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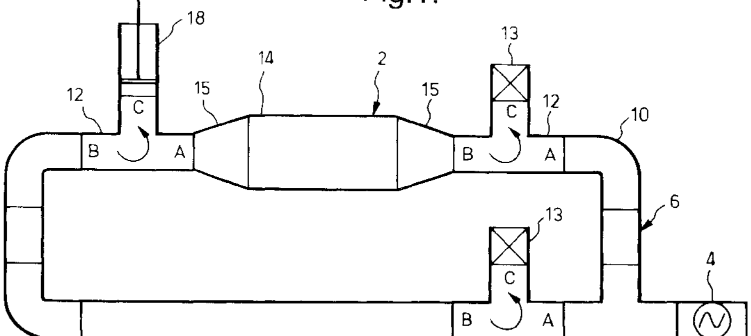
(54) Apparatus & method for heating objects with microwaves

(57) An apparatus and method for heating planar and non-planar objects using microwaves, the method comprising: providing at least two beams of travelling microwaves from a coherent microwave source (4); directing each beam of travelling microwaves into separate arms (8,10) of a waveguide (6); isolating the beam of travelling microwaves in each arm using a microwave circulator (12); forming a standing wave from the travelling waves at the working area (14) where the arms meet; and varying the phase of at least one beam of travelling microwaves by altering the path length of the microwaves in the waveguide to move the standing wave. An object passing through the working area is irradiated by the microwaves, thereby generating complex interference patterns in the object. Controlling changes to the phases of the incident microwaves changes and controls the time-averaged superposition of the interference patterns, facilitating effective volumetric heating of the object.

Fig.1.



EP 0 792 085 A2

Description

FIELD OF THE INVENTION

The present invention relates to an apparatus and method for heating objects, such as food products, with microwaves.

BACKGROUND ART

It is well known to employ microwave radiation for heating purposes. A long-standing problem has been the non-uniform spatial distribution of microwave energy in a heating cavity, resulting in hot and cold spots at different locations in the cavity. Known methods to eliminate these hot and cold spots include using an electromagnetic wave mode stirrer to change the reflection patterns of the radiation and/or placing the object to be heated on a turntable in the cavity, ostensively passing the object through the hot and cold spots. Uneven heating can also result from the dielectric and thermal properties of the object to be heated, together with its size and geometry.

US 4464554 (General Electric Co) discloses an excitation system for a microwave oven; means are provided to shift the phase of a standing wave field pattern in a wave guide between a first phase relationship and a second phase relationship, thereby improving the uniformity of a time-averaged energy distribution in the oven cavity.

EP 136453, US 4775770, US 4866233 and US 4952763 (Snowdrift Corp) provide methods for the controlled microwave heating of objects in sealed packages; the microwaves emanate from either one microwave emitter subdivided into two or, preferably, from two microwave emitters. The two resulting power distributions are superposed to a sum field at least when time averaged and the object is placed in a region of maximum field strength of the sum microwave field, thereby achieving a predetermined temperature distribution in the object, the distribution being a scalar addition of the two or more independent temperature fields.

FR 2523797 (Centre National de la Reserche Scientifique) discloses means for heating objects with high aspect ratios, such as paper, where the object passes consecutively through slots in two waveguide arms. The microwave fields in the arms are standing waves displaced transversely to the direction of propagation of the object by the waveguide wavelength divided by four. EP 446114 and US 5278375 (Microondes Energie Systemes) disclose similar means for heating sheet objects passed through slots in a waveguide.

Mexatas, A.C. & Meredith, R.J. (1983) in "Industrial Microwave Heating", published by Peter Peregrinus Ltd., London, UK (reprinted 1993) pp 170-1 discuss quarterwave displacement between electric fields in two cavities to evenly heat a planar object. They state that this method can only be used to heat materials in sheet form where the thickness is a small fraction of the width, otherwise the material experiences large field variations along its length.

These known methods of heating objects using microwaves are based on the time-averaged superposition of scalar heating patterns. This results in a number of restrictions in use, such as a limited distance over which the heating method can be applied for even heating, limited control of the heating pattern distribution and effective heating only with objects that have high aspect ratios, such as planar objects, eg. paper or biscuits (since the method of time-averaged superposition of scalar heating patterns cannot be used to produce even three-dimensional heating in non-planar objects) .

The present invention seeks to provide an improved apparatus and method for heating objects using microwaves.

SUMMARY OF THE INVENTION

According to the present invention, there is provided an apparatus for heating objects using microwaves, the apparatus comprising:

a working area for positioning an object;
first and second elongate microwave transmission members each having an end located at the working area;
a single microwave source or a plurality of coherent microwave sources;
a means for providing a first beam of microwaves and a second beam of microwaves from the output microwave energy of the microwave source or sources;
a means for coupling the first beam of microwaves to the end of the first microwave transmission member remote from the working area and a means for coupling the second beam of microwaves to the end of the second microwave transmission remote from the working area;
a means associated with each microwave transmission member for isolating the microwaves therein; and
a means for varying the phase of microwaves in the first and/or second microwave transmission member;

wherein the apparatus is arranged such that the first beam of microwaves enters the working area in a first direction and the second beam of microwaves enters the working area in a second direction, and the angle between the first and second directions is non-orthogonal.

The microwaves travelling in each microwave transmission member, from the microwave source or sources, meet at the working area. The microwaves travelling in the first microwave transmission member and the microwaves travelling in the second microwave transmission member are coherent and mutually exclusive. Hence, vector addition of the microwave electric fields occurs to form an interference pattern, or standing wave, in the working area. When no object is present in the working area, the interference pattern is of a simple sinusoidal form. The phase of this standing wave can be varied. This is termed phase control.

In contrast, in the prior art, the microwaves used are not coherent and mutually exclusive; hence, scalar addition (rather than vector addition) of the microwave electric fields occurs to form a scalar standing wave in the working area. The phase of this standing wave continuously varies, so it can not be controlled.

In the present invention, when an object is partly or fully present in the working area, such as when the object is passed through the working area, the object is irradiated by the microwaves travelling in each microwave transmission member. A new and complex interference pattern is generated within the object by vector addition of the incident microwave electric fields.

The initial phase of the microwaves is important, and may vary according to the object.

