waveguides beyond-cutoff **17** are provided at end wall **15** to allow the product to leave the interior of the cavity. As illustrated, the roller product transport system defines a roller surface for the product extending between the entrance and exit waveguides beyond-cutoff. Such product transport system is most desirably the one described and claimed in patent application Ser. No. 473,335 filed May 28, 1974 contemporaneously herewith and assigned to the same assignee as this application. The disclosure of such application is hereby incorporated by reference.

Means are provided for generating electromagnetic energy to be introduced into the cavity. In this connection, the energy is introduced into the cavity at six positions distributed spacially about the top wall **18** of the cavity, and a magnetron power pack **19** is provided for each of such locations. The power packs cumulatively provide, in effect, a source of electromagnetic energy for the cavity.

Each of the power packs **19** is connected with a feed port arrangement, generally referred to by the reference numeral **21,** for introducing microwave energy into the cavity. Such connection is provided via a waveguide **22** which includes a vertical section **23** (only one of which is shown in detail) joined to a flexible waveguide section **24** projecting downward toward the cavity.

The end of each waveguide section **24** is connected with an associated feed port **21** for introducing microwave energy into the cavity at the location of the feed port. That is, the flexible waveguide section **24** is communicably connected to one arm of a three-arm circulator **27** which is part of the feed port arrangement. The circulator has a dummy load in its branch arm so that it acts, in effect, as a load isolator. The lower arm **28** of the circulator is connected via a flange **29** with a waveguide extension referred to generally by the reference numeral **31.**

As a particularly salient feature of the instant invention, the waveguide extension **31** projects obliquely into the interior of the cavity. That is, the waveguide extension **31** includes a first section **32** projecting downward from the flange **29** and passing through an aperture **30** in the top wall of the cavity into the cavity interior. The extension **31** is angled obliquely within the cavity toward a side wall of such cavity. That is, the section **32** terminates within the cavity in a 45° elbow **33** having an end section **34** thereon. Because of such, microwave energy propagating downwardly in the waveguide extension will be angled obliquely by an angle of 45°.

An impedance matching iris is provided on the free end of each of the waveguide extensions **31** for coupling electromagnetic energy from such extension into the multi-mode cavity. More particularly, a cylindrical plate **36** is secured via bolts **37** passing through slots **38,** for example, to an annular flange **39** rigidly secured to the free end of the waveguide section **34.** The plate **36** includes a transmission slot **40** which communicates the waveguide with the interior of the cavity. The slot **40** is oriented optimumly to the direction of the electric field vector through said waveguide to optimize the coupling of energy from the waveguide into the cavity. In this connection, the bolts **37** securing the plate **36** to the flange **39** are spaced equally from one another circumferentially of the plate so that registration of the slots **38** in the plate with bores threaded in the flange can be made with the transmission slot at different angles of orientations with respect to the waveguide section **34.** Thus, the orientation of the iris transverse to the direction of waveguide extension is adjustable. As will be discussed below, this adjustability enables each of the feed ports to be adjusted as necessary to provide efficient coupling of energy into the cavity.

As another salient feature of the instant invention, each of the waveguide extensions is mounted on the top wall of the cavity for rotation thereto in a plane transverse to the direction of wave propagation through the portion of the extension which extends through the cavity wall. More particularly, as is best illustrated in FIG. **4,** the waveguide extension includes an annular mounting flange **41** rigidly secured thereto which mates with a corresponding annular mounting flange **42** rigidly secured to the top wall **18** is the cavity via bolts **43** or the like. As is illustrated, the flanges **41** and **42** are clamped together with a conventional clamp ring **44.** Loosening of the clamp ring will allow the flange **41** and, hence, the waveguide extension of which it is a part, to be rotated as indicated by arrows **46** about an axis represented by the center line **47** relative to the flange **42.** The center line **47** extends in the direction of wave propagation through the waveguide section **32** and thus the rotation is transverse to such direction. Tightening of the ring clamp **42** will frictionally engage the mounting flange **41** to the flange **42** and this maintain the waveguide extension at a desired orientation.

