

Feb. 11, 1969

I. RYMAN ET AL

3,426,439

MICROWAVE DRYING SYSTEM

Filed Feb. 16, 1967

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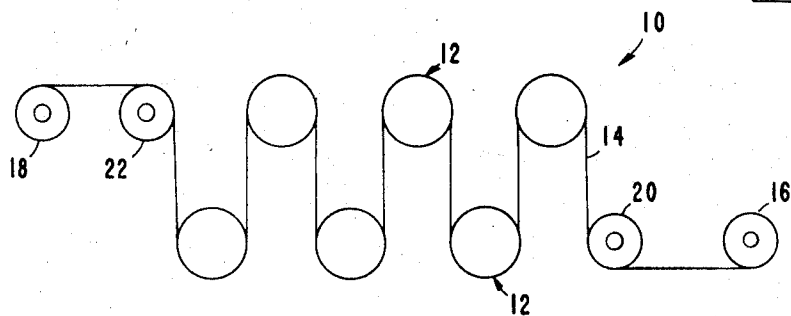


FIG. 1

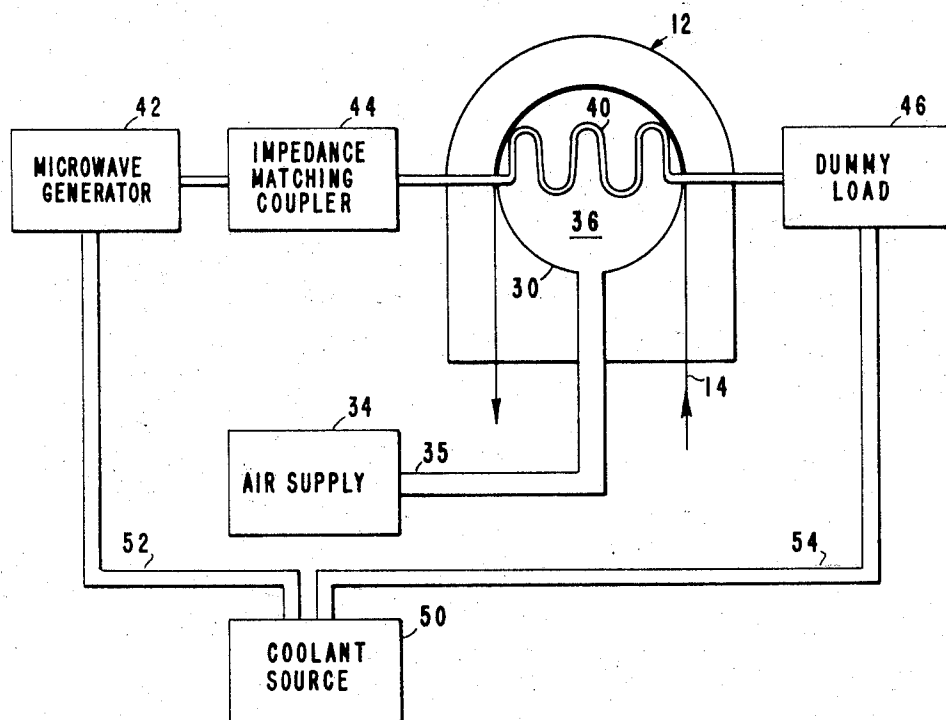


FIG. 2

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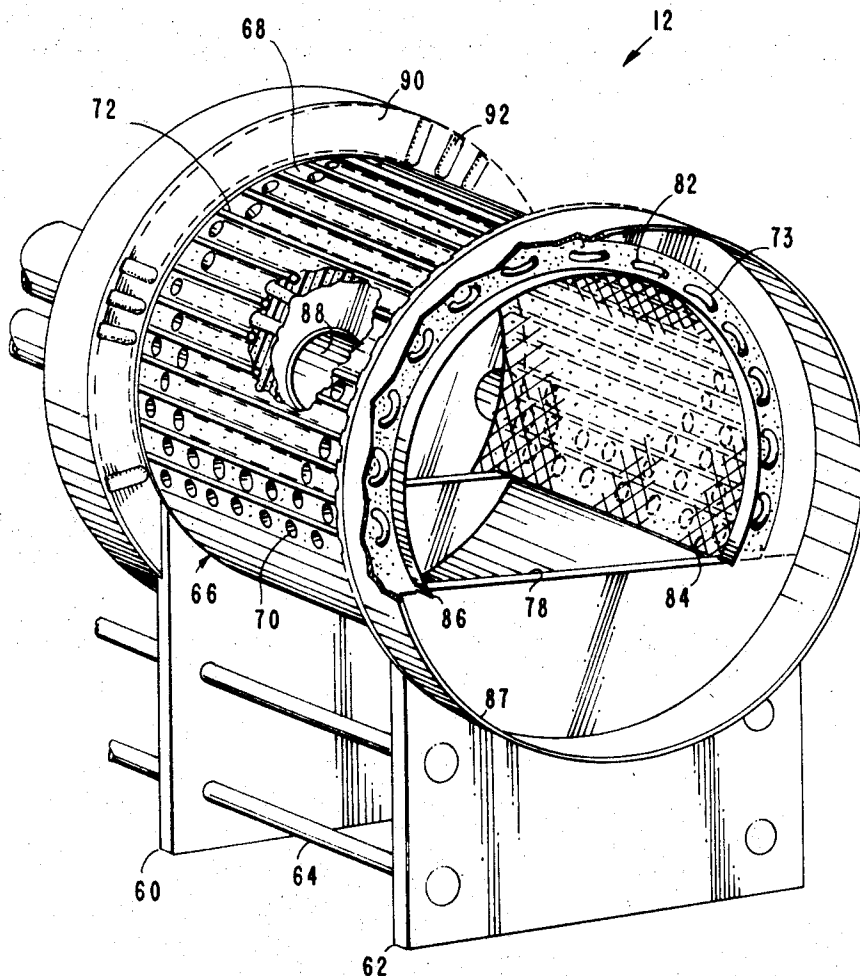
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FIG. 4(a)