The phase of the microwaves in at least one of the microwave transmission members can be varied, thereby generating different interference patterns in the object (with respect to the spatial distribution of the microwave field). Time-averaged superposition of the interference patterns within the object can result in rapid, time-averaged uniform heating of the object in up to three dimensions; hot and cold spots can be effectively eliminated.

The depth of heating can also be controlled by using phase control to select interference patterns which, for example, target microwave energy away from the incident surfaces. This is only possible when the microwaves in each transmission member are coherent and mutually exclusive (ie. when cross-talk between the microwaves in each transmission member is substantially avoided to maintain time-averaged coherence) so that interference patterns can be generated from destructive and constructive interference of the microwaves.

In contrast, in the prior art, destructive and constructive interference cannot occur because without both coherent and mutually exclusive microwaves, only scalar addition of the power distributions, and not vector addition of electric fields as in the current invention, is possible. Therefore, in the prior art, the microwaves always add where they meet in the object; this is in contrast to the present invention where selected areas of the object can be targeted for no heating whatsoever.

It is well known that the power absorbed by a dielectric material is proportional to the square of the electric field. In the case of coherent and mutually exclusive microwave signals of equal amplitude, as in the present invention, the electric fields add so that the resultant power distribution is proportional to four times the amplitude of either microwave signal. In scalar addition, the power distribution set up by each electric field, not the electric field itself, add so that the resultant power distribution is proportional to twice the amplitude of either microwave signal (the electric fields continuously constructively and destructively interfere on nanosecond time scales, so the time-averaged power distribution is simply the average electric field strength in the object, that is twice the amplitude of either microwave signal). Therefore, a further advantage of the current invention is that more intensive heating is possible from the same power source.

Moreover, the effective depth of heating can be increased with the use of phase control. By selecting interference patterns that target energy at the centre (or any other predetermined position) within an object, and exploiting the increased intensity of heating that is possible, as explained above, more unabsorbed microwave energy can be made available at greater depths, compared to methods in the prior art, for significant heating.

Thus the apparatus and method of the present invention provide phase control which, in the direction of phase control, can vary and select heating patterns for time-averaged targeted- or even-heating of an object. The effective depth and intensity of the targeted- or even-heating can also be increased.

Phase control may be applied in one, two or three dimensions in order to achieve time-averaged even heating in one, two or three dimensions, respectively. Alternatively, if phase control is applied in one-dimension, other means may be employed to achieve time-averaged even heating in another dimension; for example, the object to be heated is moved in a direction which is perpendicular to the direction of phase control, or the working area is altered by having castellated, dielectrically lined or narrow walls.

In the methods of the prior art, only time-averaged superposition of scalar heating patterns is possible because the microwave sources are not both coherent and mutually exclusive.

Providing a number of beams of microwaves from a single microwave source ensures that the beams are coherent. A plurality of phase-locked microwave sources are also coherent.

The angle between the respective directions of the first and second beams is preferably 0 to 30, 150 to 210 or 330 to 360 degrees. Preferably, the angle is 180 degrees.

The microwave transmission member may be a hollow waveguide, a coaxial cable, microwave stripline, or any other means for transmitting microwaves.

The first and second microwave transmission members may be the first and second arms of a single waveguide, which is in the form of a loop.

The working area may be formed by the meeting of two waveguides or waveguide arms, so that the object is in an area bound by walls. An alternative is that it may be located between two parallel antennae which are mutually coupled via an object to be heated, so that the object is in a working area not bound by walls.

Preferably, the means for varying the phase of a microwave in the first and/or second microwave transmission member comprises means for altering the path length of a microwave in a microwave transmission member. In one example, a sliding short is used to vary the electrical path length of a microwave beam in a waveguide arm. Adjustable stubs, a stub tuner, or other means for changing the effective waveguide length may also be used; for example, full or part introduction of a dielectric material into the transmission arm of a waveguide to change the original path length.

The means associated with each microwave transmission member for isolating the microwaves therein may comprise an isolator, such as a microwave circulator.

According to a further aspect of the invention, there is provided a method for heating objects using microwaves, the method comprising:

providing at least two beams of travelling microwaves from a single microwave source or a plurality of coherent microwave sources;
directing each beam of travelling microwaves into a separate microwave transmission member;
isolating the beam of travelling microwaves in each microwave transmission member;
forming a standing wave from the travelling waves at a working area which is where the microwave transmission members meet for locating an object to be heated;
and varying the phase of at least one beam of travelling microwaves in order to move the standing wave.

The present invention therefore provides a dynamic phase control system for the even- or targeted- heating of nonplanar objects in up to three dimensions.

DETAILED DESCRIPTION OF THE INVENTION

Examples of the apparatus and method of the invention will now be described to illustrate, but not to limit, the invention, with reference to the accompanying figures, in which:

figure 1 is a diagrammatic representation of a first embodiment of the apparatus;
figure 2 is a diagrammatic representation of a second embodiment of the apparatus;
figure 3 is a perspective view of a working area and the ends of waveguides;
figure 4a is a plan view of a tray;
figure 4b is a side view of a tray;
figure 5 is a perspective view of a working area containing a tray of food material supported on a block;
figure 6a is a series of thermal distribution images;
figure 6b is a series of power distribution images;
figure 7a is a series of thermal distribution images;
figure 7b is a series of power distribution images;
figure 8a is a power distribution image; and
figure 8b is a power distribution image.

Referring to figures 1 and 2, the apparatus 2 comprises a microwave generator 4 feeding into a waveguide 6, which is split via an E-plane series tee 7 into a first arm 8 and a second arm 10. The tee is tuned such that power introduced into any arm of the tee is divided such that half the power exits from each of the other two arms of the tee. The microwave generator is a magnetron or a travelling wave tube, for example. A circulator 12 (or other isolating means) is associated with each arm.

Circulators are three port ferrite devices which are labelled in the following way in figures 1 and 2:

- microwaves entering port A exit at port B
- microwaves entering port B exit at port C
- microwaves entering port C exit at port A.

In normal use, power enters port A from the microwave generator. The isolation of a circulator is customarily defined as how efficient the device is at diverting power entering port B to port C; the higher the isolation, the more power is diverted to port C. For the present invention, all circulators should have better isolation than 10 dB, preferably better than 20 dB, optimally better than 30 dB at the frequency (or over the frequency band) of operation of the microwave generator.

