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(57) Abstract

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WAVE ENERGY DEVICE

5 The present invention relates to a wave energy device for abstracting energy from a wave in a fluid. Particularly but not exclusively the device can be used in the offshore seaboard or on inland fresh water lakes or even in the deeper ocean.

10 There has been much research into the characteristics of waves. In an idealised wave situation there is a level below the mean fluid level below which the fluid is relatively undisturbed. This level is known as the effective wave base.

15 According to the present invention there is provided a wave energy device comprising a tube adapted to float upright in liquid with the lower end of the tube generally disposed below the effective wave base of the liquid and open to the liquid, and means for harnessing power from the changing fluid level in the tube relative to a datum on the tube.

25 Preferably there is provided a float arrangement associated with the tube and a ballast arrangement associated with the tube to assist the floating of the tube.

30 It is a preferred feature that the power harnessing means comprises a turbine rectifier which, in use, rotates in the same direction regardless of the through flow of liquid or gas.

35 Conveniently the turbine rectifier is mounted at the upper end of the tube and the turbine rectifier may also operate to atmosphere. Alternatively the turbine

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rectifier may operate into a plenum chamber.

5 Preferably the upper end of the tube is covered with
an inverted cup member, the periphery of which extends
into the fluid. When acted upon by a peaking wave, the
fluid forces its way up the inside of the cup member
which movement complements relative dropping of the
10 fluid level in the tube and vice versa when the device
is in the wave trough.

In a preferred arrangement the cup member is provided
with a one way valve member which vents the inside to
15 atmosphere if, during use, the pressure inside the cup
member falls below atmospheric.

It is a preferred feature that the float arrangement
comprises a float attached to the tube and/or a float
20 attached to the cup member.

Preferably the tube has a constant cross section along
a substantial proportion of its length.

25 In a preferred embodiment the tube may comprise an
assembly of pipes of different lengths, at least one
pipe extending below the effective wave base, thereby
to increase the range of wave frequencies to which the
device may respond.

30 The assembly may comprise a plurality of
longitudinally extending radial segments of the tube,
each radial segment being a pipe. Alternatively, the
tube may comprise one or more bundles of individual
35 pipes. In a further alternative the tube may comprise
concentric pipes.

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5 If the assembly comprises concentric pipes they may be in parallel, each having individual access to the water. Alternatively, the concentric pipes may form an annular continuous passage, thereby arranging the pipes in series.

10 In another embodiment of the invention the tube may be helical, or may comprise a plurality of intertwined helical tubes.

15 In yet another embodiment of the invention the tube may comprise one or more pipes having closable apertures at intervals in their side walls.

In another embodiment one or more of the pipes may be extendible.

20 In another embodiment, the cup 31 may be of cylindrical form, the space between the outer side of the tube and the inner side of the cup being divided vertically into segments formed by a number of interstitial walls extending above and below a lower rim of the cup.

25 In another embodiment the cup may be provided with a flange around its lower rim.

30 In another embodiment the cup may be of truncated spherical form. A toroidal float collar may be fixed to the lower rim of the cup. A collar float may be positioned around the tube.

35 An upper part of the cup may be of rigid construction and the lower part may be a flexible or semi-rigid skirt. The skirt may be provided with floats.

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5 The device may include means for monitoring the wave spectrum of the water and means for controlling the lengths of said one or more extendible pipes, or means for controlling the opening and closing of said apertures, in accordance with signals generated by the monitoring means.

10 The invention will now be described by way of example only with reference to Figures 2 - 21 of the accompanying diagrammatic drawings in which:

15 Figure 1 illustrates the general behaviour of an open ended tube in a wave.

Figure 2 shows a wave energy device according to the present invention.

20 Figures 3 - 5 show further embodiments of a wave energy device according to the present invention.

25 Figures 6(a) and 6(b) show a further type of wave energy device according to the present invention, in peak and trough conditions respectively.

Figures 7 - 14 show further embodiments of the invention.

30 Figures 15 - 17 show various operations of the embodiment of Figure 10.

Figures 18 - 20 show further embodiments applicable to the embodiments of Figures 6(a) - 17.

35 Figure 21 shows a compound impulse/reaction turbine design to match a multiple pipe embodiment such as is

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shown in Figure 8(a).

5 In Figure 1 there is shown a representation of a wave
10 in a fluid e.g. water, the wave 10 being shown as
having a theoretical, sinusoidal form for the sake of
simplicity. It will be seen how the wave 10 deviates
from the mean fluid level indicated by line 11. It has
15 been found that below a certain depth 12 beneath a
wave the water is relatively calm and undisturbed by
the surface wave. This depth is known as the
"effective wave base" and it has been found that this
depth is about equal to about half the wave length
"lambda". The depth may, however, be more or less than
this depending on various factors and conditions.

Figure 1 also shows a floating tube 13 having a float
14 and a ballast arrangement 15 spaced apart along its
20 length such that the tube 13 floats generally upright
in the water. The tube 13 is long enough to extend
into the calm water below the effective wave base 12.
The Figure shows the tube 13 at the peak of a wave, at
the trough of a wave and at the mid-way position
25 between the two.

Looking firstly at the midway position the tube is
effectively floating at mean water level and the level
of the water in the tube, shown as 16, is also at mean
30 sea level. As the tube 13 rises on the crest of a
wave, the lower end of the tube 13 remains below the
effective wave base 12 and so if there were no
fluid resistance in the tube the water level 16 in
the tube will remain substantially at mean sea level
11. It will be appreciated that this results in a
35 lengthening of the column of air between the water
level 16 and the upper free end of the tube 13.

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5 The tube 13 then passes the midway position until it reaches its trough position shown on the right of Figure 1. Again, the lower end of the tube projects into the calm water below the effective wave base 12 and again in the absence of fluid resistance the water level 16 in the tube remains substantially at mean sea level 11. Clearly, the column of air between the water level 16 and the upper free end of the tube 13 has now been reduced.