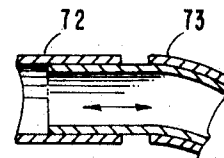
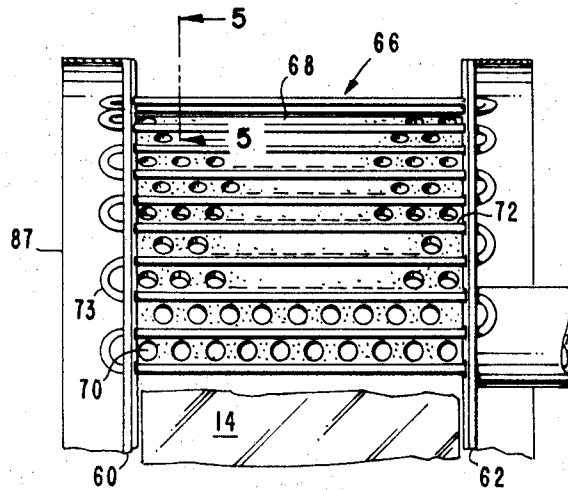


FIG. 4(b)

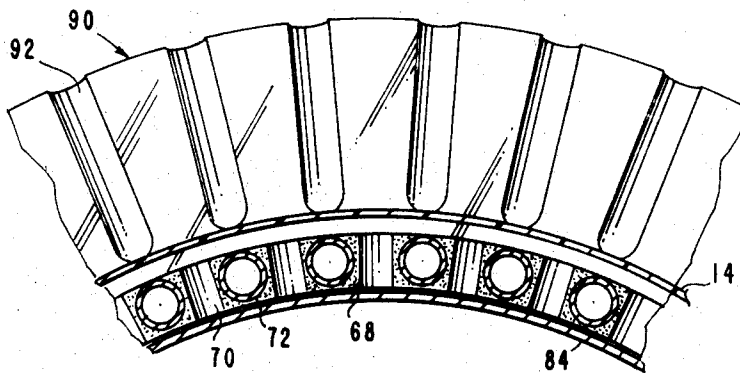


FIG. 5

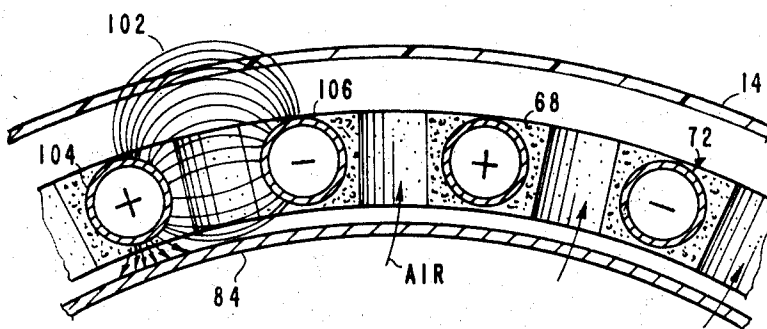


FIG. 6

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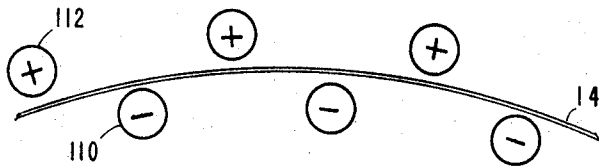