In normal use, a circulator immediately follows a microwave source, with a dummy load 13 attached to port C. Reflected power is diverted from port B to port C thus protecting the source. Dummy loads are usually water cooled, but may be cooled using air or other coolants. Optimally, a dummy load is designed for a circulator to minimise impedance mismatches.

As shown in figures 1 and 2, the waveguide is a rectangular loop, but may also be a circular loop or a square loop, for example. The end of each arm of the waveguide joins with the end of the other arm. At the location of this joint, a working area 14 is defined and two opposing waveguide walls have apertures 16 therein; the apertures shown in figure 3 are rectangular. Preferably, these walls do not cut any microwave field lines. The apertures provide means for passing an object through the working area of the waveguide. Referring to figure 3, a feed 17 extends outwardly from each aperture 16 to provide a passageway for feeding the object to the working area 14. Horizontal access to the working area is preferred as a conveyor belt can be run through the working area, with naked or packed objects to be heated on the belt. Two 90-degree-twist-sections 15 may be used and are shown in both figures 1 and 2 to allow horizontal access into the working area. Other 'twist' angles could also be used.

The working area may have fully or partly dielectrically lined walls, and also may have fully or partly castellated walls to modify the electric field pattern, and the indentations of the castellated structures may be dielectrically filled.

In an alternative example, both arms of the waveguide taper towards the working area, as shown in figure 3, preferably over a distance of the waveguide wavelength divided by four, so that the working area is narrowed. The tapered region 19 may be partly or fully dielectrically filled, with for example polytetrafluoroethylene, or with different dielectric materials in each tapered region, to control the impedance matching between the arms and the working area. This allows control of the electric field and/or microwave modes present in the working area.

Microwaves from the generator 4 are split into two beams and directed in opposing directions through the waveguide loop (ie. one beam in first arm 8 and one beam in second arm 10). The angle between the respective directions of the beams when entering the working area is 180 degrees. The circulators act to isolate the microwave energy propagated into one arm from the microwave energy propagated into the other arm. The waves travelling in each arm meet and generate a standing wave at the working area and in the region of the waveguide loop bound by the circulators. The microwave energy in each arm is sufficiently isolated using two circulators with dummy loads to prevent substantial cross-talk therebetween.

The first arm 8 has a variable path length section which comprises a circulator and a sliding short (instead of a dummy load). Power entering port B leaves at port C to the sliding short 18. Power reflects off the sliding short and re-enters port C but leaves at port A. The short is moved to predetermined positions which alter the electrical path length of a microwave travelling in the arm, thereby varying the phase of the standing wave, as detected at any one position, using for example, a slotted line waveguide 21 with appropriate detector (see figure 2). Consequently, the standing wave can be controllably moved in the region bound by the two circulators 12. Microwaves from the second arm 10 travelling through the working area will enter port A and leave at port B with their path length unaffected. The sliding short is preferably motorised via a programmable computer control system, so that the phase of the microwaves in the first arm 8 can be continuously varied.

A four stub tuner 19 is used in the apparatus of figure 2 to balance the amount of power in each arm. Slotted line waveguide 21 is also used to allow access for a probe to measure the relative phase of the standing wave at any instant in time. This measurement might form part of a control system, for example, to enable dynamic control of the phase of the standing wave.

To enable dynamic phase control to be implemented, the control system preferably comprises a motorised sliding short interfaced to a computer. The position and dwell time of the sliding short over the duration of heating an object may be pre-programmed according to the type of object and the final heating profile required.

In an alternative example, the stub tuner 19 can be used to vary the amplitude of the microwave power in each arm, allowing further control of the resultant power distribution. Additionally, the E-plane series tee 7 can be tuned to unevenly split the power entering arms 8 and 10, to further control the resultant power distribution. For example, for variable thickness objects, eg objects with a tapered cross-section along the direction of phase control, it may be preferential to impose an initial power distribution to assist the phase control method.

Alternatively, slotted line measurements, measurements of the power in each transmission arm, on-line measurement of the object temperature, etc. can provide feedback or feedforward control of the sliding short, stub tuner and/or a tunable E-plane series Tee.

The frequency of the microwaves is between 0.4 and 10 GHz. Industrial, Scientific and Medical (ISM) frequencies are preferred, particularly 896, 915, 2450 and 5800 MHz.

An object to be heated is passed through the working area 14. The microwaves travelling in each arm hit opposite faces of the object. This generates an interference pattern within the object, the pattern being dependent on the complex permittivity of the object and the phase of the standing wave which is present and adjacent to the object in the working area. As the object passes continuously, or in step fashion, through the working area, the sliding short is moved to vary the path length of the microwave travelling in the first arm, and therefore the phase of the standing wave. This generates at least one other different interference pattern within the object.

Controlling changes to the phases of the incident microwaves changes and controls the time-averaged superposition of interference patterns facilitating more effective volumetric heating of the object in up to three dimensions.

In an alternative example, if targeted heating is required, or the initial temperature distribution of the object is not uniform, or the object's complex permittivity changes with temperature, or the object's geometry changes with temperature, or additional heating methods are being combined with phase control such as the use of hot air, or any combination of these, one interference pattern may be sufficient to achieve the desired heating pattern.

This invention therefore achieves an optimisation of the time-averaged superposition of interference patterns.

The optimisation may result in interference patterns having different dwell times; the phases used to generate different interference patterns to be superposed are not necessarily 180 degrees out of phase. In contrast, in the prior art, the standing waves for scalar addition to be superposed are approximately 180 degrees out of phase.

Examples

A waveguide circuit was set up as shown in figure 2. A waveguide having an internal cross section of 248 x 124 mm was used, together with a 5 kW 896 MHz low ripple (less than 5%) microwave generator. The working area comprised a section of waveguide with a hinged lid to facilitate easy removal of objects placed therein. The circulators had isolation characteristics of better than 30 dB at 896 MHz.

Model food materials in polyethylene trays were placed in the working area and heated. The model food materials were chosen to be representative of the dielectric properties of many frozen food products (model 1) or high moisture content non-frozen food products (model 2). Properties of the model materials are detailed in the following table.