10 Continuous rising and falling of the tube 13 on a wave 10 therefore results in an air column which oscillates relative to the tube. This moving air column, or even the water column below which also effectively oscillates, can be harnessed and converted into power. Abstraction of power will then affect the water level in the tube.

20 In Figure 2, a rectifying turbine 17 is attached to the top of the tube 13. The rotor of the turbine 17 rotates in the same direction regardless of the air moving through it. It will be seen that the turbine 17 operates to atmosphere. However, in Figure 3 the turbine 17 operates with a closed plenum chamber 18 such that the oscillating air column is part of a closed system. This also gives the device a pneumatic spring effect. It would also be possible to replace the rectifying turbine with a conventional turbine in association with rectifying valves (e.g. flap, ball, fluidic gate, or other types).

35 In Figure 4 the tube is provided with a water turbine 19 located in the tube 13 so as to be operated by the oscillating water column. The turbine 19 has a power take-off shaft 20 and the device may also incorporate mechanical, hydraulic or electrical rectification.

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5 In Figure 5 there is an inner float 21 which floats on the water column in the tube 13. The vertical displacement of the inner float 21 in a wave can be harnessed mechanically, hydraulically or electrically to produce power.

10 Other ways of harnessing the power of the oscillating air/water column will, however, be apparent.

15 In Figures 6(a) and 6(b) there is shown a modified arrangement 30 which still incorporates a tube 13 which extends into the calm water below the effective wave base. The tube 13 also has a float 14, a ballast arrangement 15 and a rectifying turbine 17 at its upper end. Surrounding the turbine 17 and upper end of the tube 13 is a cup arrangement 31 of plenum having a downwardly extending cylinder 32 which in turn is provided with float means 33. The cup arrangement and cylinder are rigidly attached to the tube 13 and/or turbine by means which are not shown. It may, however, be desirable for there to be some possible movement between the cup and cylinder for adjustment and tuning purposes.

25 When put into water the cylinder extends into the water and the arrangement 30 is such that it floats with the tube 13 generally upright. An optional one-way valve 34 may be provided, which valve 34 is such that the inside of the cup member is vented to atmosphere if the inside pressure falls below atmospheric.

35 When the arrangement rises towards the peak of a wave (Figure 6(a)), water surges upwards in the cylinder 32, often to a level above the water level of the

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5 wave, whilst at the same time the water level 16 in
the tube 13 goes down relative to the turbine 17. When
the arrangement 30 falls towards the trough of a wave
(Figure 6(b)) the water surges downwardly in the
cylinder 32, often to a level below the water level of
the wave, and there is a complementary rise of the
water level 16 in the tube 13 relative to the turbine
10 17.

15 It will be appreciated that the water level in the
cylinder acts rather like a piston on the air within
the cup arrangement 31 and above the column of water
in the tube 13. The arrows 35 indicate the general
flow of air through the turbine 17 during such wave
movements.

20 In use of the arrangement 30 the water level in the
cylinder should stay within the cylinder at all times
even in the lowest wave trough. If air enters or
leaves the cup arrangement 31 via the lower margin of
the cylinder 32 then the dynamics of the arrangement
could be altered to undesirable effect.

25 This is especially of concern in practice because the
device will in reality probably tilt during the action
of a wave and this tilting could result in a greater
chance of air being lost from the plenum below the
30 free edge of the cylinder. For this reason the valve
34 can be provided to vent the inside of the plenum to
atmosphere.

35 The particular arrangement of floats 14, 33 and
ballast 15 is illustrative only and would preferably
be tunable so as to maximise the efficiency of the
wave energy device in particular conditions. This is

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true for all embodiments of the invention. Also with reference to Figures 6(a) and 6(b) it will be clear that the turbine 17 could be replaced by other
5 suitable harnessing means.

The ballast 15 can also act as a drogue against lateral or vertical movement of the device and improve efficiency. The ballast 15 and/or cylinder 32 and/or
10 the tube 13 could also be shaped or have an appropriate cross-section so as to orientate the device in a particular way depending on prevailing winds or tidal streams. Alternatively or in addition, this could be achieved by the device having vanes for
15 operation either by air or fluid flow.

Further embodiments of the invention will now be described with reference to Figures 7 - 17 in which mean sea level is indicated by chain line 100.
20 Figures 7 - 17 also have features common to Figures 6(a) and 6(b), viz. plenum cup member 31 and downwardly extending cylinder 32. The cylinder 32 may possibly include the float 33 of Figures 6(a) and 6(b), but for clarity the float is not shown in
25 Figures 7 - 17.

In Figure 7 there is shown in vertical section a further embodiment of the floating tube 13 in which it is divided into eight radial segments or pipes 36,
30 seven of which are truncated at their base to give pipes of different lengths - a "panpipes" set of different frequencies, the eighth segment remaining unshortened and extending below the effective wave base. Figure 7(a) is a section through the tube 13 of
35 Figure 7 taken at line 100.

We have found, as shown in the embodiment of Figure 7,

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that the range of wave frequencies to which the device is responsive is increased by virtue of the different resonant frequencies inherent in the pipe-like segments 36 of different lengths. This, in effect, facilitates broadband reception of wave frequencies.

Furthermore, an assembly of pipes 36 of different lengths will allow the possibility of harmonic interaction, i.e. interference or beat frequencies, which could contribute to the desirable objective of extending the range of sea profiles or locations where the device may be usefully deployed. A problem experienced with earlier point-absorber devices is that their energy capture characteristic tends to be very peaky, centering on either the buoy heaving frequency or the single fluid column resonance, restricting the situations in which such single column devices may be used.

Nevertheless, for optimum efficiency, it is important for tubes 13 having multiple radial segments 36 of different lengths that at least one segment projects deep enough to be able to enter the relatively still water level of the effective wave base.