In order to physically permit rotation of the waveguide extension without having to reorient its associated power pack, the flexible waveguide **24** is one which is also twistable along the direction of wave propagation therein. The waveguide will therefore enable differing orientations of the end of feed waveguide section **23** and the entrance into the isolator **27** to be acheived. The isolator is secured to the waveguide extension via flange **29** for rotation therewith.

Because the waveguide extensions are mounted for rotation relative to the top wall, the direction in which energy enamating therefrom toward another wall can be changed. That is, because of the angular relationship between the waveguide end section **34** and the waveguide section **32** of each waveguide extension, rotation of the extension about the axis 47 will change the direction at which the end section 34 points at the side walls of the cavity. Thus, the modes generated within the cavity can be controlled by appropriately setting each of the waveguide extensions relative to a reflecting side wall.

The waveguide extension 31 is a so-called "H"-plane waveguide extension. That is, the elbow 33 angles the extension away from or out of the plane of the narrow walls 51 of the section 32. As shown, the broad walls 52 of the full waveguide extension remain in the same plane. In the modes of exitation of the waveguide extension, it is the "H" field vector which remains in the same plane with the construction even though the direction of propagation of the energy is changed.

For best results in mode exitation and superposition, it is preferred that several of the waveguide extensions be "H"-plane extensions as dipicted in FIG. 4, and several others be E-plane extensions. An E-plane extension is shown in FIG. 6. As illustrated therein, the elbow 33′ connects the waveguide section 32 and the end section 34 of such extension in an oblique relationship which is rotated 90° with respect to the oblique relationship shown in FIG. 4. That is, it is the narrow walls 51 of the end section 34 and section 32 which remain in the same plane, and the extension is angled out of the plane of the broadwalls of the section 32. It should be noted that the only part of the "E"-plane extension shown in FIG. 6 which differs from the extension shown in FIG. 4 is the elbow 33′. That is, parts are intechangeable and it is only the elbows 33 which determine whether or not the waveguide extension is a so-called "H"-plane waveguide as shown in FIG. 4 or an "E"-plane waveguide as shown in FIG. 6. Because of such similarity, like parts in the two differing waveguide extensions are referred to by the same reference numerals.

A desired electric field strength uniformity in the cavity 12 is obtained by rotating the various waveguide extensions relative to the side walls and to one another. Most simply, the field strength uniformity for differing settings is determined emperically. The rotational position of the waveguide extensions 31 should also be adjusted relative to one another to reduce "cross talk", i.e., the reflection of power from one of the waveguide extensions into another. The iris on each of the waveguide extensions is adjusted to provide most efficient coupling of the energy from the particular waveguide into the cavity.

Although the invention has been described in connection with a preferred embodiment thereof, it will be appreciated to those skilled in the art that various changes and modifications can be made without departing from its scope. For example, feed port arrangements which include rotatable waveguide extensions angled obliquely within a standing-wave cavity are useful for purposes besides providing uniform field strength within a cavity. For example, such an arrangement can be used to direct traveling wave electromagnetic energy within a standing wave cavity onto a particular product or portion thereof which is to receive an added degree of microwave treatment. It is therefore intended that the coverage afforded applicant be limited only by the claims and their equivalent language.

What is claimed is:

1. An applicator for treating a product with electromagnetic energy comprising a multi-mode cavity capable of supporting electromagnetic energy within its interior; a source of electromagnetic energy; a waveguide for conveying electromagnetic energy from said source to said cavity; and at least one feed port connected with said waveguide for introducing said electromagnetic energy into said cavity, said feed port including a waveguide extension projecting obliquely into the interior of said cavity for directing energy emanating therefrom angularly toward a stationary reflecting surface to generate with said energy a plurality of standing wave modes within said cavity; said feed port further including an impedance matching iris at the free end of said waveguide extension for coupling electromagnetic energy from said extension into said multi-mode cavity.

2. The applicator of claim 1 wherein said iris is mounted on the free end of said waveguide extension for adjustment of its orientation relative thereto transverse to the direction of wave propagation within said waveguide extension.

3. The applicator of claim 1 wherein said waveguide extension project through a wall of said cavity into the interior thereof where it includes an elbow angling the same obliquely toward another wall of said cavity which acts as said reflecting surface.