Material	Thermal Conductivity at 20°C W/m-K	Specific-Heat Capacity at 20°C J/kg-K	Complex Permittivity at 896 MHz & 20°C
Model 1	0.9	1050	5.5 - j 0.11
Model 2	0.6	3870	73 - j 17

Model 1 was a soft plastic material called Plasticine™ (which is available from Trylon Ltd, Northants, UK). Its analytical composition was 78.1% ash, 21.2% oil and 0.7% water.

Model 2 was a mixture of 91% water and 9% TX151 powder (TX151 is the product name of a hydrophillic powder available from Weatherford, Kirkhill Ind Est, Aberdeen, UK) . Its analytical composition was 93.6% water, 3.7% carbohydrate, 2.2% ash, 0.5% protein

Complex permittivity was measured using an open ended coaxial probe (model HP85070B from Hewlett Packard).

Referring to figures 4a and 4b, each polyethylene tray 22 had a top edge defining an open face having a width w of 122mm and a length z of 171mm; a base having a width x of 100mm and a length y of 150mm; a depth D of 35mm; a top edge corner radius r_1 of 30mm, a horizontal base corner radius r_2 of 15mm and a vertical base corner radius F of 6mm. The model materials completely filled the trays, but did not overspill.

As shown in figure 5, each tray 22 was supported on a polytetrafluoroethylene block 23 positioned at the centre of a working area 14 so that the mid-depth horizontal plane of the tray was approximately coincident with the half height of the waveguide. Block 23 had a width a of 34mm, a height b of 42mm and a length c of 72mm. The model materials were heated for a time sufficient to raise the temperature by a maximum of 20°C.

After heating, thermal images of the mid-depth horizontal plane of the model material were taken using an infrared scanner (model 870 obtained from Agema, Sweden). To prevent excessive perturbation of the temperature distribution from, for example, slicing the material with a knife, a layer of polyethylene cling film was placed at the half height of the tray as the model material was prepared in the tray: care was taken to exclude all air bubbles. After heating, the cling film and upper half of the model material were simply lifted out to expose the surface of the model material at the half depth height.

A three dimensional Finite Element Time Domain (3D FETD) microwave model was also used to simulate heating of the model materials. Figure 5 shows the section of waveguide modelled. The microwave model produced power distributions at the same plane as the measured temperature distributions to allow a qualitative comparison with the thermal images. Constant dielectric properties were assumed in the microwave model to reduce computational times (temperature rises in the experiments were kept to no more than 20°C to minimise the effect of temperature dependent complex permittivity) .

For each experiment, a tray containing model material was heated under a constant phase condition, ie the sliding short remained in one position. The 0° phase condition was arbitrarily defined as the home position of the sliding short. A fresh tray of model material was used for each experiment. The sliding short was then moved by a distance known to give a 30° movement in the standing wave pattern in the working area relative to the previous short position. In this way, the heating pattern at the half tray height plane was measured every 30°.

The FETD model was run to simulate the above experimental conditions. To compare the measured temperature distributions with the simulated power distributions, the thermal images and simulated power distribution had to be phase matched. For example, say for a given sliding short position the temperature distribution phase matched the simulation power distribution at 120°; when the sliding short was moved by a distance α, which is known from the dimensions of the sliding short to produce a phase change of 35°, the simulation result at 155° should have matched the corresponding experimental result. NB It is the phase change between the two points which is important and not the absolute phase of either.

Experiment 1

Model material 1 was heated in the tray; the direction of power flow, and therefore phase control, was parallel to the width w of the top edge of the tray. Figure 6a shows the measured thermal distribution images at each 30° phase change; the lighter the shading, the greater the temperature. It can be seen that the "hot spot" moves through the material.

3D FETD simulations were carried out. Figure 6b show the simulated power distribution images at each 30° phase change; the lighter the shading, the greater the power.

In figure 6b, the outline of the top edge of the tray can be seen. In figure 6a, the images are of the interior of the tray. It can be seen that there is a very close match in the position and size of the distributions of the thermal images and the FETD simulations at each phase condition.

Experiment 2

Model material 2 was heated in the tray; the direction of power flow, and therefore phase control, was parallel to the width w of the top edge of the tray. Figure 7a shows the measured thermal distribution images at each 30° phase change; the lighter the shading, the greater the temperature. It can be seen that the "hot spots" move through the material. From a comparison with figure 6a, it can be seen that the thermal distributions for model material 2 were more complex than for model material 1.

3D FETD simulations were carried out. Figure 7b show the simulated power distribution images at each 30° phase change; the lighter the shading, the greater the power.

In figures 7a and 7b, the images are of the interior of the tray. It can be seen that there is a very close match in the position and size of the distributions of the thermal images and the FETD simulations; ie the same changes in power distribution and heating pattern can be seen as the phase of the standing wave in the working area changes.

Comparative Experiment

To demonstrate the advantages of phase control in experiments 1 and 2, in which vector addition results, scalar conditions were imposed on the travelling waves in arms 8 and 10 of the waveguide loop to simulate scalar addition. The model materials of experiments 1 and 2 were used. Only one power distribution is possible under scalar addition conditions; hence, only one heating pattern is possible. The images resulting from scalar addition are shown in figures 8a (model 1) and 8b (model 2); again, the lighter the shading, the greater the power. The difference in the power distributions of the two materials is clear.

As a result of scalar addition providing only one power distribution, no controlled or targeted heating is possible.

These examples demonstrate the principle of phase control heating; they show that the heating pattern can be controlled so that areas within a material can be targeted with microwave energy. Experimental conditions were designed so that complex heating patterns would arise to demonstrate the principle of phase control. By appropriate time-averaged superposition of the interference patterns, desired heating patterns can be obtained.

It is clear that the phase of the standing wave in the working area may be controllably changed in a first direction to obtain the desired heating patterns in one-dimension.

To obtain the desired heating patterns in two-dimensions, phase control is applied in a first dimension and either phase control may also be applied across the second dimension or, more preferably, the object may be moved in a direction which is perpendicular to the first dimension.

To obtain the desired heating patterns in three-dimensions, phase control may be applied across all three dimensions; or phase control may be applied across two dimensions and the object may be moved in a direction which is perpendicular thereto; or phase control may be applied across two dimensions and the working area may have fully or partly dielectrically walls, or have fully or partly castellated walls, or have a narrowed width, as shown in figure 3, to modify the electric field pattern and/or modes present in the working area.