A further advantage of the embodiment of Figure 7 is that the tube structure 13 has inherent structural strength by virtue of its segmentation.

In Figure 8 there is shown in vertical section another embodiment of the tube 13 in which it is constructed of a bundle of pipes 38 of different lengths, one of the pipes being long enough to extend below the effective wave base. Figure 8(a) is a section through the tube 13 of Figure 8 taken at line 100. The feature

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90 shown in Figure 8(a) may be a central pipe, as shown in Figure 8, or it may be the axle of a turbine, which will be described below with reference to Figure 21.

As with Figure 7, the range of wave frequencies to which the device is responsive is increased by virtue of the different resonance frequencies inherent in the varying length pipes 38. The possibility of harmonic interaction also exists. The bundle of pipes 38 also has an inherently high degree of mechanical strength.

Figure 9 shows in side view a tube 13 formed from a pipe or hose 40 helically wound around a central blank core 41. This has the advantage that the overall length of the water column can be substantially increased, with a lower resonance frequency, relative to the vertical height of the tube. Figure 9(a) is a section through the tube 13 of Figure 9 taken at line 100. In an alternative arrangement there may be provided two or more intertwined hoses 40, possibly of different lengths.

Figure 10 shows a tube 13 comprising a bundle of concentric pipes 43, 44, 45. The outer pipe 43 is closed off at its lower end by a plate 46 which has a central aperture down through which the central pipe 45 passes to below the effective wave base. The middle pipe 44 does not extend down as far as the plate 46, but all three pipes are open at their top end. Hence, the pipes 43, 44, 45 define an annular continuous passage which puts the water columns within the pipes in series, rather than in parallel as in Figures 7 and 8. This particular construction of the tube 13 enables some degree of on-site tuning. Figure 10(a) is a

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5 section through the tube of Figure 10 taken at line 100. A more detailed description of its operation will be given below with reference to Figures 15 - 17.

10 Figure 11 shows a tube 13 comprising a bundle of concentric pipes 48, 49, 50 wherein the bottom ends of the pipes are trimmed from the centre outwards to give a "panpipes" effect. Again, the central pipe 50 extends to below the effective wave base. Figure 11(a) is a section through the tube 13 of Figure 11 taken at line 100.

15 Figure 12 shows a tube 13 comprising a single pipe provided along its length with holes 52 adapted to be opened or closed by means (not shown) so that the resonant tube length can be tuned like a musical wind instrument. Figure 12(a) is a section through the tube 20 13 of Figure 12 taken at line 100.

25 Figure 13 shows a variant of Figure 8 in which a bundle of pipes 54, 55, 56 is collected together into a single pipe 57 below the water level 100. The summation of the individual pipe frequencies is combined within the water part of the column whereas in Figure 8 this summation takes place within the air part of the column.

30 Figure 14 shows a tube 13 which comprises a first pipe 58 telescopically inserted within a second pipe 59 so that the tube may be extended to a required resonance length by actuating means (not shown). The tube 13 is thus directly tunable.

35 With the embodiments of Figures 12 and 14 there may be provided means (not shown) for monitoring the wave

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spectrum of the water and controlling the resonance of the tube 13 accordingly so as to provide the optimum effect.

Figures 15 - 17 show a detailed further explanation of Figure 10 above.

Figure 15 shows a still-water situation in which the two annular columns between the mouth of the plenum cup 31 and the mouth of the central pipe 45 have been charged with water to the midway position and where pressures in each air column space are equalised. When subject to wave motion, all water and air columns will oscillate, in the direction senses indicated by the double arcs.

Figure 16 shows a still-water situation in which, by injection of air into the innermost air space, a positive gauge pressure exists therein which alters the water/air column lengths as indicated, thus changing the spread of response frequencies for each annular component. A measure of on-site tuning is therefore possible. When subject to wave motion, all columns will oscillate in their altered modes. If an air turbine is being used to extract the energy, it will benefit from the slightly denser air in the aperture.

Figure 17 shows the reverse of Figure 16, whereby air has been exhausted from the innermost air space. Apart from reducing the air density slightly, it has similar positive attributes to the embodiment shown in Figure 16.

For all those embodiments which include an inverted

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cup arrangement 31 as referred to above and
schematically illustrated in Figures 6(a) and 6(b)
5 through to Figure 17 or any embodiment covered by the
invention although not specifically illustrated, the
cup has been indicated, for simplicity and generality,
as being of cylindrical form. However, the cup 31 can
take other forms in order to optimize energy capture
10 at the wave surface and to further facilitate tuning
and bandwidth, and also for reasons of structural
strength.

Hence, with reference to Figures 18 to 20, alternative
15 embodiments of the cup 31 will now be described.

Figure 18 shows a version of the cup 31 having a
cylindrical form but in this case with the space
between the outer side of the tube 13 and the inner
20 side of the cup being divided vertically into segments
60 formed by a number of interstitial walls 61 (four,
for example, being depicted) which extend some way
above and below a lower rim 62 of the cup. The
disposition of the walls 61 is shown in Figure 18(a)
25 which is a section through the cup 31 of Figure 18
taken at line 100.

Figure 18 also shows the possibility of a flange-type
extension 63 around the lower rim 62 of the cup 31
30 which could serve, together with the segment walls 61,
to create a converging collection, containment and
acceleration channel for the surface element of the
wave and also, possibly, could reduce the chances of
unwanted additional atmospheric air being sucked into
35 the internal closed cycle working medium via vortices.