FIG. 7

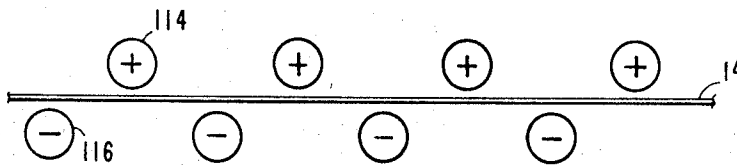


FIG. 8

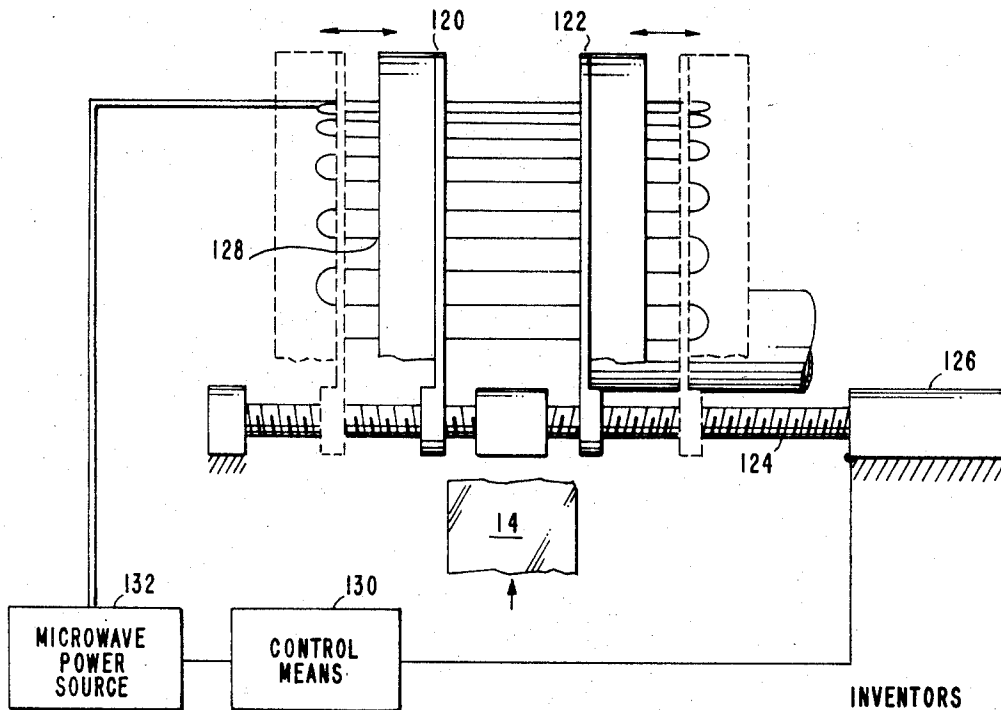


FIG. 9

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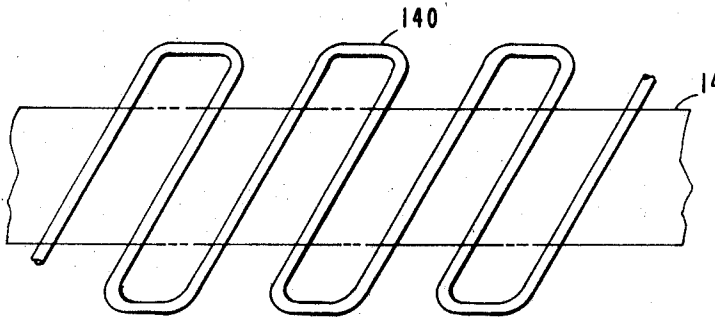


FIG. 10

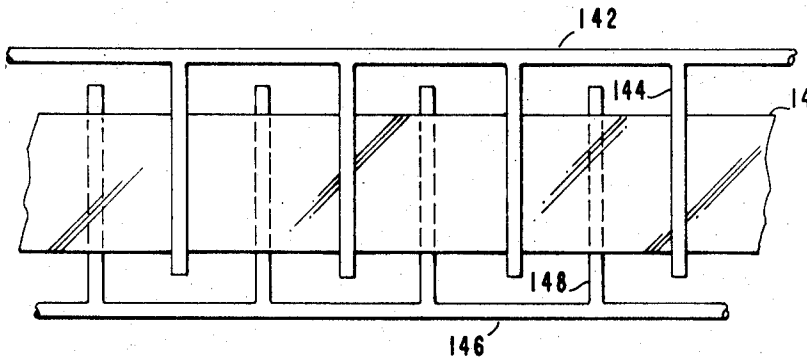


FIG. 11

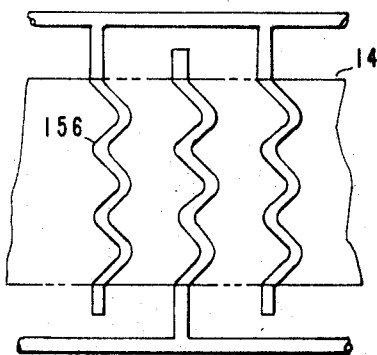


FIG. 12

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3,426,439

MICROWAVE DRYING SYSTEM

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U.S. Cl. 34—1

20 Claims

Int. Cl. F26b 3/34; H05b 9/06

ABSTRACT OF THE DISCLOSURE

An apparatus useful for drying film and the like at high speeds by the application of microwave energy. A conductor is serpentine through a perforated surface which may, for example, be substantially cylindrical or planar. Microwave energy is coupled to the conductor to establish a fringing electromagnetic field through which the film is pulled. The film is spaced from the surface by an air bearing formed by exhausting air through the surface perforations.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates generally to apparatus useful for drying material and more particularly to apparatus employing microwave electromagnetic fields adapted to very rapidly dry a continuously moving film strip.

As the quantity of wet processed film used by both the military and industry has continued to mount, the need for improved film drying apparatus has become increasingly apparent. Conventional prior art film drying techniques, typified by hot air impingement, have been pushed almost to their limit in both efficiency and speed and yet are not able to satisfactorily cope with the increasingly demanding application requirements.