A preferred option for three-dimensional heating is to apply phase control in the first dimension, move the object in the second dimension and modify the working area in the third dimension.

It will be appreciated that, so long as phase control is applied in at least a first dimension, a variety of other means may be used to effect heating in a second and/or a third dimension.

The apparatus and method of this invention are suitable for the time-averaged even- or targeted-heating of a three-dimensional solid or particulate solid object, such as a packed food product, in the direction(s) of phase control, in up to three dimensions. For example, the object may be chicken coated with batter and breadcrumbs, or vegetables such as peas, broccoli, spinach and sweetcorn. It may also be used for sealing lids or heating plastics.

The object may be pre-packed in a container (eg a tray with a film lid; a bag or pouch; a plastic can; a plastic can having a metal top and a metal base.) If the object is pre-packed, it is preferably packed with a means for minimising deformation of the pack during heating and cooling (eg using a rigid sleeve). If the object is to be heated above 100°C, then external pressure may be applied.

The food product may be initially at ambient, chilled or freezing temperatures. Typically, this invention is used to heat food products to temperatures of above 50°C, particularly to pasteurisation temperatures (eg 70°C) and to sterilisation temperatures (eg greater than 120°C). This invention is also suited for tempering frozen objects, such as poultry, where the object is at freezing temperatures and is raised in temperature to just below its defrosting temperature.

For multi-component food products, the invention may provide controlled heating such that one component receives more heat energy than another.

Claims

1. An apparatus for heating objects using microwaves, the apparatus comprising:

a working area (14) for positioning an object;
first and second elongate microwave transmission members (8,10) each having an end located at the working area (14);
a single microwave source (4) or a plurality of coherent microwave sources;
a means (7) for providing a first beam of microwaves and a second beam of microwaves from the output microwave energy of the microwave source or sources;
a means (7) for coupling the first beam of microwaves to the end of the first microwave transmission member (8) remote from the working area and a means for coupling the second beam of microwaves to the end of the second microwave transmission member (10) remote from the working area;
a means (12) associated with each microwave transmission member for isolating the microwaves therein; and
a means (18) for varying the phase of microwaves in the first and/or second microwave transmission member;

wherein the apparatus is arranged such that the first beam of microwaves enters the working area in a first direction and the second beam of microwaves enters the working area in a second direction, and the angle between the first and second directions is non-orthogonal.

2. An apparatus as claimed in claim 1, wherein the microwaves in the microwave transmission members are sufficiently isolated to prevent substantial cross-talk therebetween.

3. An apparatus as claimed in any preceding claim, wherein the means (18) for varying the phase of microwaves in the first and/or second microwave transmission member comprises means for varying the path length of a microwave in a microwave transmission member.

4. An apparatus as claimed in claim 3, wherein the means for varying the path length comprises a sliding short (18) and a circulator (12).

5. An apparatus as claimed in any preceding claim, wherein the means (12) associated with each microwave transmission member for isolating the microwaves therein comprises a microwave circulator.

6. An apparatus as claimed in any preceding claim, wherein the angle between the first and second directions of the beams is 180 degrees.

7. An apparatus as claimed in any preceding claim, further comprising means for varying an electrical field pattern in the working area.

8. An apparatus as claimed in any preceding claim, wherein the microwave transmission members taper inwardly towards the working area.

9. A method for heating objects using microwaves, the method comprising:

providing at least two beams of travelling microwaves from a single microwave source (4) or a plurality of coherent microwave sources;
directing each beam of travelling microwaves into a separate microwave transmission member (8,10);
isolating the beam of travelling microwaves in each microwave transmission member;
forming a standing wave from the travelling waves at a working area (14), which is where the microwave transmission members meet, for locating an object to be heated;
and varying the phase of at least one beam of travelling microwaves in order to move the standing wave.

10. A method as claimed in claim 9, wherein the phase of at least one beam of travelling microwaves is varied using a sliding short (18) and a circulator (12).

11. A method as claimed in claim 9 or claim 10, wherein the beam of travelling microwaves in each microwave transmission member is isolated using a microwave circulator.

12. A method as claimed in any one of claims 9 to 11, wherein there are two beams of travelling microwaves and the angle between the directions of the beams, when they meet at the working area, is 180 degrees.

13. A method as claimed in any one of claims 9 to 12, further comprising means for varying an electrical field pattern in the working area.

14. A method as claimed in any one of claims 9 to 13, wherein the microwave transmission members taper inwardly towards the working area.