Figure 19 shows an alternative cup 31 of truncated

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spherical form. It also indicates the possibility of affixing a toroidal float collar 64 to the lower rim 62 of the cup, the shape of which may be chosen so as to be conducive to a desirably smoother (i.e. laminar) water flow in and out of the bell-mouth of the cup. It also shows the possibility of positioning a collar float 65 around the tube 13, of a shape designed to interact favourably on the water flow patterns within the bell-mouth of the cup. The cup 31 is itself attached to the tube 13 by means not shown but which will be clear to the man skilled in the art. Such attaching means may be rigid or, alternatively, articulated: for example, to afford freedom for the leading edge (as seen with respect to wave direction) of the toroidal cup float collar 64 to lift and tilt the cup so as to face an oncoming wave and vice versa for the trailing edge to tilt the cup the other way as the wave departs, thus improving the scavenging action of the internal volume of the cup.

Figure 20 shows a possible form of cup 31 where an upper part 66 is of rigid construction and a lower part 67 is a skirt of semi-rigid or flexible construction, similar to a hovercraft skirt. The skirt 67 may possibly be held open and/or articulated and/or weighted or provided with floats 68 in a manner adapted to achieve optimized energy capture.

Figures 18 to 20 are intended only to show the scope for design variants of the cup 31 and do not represent an exhaustive coverage of the possibilities arising out of the invention. Combinations and permutations of these and other variants will be apparent.

As mentioned above, power may be abstracted from the

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oscillating air/water columns in the tube 13 and the pipes which comprise it by means of a turbine. This turbine can be either a conventional axial, radial or mixed-flow unit operating in conjunction with rectifying valves; alternatively it may be one of the several designs available which are self-rectifying and hence unidirectional (for example, an axial-flow unit is used in many oscillating water column wavepower devices). In the case of a tube 13 comprising multiple pipe oscillators as envisaged in the present invention, it may be beneficial to employ specific turbine adaptations to suit the particular plural fluid flows generated.

By way of illustration, Figure 21 shows a customised variant of a compound impulse/reaction turbine 80 to match a multiple pipe embodiment such as that shown in Figure 8(a). The axle 90 of the turbine passes down between the six pipes 38 shown in Figure 8(a).

The turbine 80 is provided with a casing 83 which has a number of circumferentially spaced inlet/outlet ports 81 corresponding to the pipes 38. The turbine 80 receives a counter-clockwise torque from each individual pipe airflow 82 through the ports 81, irrespective of flow direction, by a combination of aerodynamic lift reaction from the leading faces of the aerofoil or lenticular-profiled blades 84 mounted on the turbine rotor 88 and an impulse/drag force on the trailing faces of the blades.

The space 86 within the turbine rotor 88 represents a plenum, the volume of which can be varied - either by radiusing the turbine axle 90 or by connection to an additional buffer volume acting as a capacitance - to

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optimise the system.

5 Although six input/output paths 82 are shown in Figure 21 (corresponding to the six pipes 38 of Figure 8(a)) it will be understood that any physically possible number from one upwards may be used.

10 The example shown in Figure 21 is illustrative only and does not preclude blade profiles other than lenticular, nor is it limited to the air side of the oscillating fluid columns but can apply mutatis mutandis to the water side.

15 In practice, the devices of the invention would be deployed either singly or in integral or close-coupled arrays or in spaced/phased arrays. They could be moored by direct sea anchor, by catenary or rigid or
20 fixed links to adjacent mooring buoys or other adjacent devices, by shore based lines, by attachment to shore or seabed anchored spines, by streaming from or containment within seabed based structures or from
25 or within mobile vessels or oil rigs. Other diverse options exist.

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CLAIMS

- 5 1. A wave energy device comprising a tube adapted to float upright in liquid with the lower end of the tube generally disposed below the effective wave base of the liquid and open to the liquid, and means for harnessing power from the changing fluid level in the tube relative to a datum on the tube.
- 10 2. A wave energy device as claimed in 1 wherein there is provided a float arrangement associated with the tube and a ballast arrangement associated with the tube to assist the floating of the tube.
- 15 3. A wave energy device as claimed in 1 or 2 wherein the power harnessing means comprises a turbine rectifier which, in use, rotates in the same direction regardless of the through flow of liquid or gas.
- 20 4. A wave energy device as claimed in 3 wherein the turbine rectifier is mounted at the upper end of the tube.
- 25 5. A wave energy device as claimed in 4 wherein the turbine rectifier operates to atmosphere.
- 30 6. A wave energy device as claimed in 4 wherein the turbine rectifier operates into a plenum chamber.
- 35 7. A wave energy device as claimed in any preceding claim wherein the upper end of the tube is covered with an inverted cup member, the periphery of which extends into the fluid, whereby, when acted upon by a peaking wave, the fluid forces its way up the inside of the cup member which movement complements relative

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dropping of the fluid level in the tube and vice versa when the device is in the wave trough.

- 5 8. A wave energy device as claimed in 7 wherein the cup member is provided with a one way valve member which vents the inside to atmosphere if, during use, the pressure inside the cup member falls below
10 atmospheric.
9. A wave energy device as claimed in 7 as dependent on claim 2 wherein the float arrangement comprises a float attached to the tube and/or a float attached to
15 the cup member.
10. A wave energy device as claimed in any preceding claim wherein the tube has a constant cross section along a substantial proportion of its length.
- 20 11. A wave energy device as claimed in any preceding claim wherein the tube comprises an assembly of pipes of different lengths, at least one pipe extending below the effective wave base, thereby to increase the range of wave frequencies to which the device may
25 respond.
12. A wave energy device as claimed in 11 wherein the assembly comprises a plurality of longitudinally
30 extending radial segments of the tube, each radial segment being a pipe.
13. A wave energy device as claimed in 11 wherein the tube comprises one or more bundles of individual
35 pipes.
14. A wave energy device as claimed in 11 wherein the

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tube comprises a plurality of concentric pipes.

5 15. A wave energy device as claimed in 14 wherein the pipes are in parallel, each having individual access to the liquid.

10 16. A wave energy device as claimed in 14 wherein the concentric pipes form an annular continuous passage, thereby being arranged in series.