DESCRIPTION OF THE PRIOR ART

The prior art reveals that various technologies have been applied to the problem of film drying in an attempt to increase both speed and efficiency without sacrificing quality. Probably the most prevalent prior art technique involves bringing high velocity hot air into contact with the film. Other attempts have involved the application of ultrasonic, infrared, laser, and microwave technologies to the drying problem. Thus far however, none of these various attempts has provided a satisfactory drying apparatus capable of efficiently operating on various widths of film at speeds in excess of about 100 ft./min.

The prior art attempts at drying by utilizing microwave energy have usually involved an apparatus comprised of a slotted serpentine waveguide having a rectangular cross-section compatible with the frequency employed. In such an apparatus, the film is pulled through the slots and is thus exposed to the microwave energy being propagated through the guide. Such an arrangement presents many problems in addition to that of tailoring the absorption of power to suit the film emulsion characteristics.

For example, it has proved exceedingly difficult to precisely pass the film through the waveguide slots at a high speed without damaging the film by physical contact. It has also proved difficult to prevent the nonuniform dissipation of energy in the film which causes nonuniform drying. Additionally, drying in this manner has resulted in condensation within the waveguide thus modifying the characteristics thereof.

SUMMARY OF THE INVENTION

The present invention is directed to an improved appa-

ratus for effectively drying material at higher speeds than has heretofore been economically possible.

Briefly, the present invention is directed to an apparatus utilizing a gas bearing to enable a strip of material to be efficiently exposed to or illuminated by a microwave electromagnetic field.

The term "microwave" as used herein will refer primarily to the portion of the electromagnetic spectrum from 900 to 30,000 megacycles (even though any radio wave above 1000 kilocycles is, strictly speaking, a microwave). In this microwave range, four frequencies have been preassigned by the Federal Communications Commission for industrial, scientific, and medical purposes (the so-called ISM frequencies). These are, respectively, 915, 2450, 5800, and 22,125 megacycles. Of these, the two lower frequencies are those most commonly used in industry and are sometimes referred to as the L and S bands. It will be assumed that the microwave energy utilized by the embodiments disclosed herein will fall in one of these two bands.

In accordance with one aspect of the preferred embodiment of the invention, an air bearing is formed by exhausting air through a perforated surface which can, for example, be substantially cylindrical or planar. The material strip, which can comprise wet processed film, for example, is pulled over the surface but is spaced therefrom by the air bearing. Thus, there is no physical contact between the material and the surface and accordingly, the likelihood of film damage is reduced considerably as compared to prior art arrangements.

In accordance with a further aspect of the preferred embodiment of the invention, the microwave field through which the material is pulled, is developed by coupling a microwave generator to a conductor or illuminator disposed in the perforated surface. The illuminator preferably comprises a slow wave structure or transmission line which, in response to the application of microwave energy thereto, develops a pronounced standing wave pattern or fringing field along its length. Energy can be coupled to the illuminator from a standard transmission line through an impedance matching coupler.

In accordance with one feature of the invention, the illuminator, comprises an electrical conductor serpentine across the path of material movement. In accordance with another feature of the invention, the illuminator conductor is hollow to permit a coolant to flow there-through.

In accordance with another feature of the invention, the microwave energy is applied to the illuminator in such a manner that the wetter portions of the material are exposed to a relatively weaker electromagnetic field than are the drier material portions.

In accordance with one alternate embodiment of the invention, the serpentine illuminator is formed to define two spaced rows of illuminator sections, thus enabling the material to be pulled along a path between the rows of sections.

In accordance with a further departure from the preferred embodiment of the invention, the illuminator sections are disposed at an angle with respect to the material path in order to prevent nonuniform drying due to aligned node points.

In accordance with a further feature of an alternate form of the invention, means are provided for enabling different widths of material to be processed by varying the energy supplied to the illuminator. A preferred manner of accomplishing this is to provide means for physically varying the spacing between the side walls defining the air bearing volume and controlling the microwave energy applied to the illuminator as a function of the wall position.

It is pointed out that several attractive operating characteristics result as a consequence of constructing an apparatus in accordance with the preferred embodiment of the invention; notably, condensation adjacent the apparatus is substantially eliminated inasmuch as the exiting air carries the water vapor away. Additionally, the natural tendency of the material to curl as it dries is reduced by conforming it to a cylindrical surface.

DESCRIPTION OF THE DRAWINGS

FIGURE 1 schematically illustrates a drying system employing a plurality of drying units in accordance with the present invention;

FIGURE 2 is a schematic block diagram illustrating a drying unit in accordance with the present invention together with means for supplying air and microwave energy thereto;

FIGURE 3 is a perspective view of a preferred structural embodiment of the invention;

FIGURE 4a is a side view of a preferred structural embodiment of the invention;

FIGURE 4b is an enlarged fragmentary sectional view illustrating means for varying the length of an illuminator section;

FIGURE 5 is a sectional view taken substantially along the plane 5—5 of FIGURE 4;

FIGURE 6 is a schematic sectional view illustrating the electromagnetic field formed by the illuminator sections and the manner in which the field intersects the material to be dried;

FIGURE 7 schematically illustrates an alternate embodiment of the invention;

FIGURE 8 schematically illustrates a still further embodiment of the invention;

FIGURE 9 illustrates a side view of the preferred embodiment of the invention showing how it can be utilized to handle material of different widths;

FIGURE 10 is a schematic illustration of a further alternate embodiment of the invention;

FIGURE 11 is a schematic diagram of a still further alternate embodiment of the invention; and

FIGURE 12 is a schematic diagram of a still further alternate embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Attention is now called to FIGURE 1 which illustrates a system 10 comprised of a plurality of drying units 12 suitable for drying material such as strip material 14. Although the strip material 14 can comprise many different materials, the exemplary material which will be most often referred to herein will be wet processed film. However, it should be appreciated that the system 10 can be utilized to dry other materials, e.g. the coatings on paper, fabric, or any synthetic or natural fiber. Further, although, as will be better appreciated hereinafter, the invention finds its greatest utility in drying continuous strips of material, it is also useful for drying sheet material.