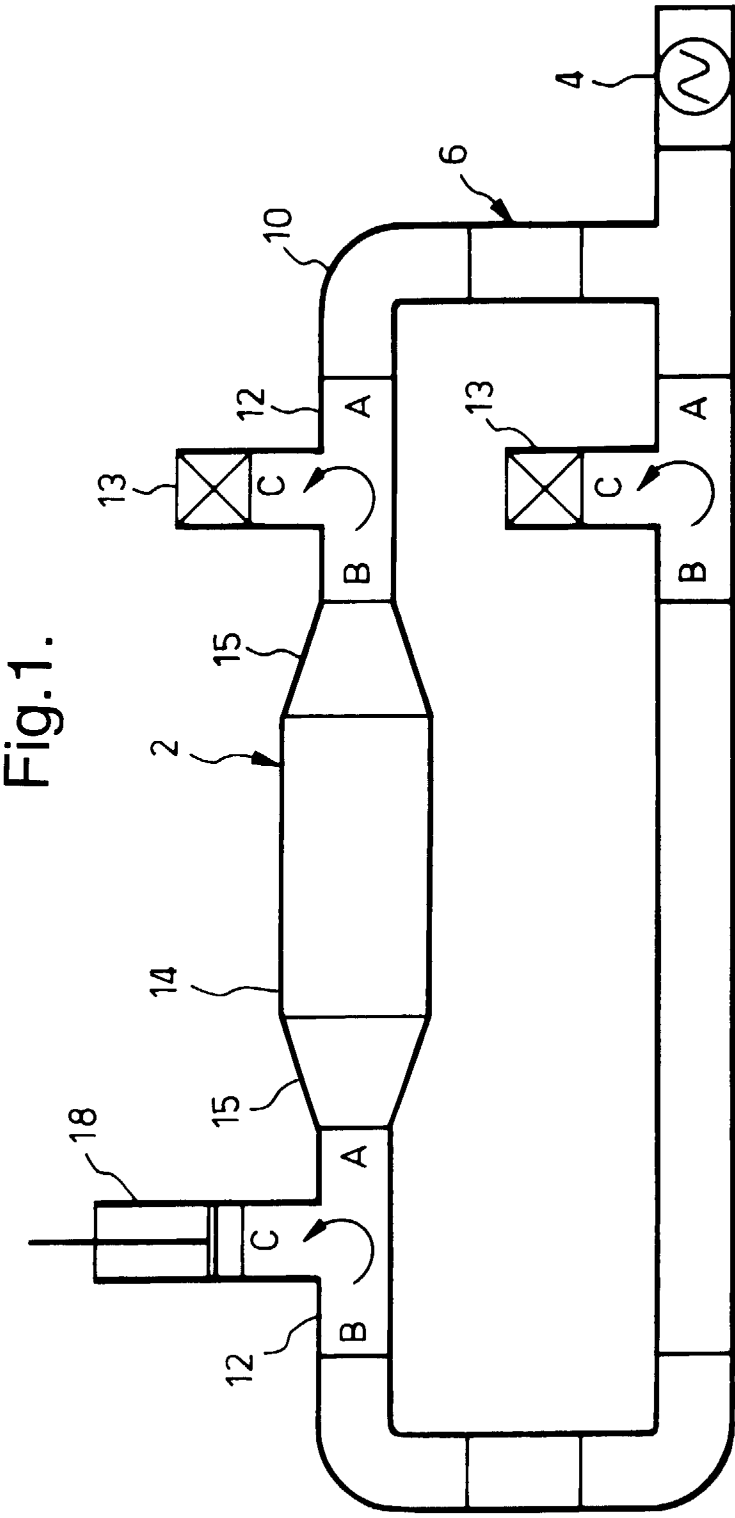


Fig.1.

Fig.2.

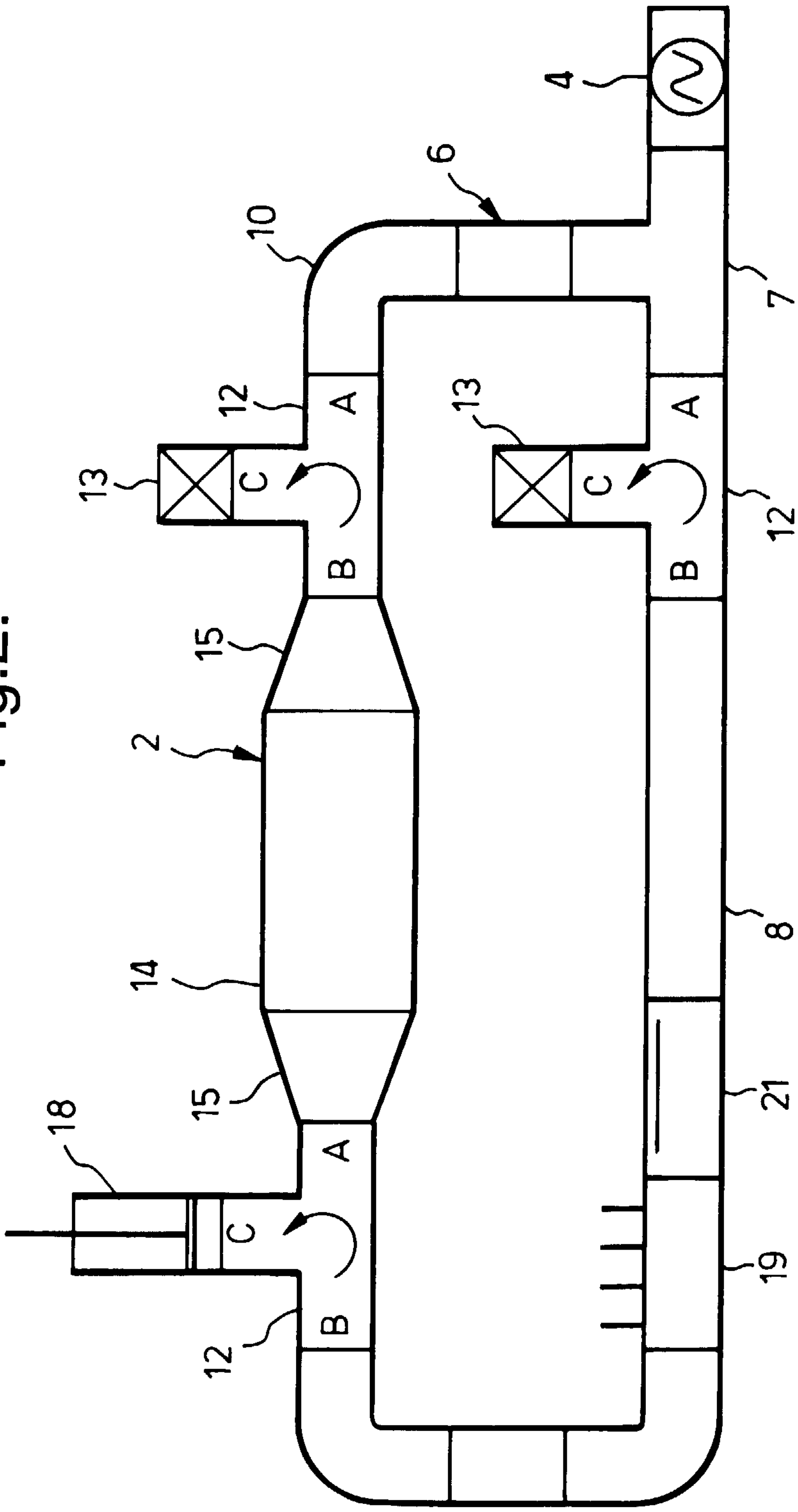


Fig.3.