17. A wave energy device as claimed in 1 wherein the tube is helical.

15 18. A wave energy device as claimed in 1 wherein the tube comprises a plurality of intertwined helical tubes.

20 19. A wave energy device as claimed in any preceding claim wherein the tube comprises one or more pipes having closable apertures at intervals in their side walls.

25 20. A wave energy device as claimed in any preceding claim wherein one or more of the pipes is extendible.

30 21. A wave energy device as claimed in 7 wherein the cup member is of cylindrical form, the space between the outer side of the tube and the inner side of the cup being divided vertically into segments formed by a number of interstitial walls extending above and below a lower rim of the cup.

35 22. A wave energy device as claimed in 7 wherein the cup is provided with a flange around its lower rim.

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23. A wave energy device as claimed in 7 wherein the cup is of truncated spherical form.

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24. A wave energy device as claimed in 21 wherein a toroidal float collar is fixed to the lower rim of the cup.

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25. A wave energy device as claimed in 7 wherein an upper part of the cup is of rigid construction and the lower part is a flexible or semi-rigid skirt.

15

26. A wave energy device as claimed in 25 wherein the skirt is provided with floats.

27. A wave energy device as claimed in any preceding claim wherein a collar float is positioned around the tube.

20

28. A wave energy device as claimed in claim 19 wherein there is provided means for monitoring the wave spectrum of the liquid and means for controlling the opening and closing of said apertures, in accordance with signals generated by the monitoring means.

25

29. A wave energy device as claimed in claim 20 wherein there are provided means for monitoring the wave spectrum of the liquid and means for controlling the lengths of said one or more extendible pipes, or means for controlling the opening and closing of said apertures, in accordance with signals generated by the monitoring means.

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30. A wave energy device as claimed in claim 11 as dependent on claim 3 wherein the turbine is provided

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5 with a casing having at least one inlet port arranged to receive an oscillating airflow from a respective pipe and to direct the airflow onto or across the blades of the turbine.

10 31. A wave energy device as claimed in claim 30 wherein the blades are of lenticular or other aerofoil section.

32. A wave energy device as claimed in claim 30 or 31 wherein the volume of air within the turbine rotor provides a plenum to optimise the system.

15 33. A wave energy device substantially as claimed in claim 32 wherein the plenum is connected to an additional buffer volume acting as a capacitance.

20 34. A wave energy device substantially as hereinbefore described with reference to Figures 2 - 21 of the accompanying drawings.

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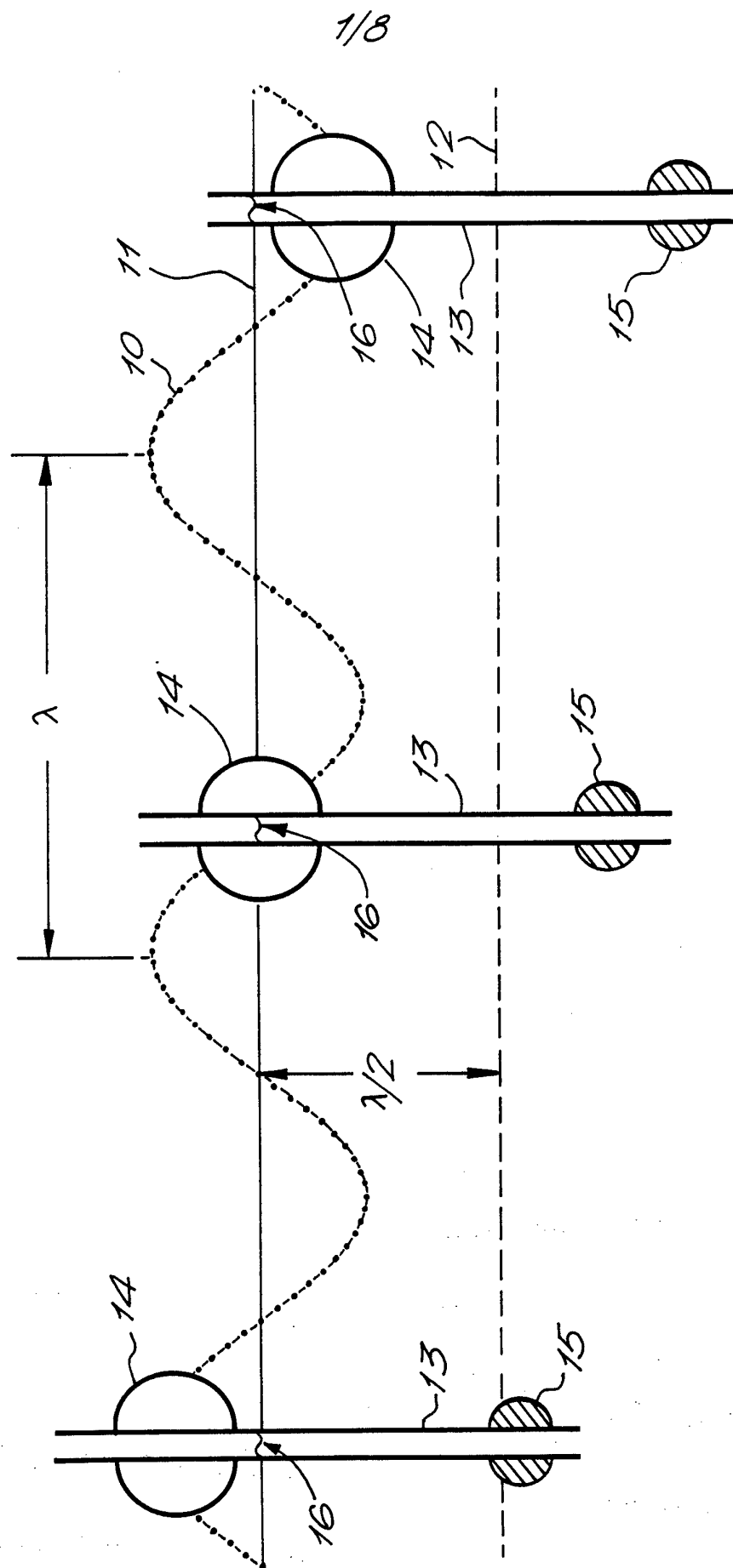


FIG. 1.