As shown in FIGURE 1, the material 14 can be fed from some supply means, such as roll 16, around a series of drying units 12 to take-up roll 18. A pair of idler rollers 20 and 22 are illustrated for guiding the material 14.

Although six drying units 12 are illustrated in the system 10 of FIGURE 1, it is pointed out that the number of drying units required depends, of course, upon the particular application. Thus, one drying unit 12 may be adequate to rapidly dry some materials while a greater number of drying units 12 arranged in tandem as shown in FIGURE 1 may be required for other materials. Inasmuch as the drying units 12 of FIGURE 1 are all intended to be substantially identical, except for perhaps the amount of power supplied to each, the remaining portion of the specification will be primarily directed to a description of the structure and operation of only a single drying unit 12.

Attention is now called to FIGURE 2 which illustrates a schematic block diagram of a single drying unit 12 in accordance with the present invention, together with apparatus coupled thereto necessary for its operation. Briefly, in accordance with the present invention, the drying unit 12 is comprised of a drum 30, having a cylindrical surface around which the strip material or film 14 passes. As will be explained in greater detail hereinafter, the drum surface has a plurality of perforations therein through which a gas such as air is exhausted to form an air bearing to space the film 14 from the surface. More particularly, an air supply source 34 is provided which is coupled by hose 35 to a plenum chamber 36 defined within the drum 30. By supplying air through the hose 35, to the plenum chamber 36, the air will be exhausted through the perforations defined in the drum surface to form an air bearing to consequently space the film 14 from the surface. In this manner, the film 14 can be pulled over the drum surface out of physical contact therewith.

In accordance with a further aspect of the present invention, a microwave electromagnetic field is generated which intersects the path of the film 14 as it is pulled around the drum 30. As will be better explained hereinafter, a serpentine conductor or illuminator 40 is provided within the drum 30, preferably coincident with the drum surface, to develop a fringing electromagnetic field. That is, a microwave generator 42, e.g. of the magnetron type, is utilized to supply microwave energy through an impedance matching coupler 44 to one end of the illuminator 40. A dummy load 46 is coupled to the second end of the illuminator 40 in order to absorb any energy not attenuated in the drying unit 12.

As will be seen hereinafter, the illuminator 40 comprises a slow wave transmission line preferably in the form of a serpentine conductive tube, e.g. of copper. The microwave energy applied thereto by coupler 44 is launched so that the energy effectively travels along the outside or skin of the conductor tube 40. Whereas most transmission lines are designed to minimize radiating fringing fields and consequent attenuation, in accordance with the present invention, frequency and dimensional parameters are selected to maximize fringing fields around the illuminator 40. Moreover, as will be mentioned hereinafter, various parameters are selected to concentrate the fringing field along the path of the film 14 around the drum 30. The electromagnetic field, intersecting with the wet film, reacts therewith to generate heat in the contained water thereby causing its migration to the film surface where it is evaporated by the escaping air.

For the purpose of introducing background information, it is pointed out that the electromagnetic field of course does not itself provide heat but heat is generated as a consequence of the interaction between the electromagnetic field and the moisture within the film 14. More particularly, some materials, called "lossless materials," do not respond to microwave emissions. However, other materials, known as "lossy materials," do respond to a microwave field. Normally, the base and gelatin emulsion of photographic film are considered "lossless." However, the moisture present in wet film is "lossy." As a consequence, in response to an alternating electro-magnetic field, the water molecules on the film attempt to align themselves with the field. Each time the field reverses, the water molecules rotate to realign themselves. This continuous rotational action at microwave frequencies creates heat by molecular friction, forcing the water to the surface and vaporizing it. The drying unit 12 in accordance with the present invention, constitutes an exceedingly useful and probably optimum configuration for presenting the microwave energy to the film 14 in order to vaporize the moisture therein. The air which is continually supplied to the unit 12 to replenish the bearing, carries the vapor away, thus preventing condensation.

It is pointed out that the direction of movement of the film 14 in FIGURE 2 is opposite to the direction of energy propagation along the illuminator 40. Thus, the wettest portion of the film is exposed to the weakest field intensity and the driest portion of the film in which the moisture is most tightly bound is exposed to the maximum field intensity.