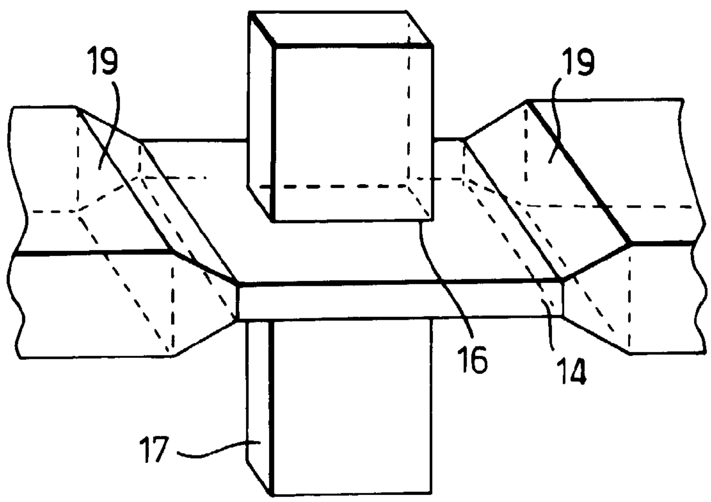


Fig.4 a.

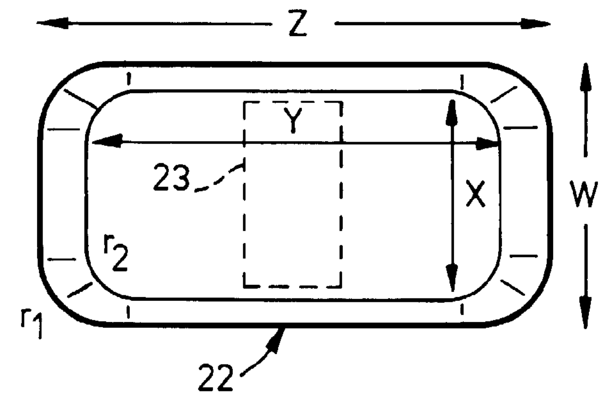


Fig.4 b.

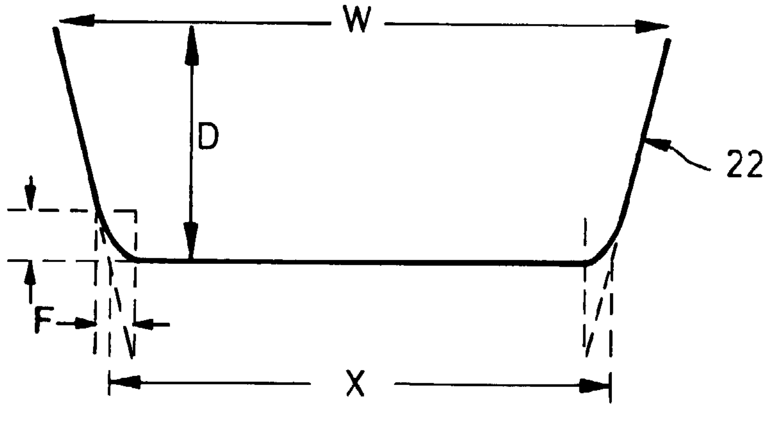
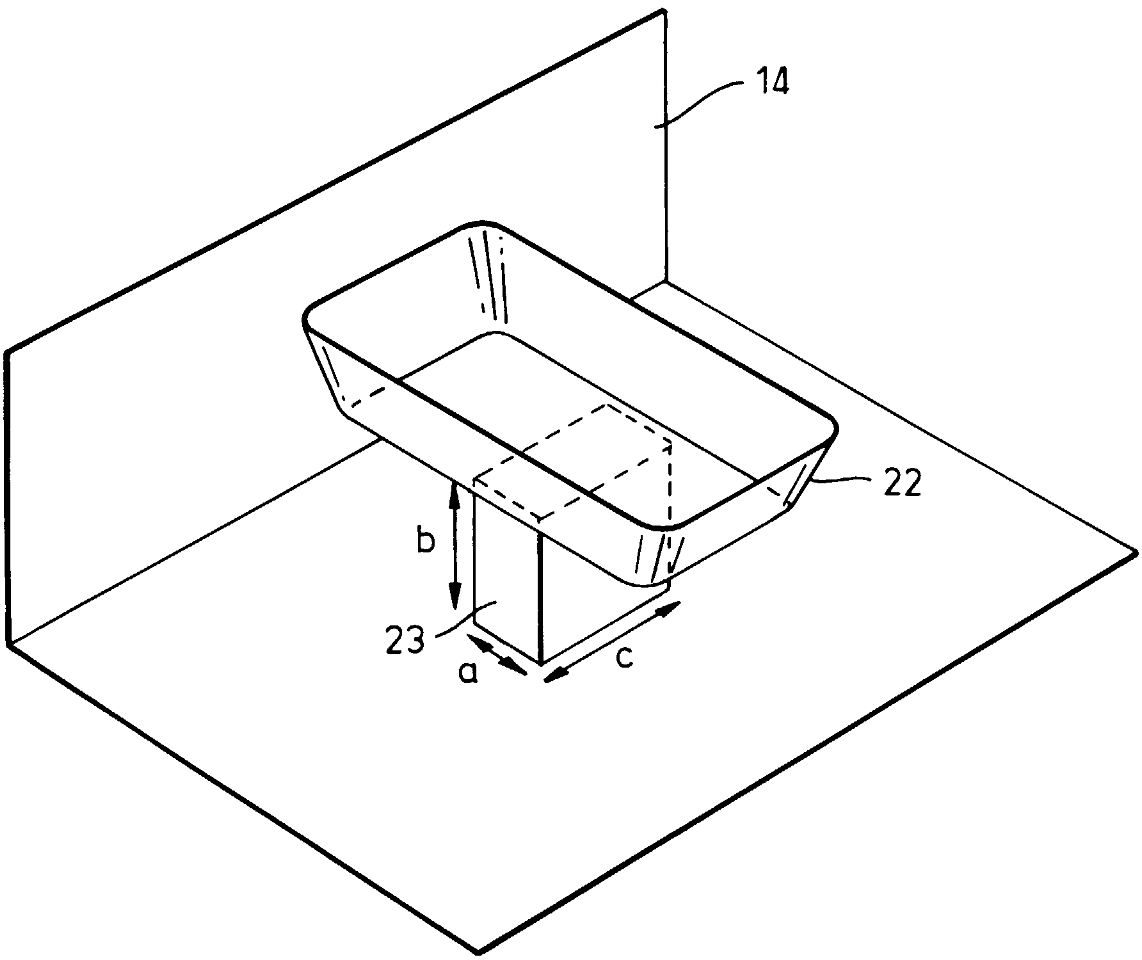


Fig.5.