4. The applicator of claim 3 wherein said waveguide extension is mounted on the wall of said cavity for rotation in a plane transverse to the direction of wave propagation therein at the location said waveguide extension projects through said cavity wall, and said waveguide connected with said feed port for conveying electromagnetic energy from said source to said cavity is twistable along the direction of wave propagation therein whereby rotation of said waveguide extension will be permitted without the necessity of reorienting the source of power connected therewith.

5. The applicator of claim 1 wherein a plurality of said feed ports are provided for introducing electromagnetic into said cavity at spacially distributed locations, each of said feed ports including a waveguide extension projecting obliquely into the interior of said cavity for directing energy emanating therefrom angularly toward a reflecting surface.

6. The applicator of claim 5 wherein each of said waveguide extensions projects through a wall of said cavity into the interior thereof where it includes an elbow angling the same obliquely toward another wall of said cavity which acts as said reflecting surface.

7. The applicator of claim 5 wherein said waveguide extension of each of said feed ports is mounted on the wall of said cavity for rotation in a plane transverse to the direction of wave propagation therein at the location said waveguide extension projects through said cavity wall, and a separate waveguide is connected with each of said feed ports for conveying electromagnetic energy to said cavity, each of said waveguides being twistable along the direction of wave propagation therein whereby rotation of the waveguide extension connected therewith will not affect the coupling between the same and said waveguide.

8. The applicator of claim 7 wherein each of said feed ports further includes an impedance matching iris at the free end of the waveguide extension thereof for coupling electromagnetic energy from said extension into said multi-mode cavity, the orientation of each of said irises transverse to the direction of wave propagation within the waveguide extension with which it is associated being adjustable.

9. The applicator of claim 8 wherein each of said feed ports further includes a load isolator for inhibiting the passage of power reflected from said cavity into the waveguide extension thereof from being transmitted to said source of electromagnetic energy.

10. The applicator of claim 6 wherein the elbow of at least one of said waveguide extensions angles the same obliquely out of the plane of the narrow walls of said extension where the same passes through the wall of said cavity and the elbow of at least one other of said waveguide extensions angles the same obliquely out of the plane of the broad walls of said extension at the location at which the same passes through the wall of said cavity.

11. An applicator for treating a product with electromagnetic energy comprising a multi-mode cavity capable of supporting electromagnetic energy within its interior;

a plurality of power packs providing a source of electromagnetic energy;

a plurality of feed ports for introducing electromagnetic energy into said multi-mode cavity;

a waveguide connecting each of said feed ports with an associated one of said power packs;

each of said feed ports including a waveguide extension which projects into the interior of said cavity and which is mounted on the wall of said cavity through which it projects for rotation in a plane transverse to the direction of wave propagation therein at the location said waveguide extension projects through said cavity wall, said extension including within the interior of the cavity an elbow angling the same obliquely with respect to the direction of wave propagation in said extension at said location said extension projects through said cavity wall;

said waveguide connected with each of said feed ports for conveying electromagnetic energy from its associated power pack to said cavity being twistable in the direction of wave propagation therein whereby rotation of said waveguide extension will not effect the coupling between the same and said waveguide connected therewith.

12. The applicator of claim 11 wherein said plurality of waveguide extensions includes both H-plane and E-plane extensions.

13. An applicator for treating a product with electromagnetic energy comprising a multi-mode cavity capable of supporting electromagnetic energy within its interior;

a source of electromagnetic energy;

a feed port for introducing electromagnetic energy into said multi-mode cavity;

a waveguide connecting said feed port with said source of electromagnetic energy;

said feed port including a waveguide extension which projects into the interior of said cavity and which is mounted on the wall of said cavity through which it projects for rotation in a plane transverse to the direction of wave propagation therein at the location said waveguide extension projects through said cavity wall, said waveguide extension including within the interior of the cavity of an elbow angling the same obliquely with respect to the direction of wave propagation in said extension at said location at which said extension projects through said wall and further including an impedance matching iris at the free end of the waveguide extension thereof for coupling electromagnetic energy from said extension into said multi-mode cavity.

14. The applicator of claim 13 wherein the orientation of each of said irises is adjustable transverse to the direction of wave propagation within its associated waveguide extension.

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