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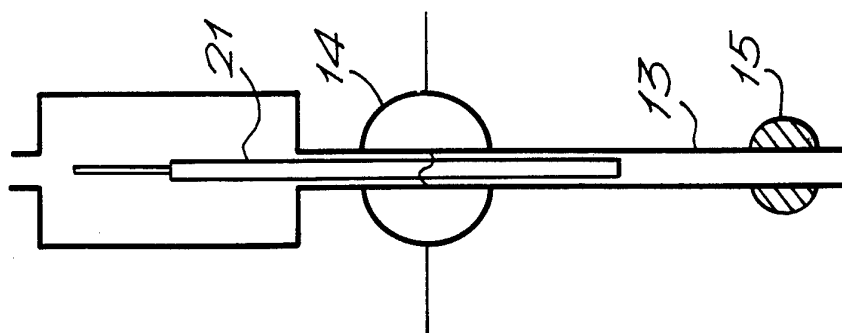


FIG. 5.

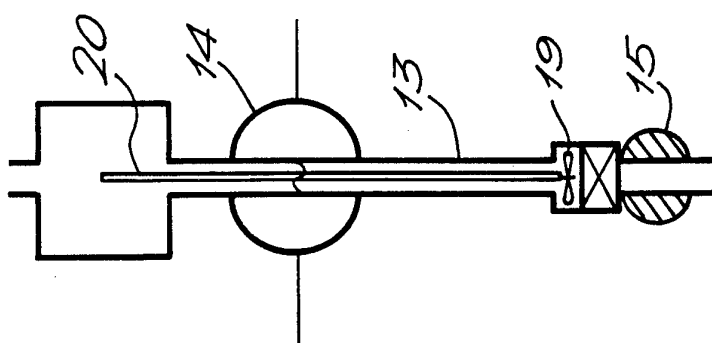


FIG. 4.

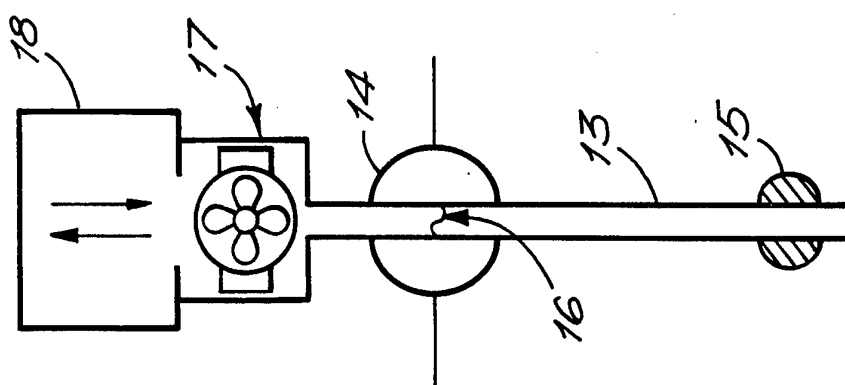


FIG. 3.

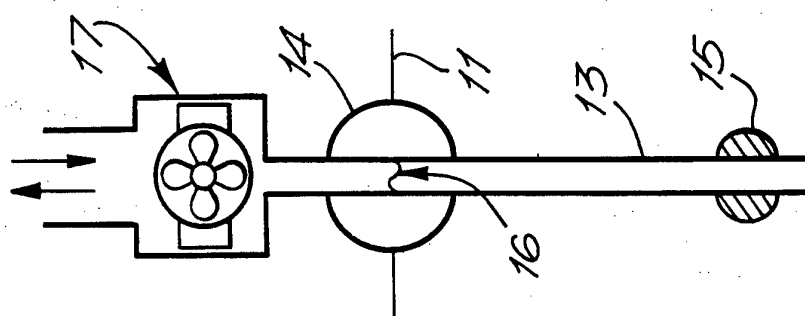


FIG. 2

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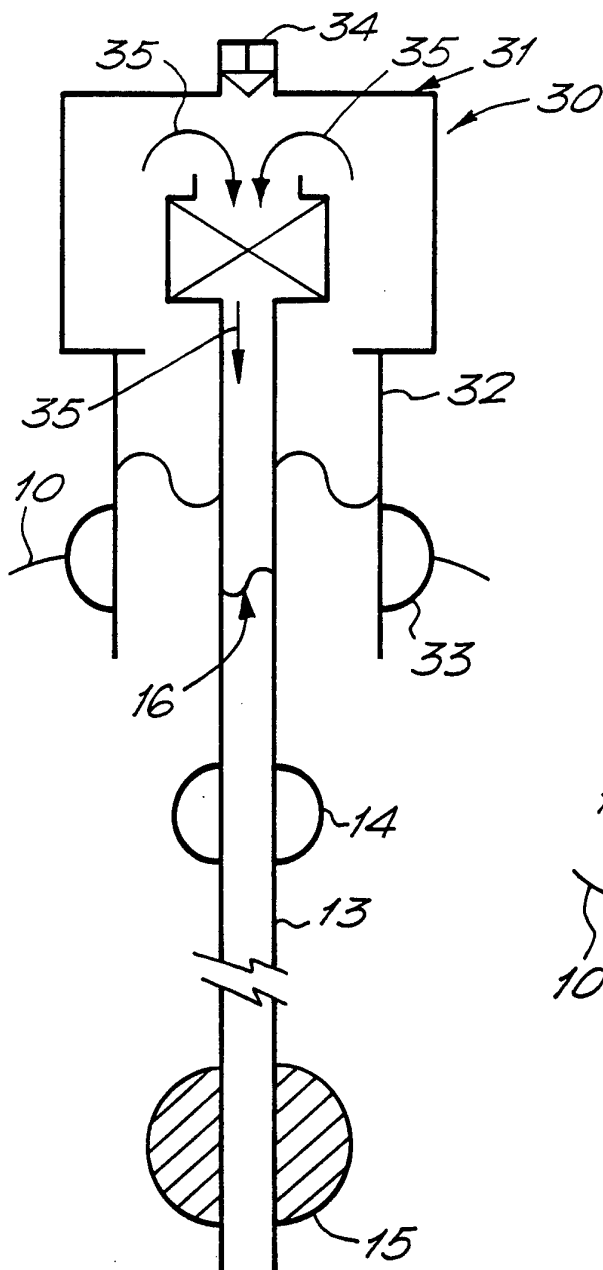