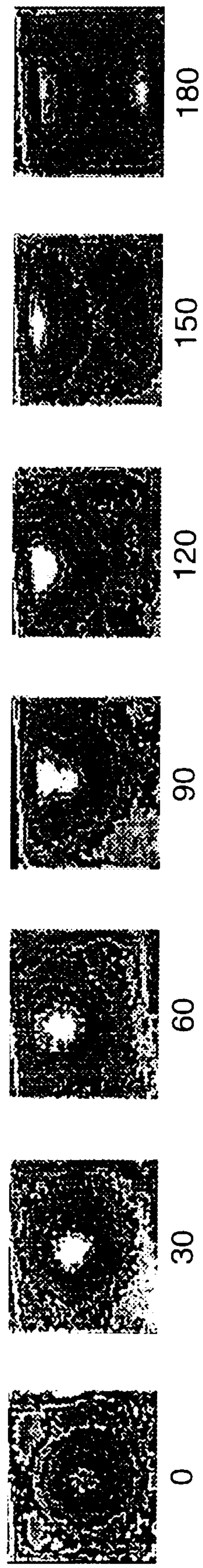


Fig.6a.

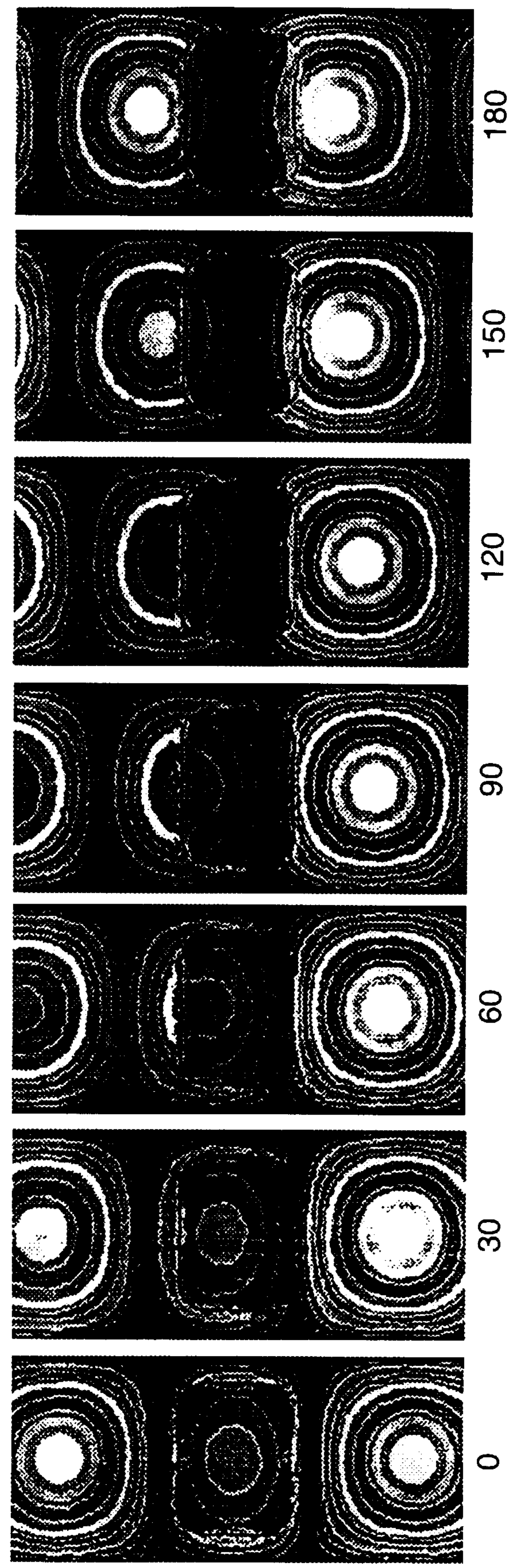


Fig.6b.

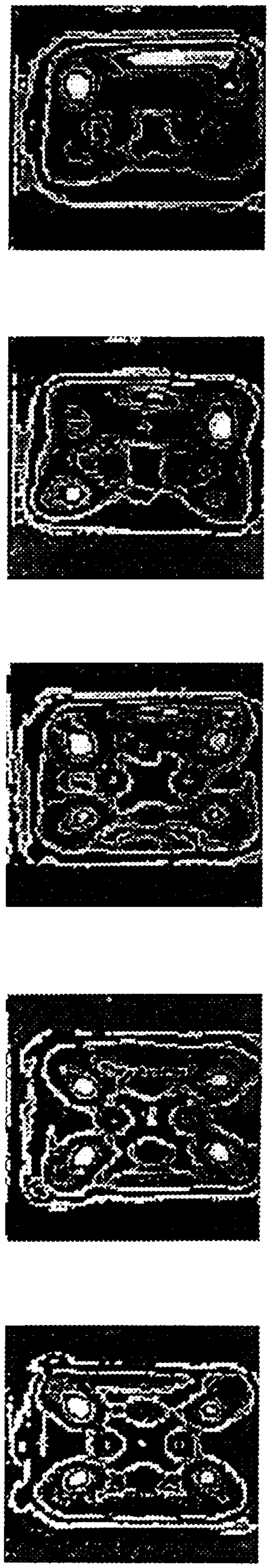


Fig.7a.

Fig.7b.

Fig.8a.

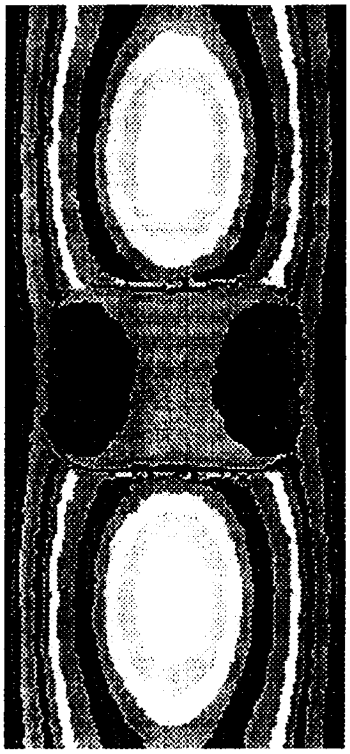


Fig.8b.