Prior to proceeding to a detailed description of various structural embodiments of the drying unit 12, further reference is made to FIGURE 2 wherein a source 50 of coolant, e.g. water, is provided for dissipating excess heat generated as a consequence of the aforescribed action. The coolant source is coupled by hose 52 to the microwave generator 42. It is contemplated that coolant be pumped through the microwave generator 42, and through the coupler 44 to the tubular illuminator 40. The tubular illuminator 40 is hollow and thus passes the coolant to the dummy load 46 which can pass the coolant through a heat exchanger (not shown) prior to returning it to the coolant source 50 through hose 54. It is pointed out that the coolant path illustrated in FIGURE 2 is shown for exemplary purposes only, and it will, of course, be appreciated that other coolant paths could be utilized. For example, if justified, separate coolant paths can be provided to each of the various components to be cooled.

Attention is now called to FIGURE 3 which comprises a perspective view of a preferred embodiment of drying unit 12 for drying material of a fixed predetermined width. The drying unit 12 is comprised of a pair of vertical frame pieces 60 and 62, which can be coupled to one another by tie rods 64. Mounted between the frame pieces 60 and 62 is a cylindrical drum 66 fabricated of any lossless material, e.g. a solid plastic foam material 68. The surface of the drum 66 is provided with a plurality of perforations 70 through which air can be exhausted. Mounted within and substantially coincident with the surface of the drum 66, is a plurality of conductor or illuminator sections 72 extending parallel to the drum axis. The opposite ends of each section 72 are coupled to different adjacent sections by U-shaped end pieces 73. Reduced end portions 74 on the U-shaped pieces 73 are slidably received in the sections 72 for tuning purposes (FIGURE 4b).

Preferably, the sections 72 and perforations 70 extend only about halfway around the drum 66 as shown in FIGURE 3 inasmuch as it is only necessary that they be disposed adjacent the film path which, as suggested by FIGURES 1 and 2, will be adjacent the drum surface only about halfway therearound. The frame pieces 60 and 62 define cutout areas 78 in alignment with the center of the drum 66. The U-shaped end pieces 73 can project beyond the plane of the pieces 60 and 62 (FIGURE 3) and be retained within slots 82.

A perforated conductive ground plane 84 is concentrically disposed within the cylinder 66 and is held in place by a conductive band 86 disposed within the cutout area 78. A sealing plate (not shown) is intended to fit over and seal the area 78 within the rim 87. Thus, the volume enclosed by the drum 66 and sealing plate functions as a plenum chamber allowing the air introduced therein from port 88 to escape through the perforations 70 in the drum surface. The perforations 70 are properly distributed over the drum surface so as to create a suitable air bearing for spacing the film 14 at a predetermined distance from the drum surface.

In order to create a satisfactory air bearing, it is additionally desirable to provide wall portions 90 adjacent the sides of the drum 66. As illustrated in FIGURES 3 and 4, the wall portions 90 can comprise integral parts of the frame pieces 60 and 62. Each of the wall portions 90 defines a series of air bleed channels 92 (FIGURES 3 and 5) immediately adjacent the drum surface. The air bleed channels 92 function to permit air to escape out from under the film 14 as it rides on the air bearing over the drum surface. If due to the air pressure and

the weight of the film, the film is driven too far above the drum surface, the amount of air bled through the channels 92 will increase, thus reducing the spacing between the film 14 and drum surface.

Attention is now called to FIGURE 6 which illustrates a schematic cross-sectional view of the drying unit 12 similar to the structural view shown in FIGURE 5. FIGURE 6, however, illustrates the instantaneous polarity of each of the conductor sections 100 in response to the applied microwave energy. The length of each illuminator section 72 from the midpoint of a U-shaped member at one end thereof to the midpoint of a U-shaped member at the opposite end thereof is selected to be equal to approximately multiples of quarter wavelengths so that corresponding portions of adjacent sections will always define opposite polarities. The polarities of the sections will, of course, reverse at the frequency of the microwave energy utilized. As an example, a microwave frequency of 2,450 megahertz, commonly called the S-band, can be employed.

As a consequence of the polarity of adjacent conductor sections 100 being opposite, an electromagnetic field represented by the field lines 102 will be established extending from each illuminator section to an adjacent section. Thus, particularly considering sections 104 and 106 as an example, it will be noted that the field 102 extends above and below the drum surface as viewed in FIGURE 6. In addition to the field established between adjacent sections, it is pointed out that a field is also established between the conductor sections and the ground plane 84.

As the film 14 moves past the drum surface, spaced therefrom by the air bearing formed by the air escaping through perforations 70, the field 102 will distort and tend to somewhat concentrate through the lossy substance, i.e. the water carried by the film 14. It is desirable of course that as large a portion of the field 102 as is possible be concentrated within the film 14 extending parallel to the film path. In order to maximize the field strength through the film, the relationship between various parameters should be optimized. Thus, it is pointed out that field concentration within the film 14 is dependent somewhat upon the spacing between adjacent conductor sections, and the frequency of the electromagnetic energy employed. Additionally, it has been found that variations in the position of the ground plane 84 affect the degree of concentration of the field within the film 14. Thus, it is desirable to critically and precisely position the ground plane 84.

It is pointed out that one of the favorable operating characteristics of the embodiment of FIGURES 3-5, is that by essentially conforming the film to the cylindrical surface of the drum, the film's inherent tendency to curl is minimized.