FIG. 6(a)

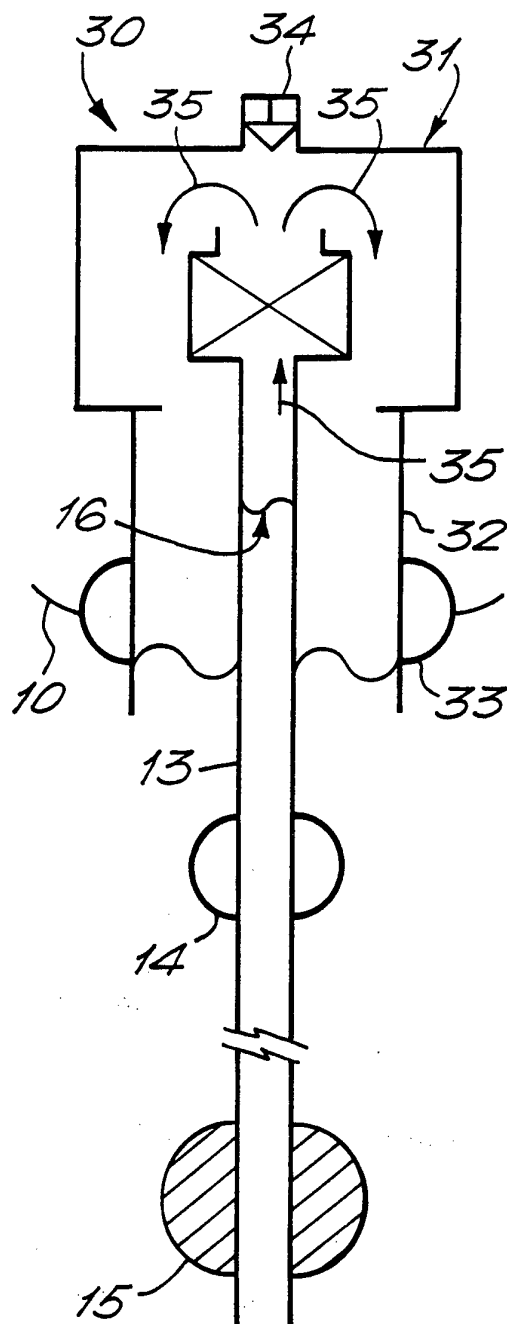
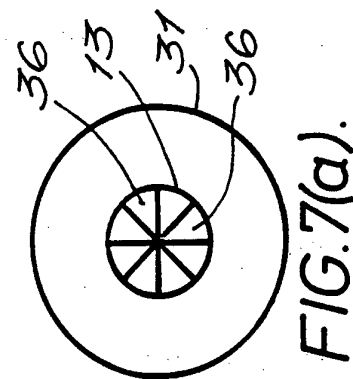
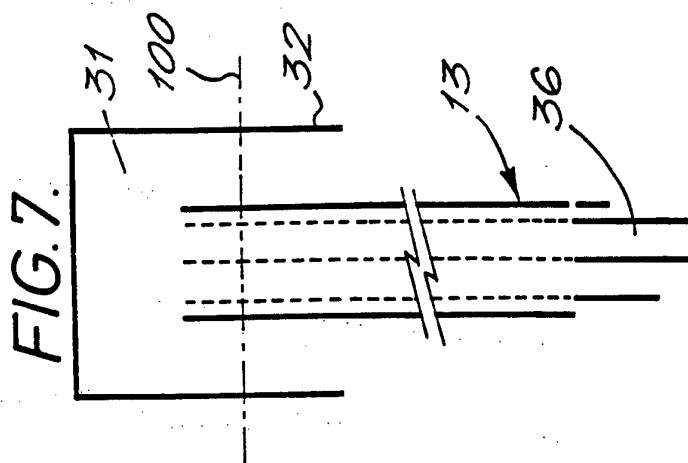
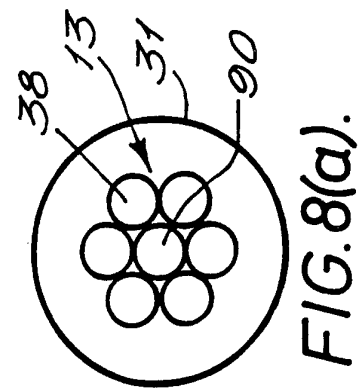
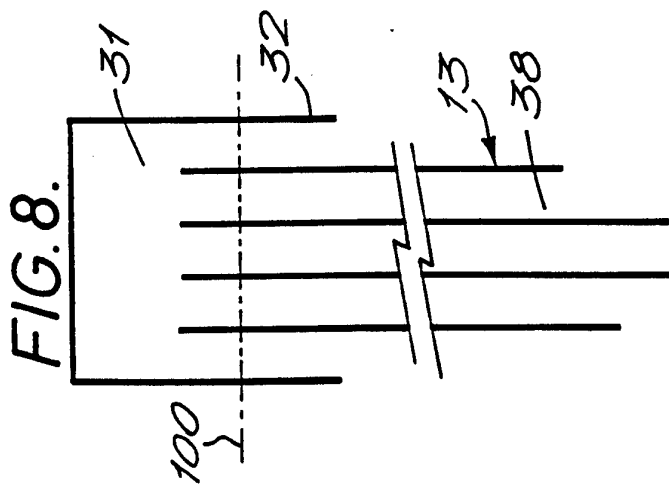
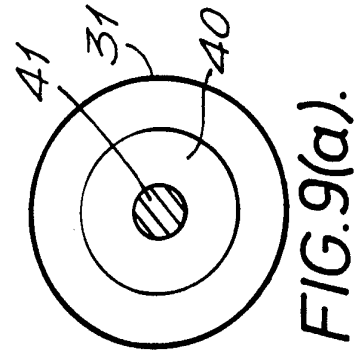