Attention is now called to FIGURE 7 which schematically illustrates an alternative embodiment of the invention. More particularly, it will be noted that whereas all of the conductor sections of the serpentine illuminator in the previously described embodiment were aligned along the periphery of a single curve, i.e. the drum surface, the illuminator sections in the embodiment of FIGURE 7 are grouped along two spaced curves. That is, the sections 110 in a lower row can be disposed and retained in the surface of a first drum (not shown) while the sections 112 of an upper row can be disposed and retained in the surface of a second drum (also not shown). In the embodiment of FIGURE 7, the film 14 will be transported between the first and second rows of sections. It is contemplated, but not necessary, that the sections 110 and 112 of FIGURE 7 form part of a single continuous tube similar to the embodiment of FIGURES 3-5, but however, serpentine around the film path. In the embodiment of FIGURE 7, it would of course be desirable to provide two air bearings to thus space the film 14 from both the sections 110 and the sections 112.

In a still further embodiment of the invention, as shown in FIGURE 8, the sections can be aligned in two parallel planes, rather than along curved rows, as shown in FIGURE 7. More particularly, a first group of sections 114 can be arranged in a plane parallel to a second group of sections 116 with the film 14 moving along a path between the groups of sections 114 and 116. It is again contemplated that in the embodiment of FIGURE 8, the illuminator be comprised of a single continuous tube with the tube being serpentine around the film path 14. The sections 114 can be disposed and retained in a first flat surface (not shown) while the sections 116 can be retained and disposed in a second flat surface (also not shown). As should be appreciated, in the utilization of the embodiment of FIGURE 8, it will be desirable to provide two air bearings to space the film 14 from both the sections 114 and 116.

Although not specifically shown in the drawings, it should also be appreciated that the embodiment of the invention illustrated in FIGURES 3-5 can be modified to employ a planar rather than cylindrical surface. In other words, the sections serpentine around the film path, shown in FIGURE 8, to define two planes of sections could be modified so that all of the sections would be aligned in a single plane with an air bearing being provided to space the film from that plane. It is also pointed out that although it has been assumed that the several sections in each embodiment form part of a single continuous conductor, it is not essential that this be so. Thus more than one conductor, each comprised of several sections, could in fact be employed.

In order to enable an embodiment of the invention to accommodate various widths of films, means can be provided, as are schematically shown in FIGURE 9, for modifying the spacing between walls 120 and 122 defining the air bearing side boundaries. In the schematically illustrated embodiment of FIGURE 9, the walls 120 and 122 are illustrated as being oppositely threaded on a rotatable shaft 124 driven by positioner motor 126. Thus as the shaft is rotated in one direction, the walls will move away from a center line and as the shaft is rotated in the other direction, the walls will move toward a center line. Other manual and automatic arrangements will of course be apparent to those skilled in the art. It is however pointed out that as the width of film being dried is changed, the power requirements of the illuminator also change. That is, inasmuch as there is an optimum amount of energy to be dissipated in a unit area of film, which optimum amount is dependent upon the rate of film movement, the type of film material, and other factors, it is desirable to vary the power delivered to the illuminator 128 as the area of film being dried is varied in order to maintain an optimum balance. As a consequence, a control means 130 is provided which is responsive to the positioner motor 126 for controlling the microwave power source 132 delivering energy to the illuminator 128. Accordingly, as the positioner motor 126 moves the walls 120 and 122 together to accommodate a lesser width film, the control means 130 responds thereto by correspondingly reducing the power delivered by source 132 to the illuminator 128.

Attention is now called to FIGURE 10 which schematically illustrates a further embodiment of the invention. It will be appreciated that in all of the embodiments thus far discussed, the conductor sections extended substantially across the film width at right angles to the path of film movement. Such an arrangement may result in non-uniform film drying due to node points of standing waves which may be established along the conductor sections. This is so because at the node points of course the electromagnetic field intensity is substantially zero. Consequently, if node points on each of the conductor sections are in alignment, a narrow line along the film may not be exposed to an electromagnetic field intensity sufficient to dry it at a rate commensurate with the other portions

of the film. In order to assure that the node points along the various illuminator sections are somewhat misaligned, the conductor sections 140 can be arranged at an angle with respect to the film path as shown in FIGURE 10.

Attention is now called to FIGURE 11 which illustrates a still further embodiment of the invention. Whereas all of the embodiments thus far discussed utilize either a single continuous tubular conductor or a plurality of conductors positioned in tandem, along the bearing surface, the embodiment of FIGURE 11 employs a series of quarter wavelength sections with alternate sections being fed from different sources. Thus, a waveguide 142 for example can couple energy to each of illuminator sections 144. Similarly, a waveguide 146 can couple energy to illuminator sections 148, each section 148 being disposed between a pair of sections 144. The conductor sections 144 and 148 of FIGURE 11 can be aligned along a single surface, e.g. similar to the embodiment of FIGURES 3-5 or can be arranged along two spaced surfaces with the film 14 moving therebetween as represented in FIGURE 11. Additionally, the conductor sections 144 and 148 can be disposed at an appropriate angle with respect to the film path 14 as is shown in the embodiment of FIGURE 10.

Attention is now called to FIGURE 12 which schematically illustrates a still further embodiment of the invention in which the illuminator sections 156 are formed by a series of successive bends which preferably have lengths equal to multiples of quarter wavelengths. By constructing the illuminator sections as illustrated in FIGURE 12, a more uniform field distribution through the film 14 is assured. Although alternate sections in FIGURE 12 are illustrated as being fed from different waveguides or transmission lines, it should be appreciated that sections of the type shown in FIGURE 12 can be employed in lieu of straight sections in any of the aforedescribed embodiments of the invention.

From the foregoing, it should be appreciated that a drying apparatus has been disclosed herein in which a piece of material, such as film or fibers, to be dried is transported through a microwave fringing field developed by an illuminator arrangement which can be fabricated in any of various manners as is suggested by the several embodiments disclosed herein. Regardless of the particular illuminator arrangement, microwave energy propagated along the illuminator will establish a fringing field through which the material to be dried is passed. In accordance with a significant feature of the invention, the material is transported through the fringing field by supporting it on an air bearing or between a pair of air bearings so as to eliminate the necessity for physically contacting the film. As a consequence, the film rides a predetermined distance from the illuminator sections generating the fringing field. The moving air, in addition to supporting the film and spacing it from the illuminator sections, carries away the water vapor developed as a consequence of the molecular heating in the film.

What is claimed is:

1. Apparatus for drying material comprising: means for transporting said material along a predetermined path; a transmission line disposed adjacent said path; and means for propagating electromagnetic energy along said transmission line to develop an electromagnetic fringing field intersecting said path.
2. The apparatus of claim 1 wherein said transmission line is comprised of a plurality of sections each extending across said path.
3. The apparatus of claim 1 wherein said transmission line is comprised of a plurality of sections extending substantially parallel to one another and to the plane of said path and substantially perpendicular to the direction of said path.
4. The apparatus of claim 2 wherein said sections are disposed at an angle relative to the direction of said path.

5. The apparatus of claim 1 wherein said transmission line is comprised of a plurality of sections arranged in first and second spaced rows, said first and second rows being disposed on opposite sides of said path.

6. Apparatus for drying material comprising:
means including a surface having openings therein for transporting said material along a predetermined path;

an illuminator disposed adjacent said path;
means for propagating electromagnetic energy along said illuminator to develop an electromagnetic fringing field intersecting said path;

means for moving said material along said surfaces; and

means for exhausting a gas through said openings to space said material from said surface.

7. The apparatus of claim 6 wherein said illuminator extends substantially coincident with said surface.

8. The apparatus of claim 7 wherein said illuminator is serpentine in said surface and includes a plurality of illuminator sections each extending substantially perpendicular to the direction of said path.

9. The apparatus of claim 6 wherein said surface is substantially cylindrical.

10. Apparatus adapted to dry material adapted to move along a predetermined path, said apparatus comprising:

a transmission line;

microwave generator means coupled to said transmission line for propagating energy therealong and for developing a fringing field intersecting said path; and means creating a gas bearing between said material and said transmission line for supporting said material in spaced relationship with respect thereto.

11. The apparatus of claim 10 wherein said transmission line includes at least one section extending substantially parallel to the plane of and substantially perpendicular to the direction of said path.

12. Apparatus adapted to dry material adapted to move along a predetermined path, said apparatus comprising:
an illuminator comprising a hollow tube capable of passing a coolant therethrough;

microwave generator means coupled to said illuminator for propagating energy therealong and for developing a fringing field intersecting said path; and

means creating a gas bearing between said material and said illuminator for supporting said material in spaced relationship with respect thereto.

13. Apparatus adapted to dry material adapted to move along a predetermined path, said apparatus comprising:
an illuminator;

microwave generator means coupled to said illuminator for propagating energy therealong in a direction substantially opposite to the movement of said material along said path for developing a fringing field intersecting said path; and

means creating a gas bearing between said material and said illuminator for supporting said material in spaced relationship with respect thereto.

14. Apparatus adapted to dry material adapted to move along a predetermined path, said apparatus comprising:

an illuminator;

microwave generator means coupled to said illuminator for propagating energy therealong and for developing a fringing field intersecting said path;

a surface defining openings therein;

said illuminator being disposed substantially coincident with said surface; and

means creating a gas bearing between said material and said illuminator including means exhausting gas through said openings toward said path for supporting said material in spaced relationship with respect to said illuminator.

15. The apparatus of claim 14 including a conductive perforated ground plane disposed adjacent said surface remote from said path.

16. The apparatus of claim 14 including first and second walls extending parallel to said path on either side of said surface;

said walls defining gas bled channels therein adjacent said surface.

17. The apparatus of claim 14 including first and second walls extending parallel to said path on either side of said surface;

means for varying the spacing between said first and second walls.

18. The apparatus of claim 17 including means responsive to the spacing between said first and second walls for controlling said microwave generator means.

19. The apparatus of claim 14 wherein said surface is substantially cylindrical defining a plenum chamber therein; and

means for supplying said gas to said plenum chamber.

20. Apparatus adapted to dry material adapted to move along a predetermined path, said apparatus comprising:

an illuminator comprised of a first group of sections arranged along a first surface and a second group of sections arranged along a second surface;

means for passing said material along said path between said first and second surfaces;

microwave generator means coupled to said illuminator for propagating energy therealong and for developing a fringing field intersecting said path; and

means creating a gas bearing between said material and said illuminator for supporting said material in spaced relationship with respect thereto.

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