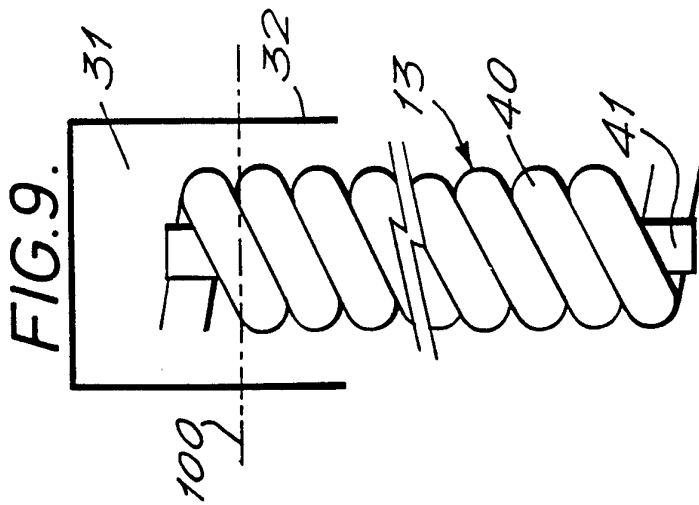
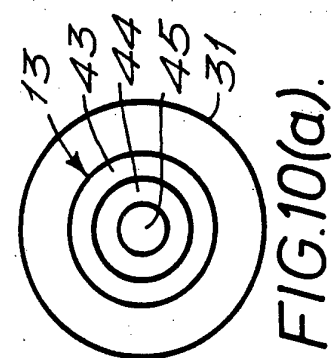
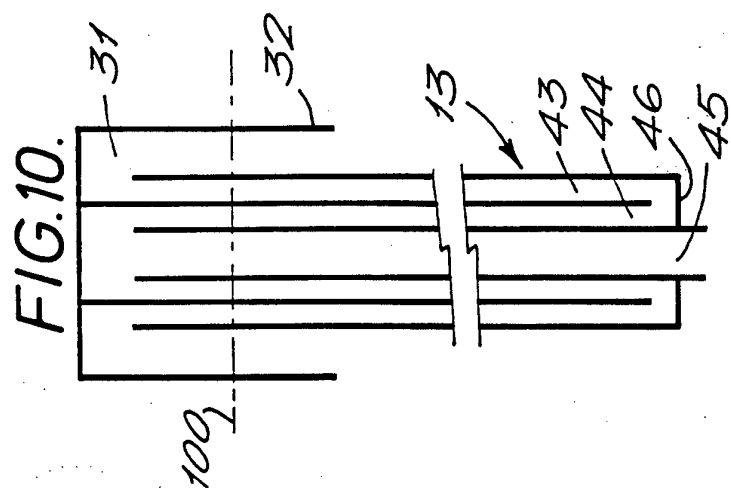
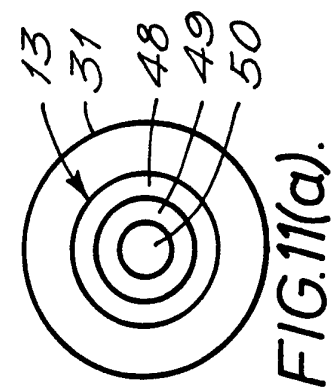
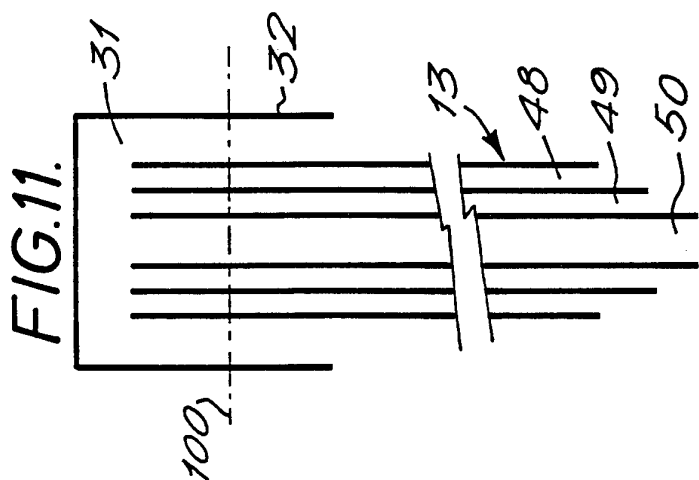
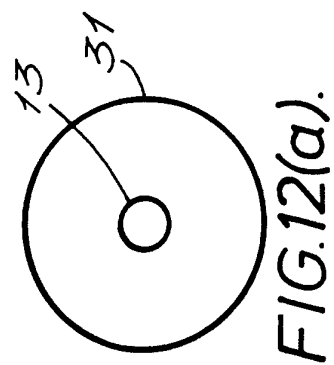
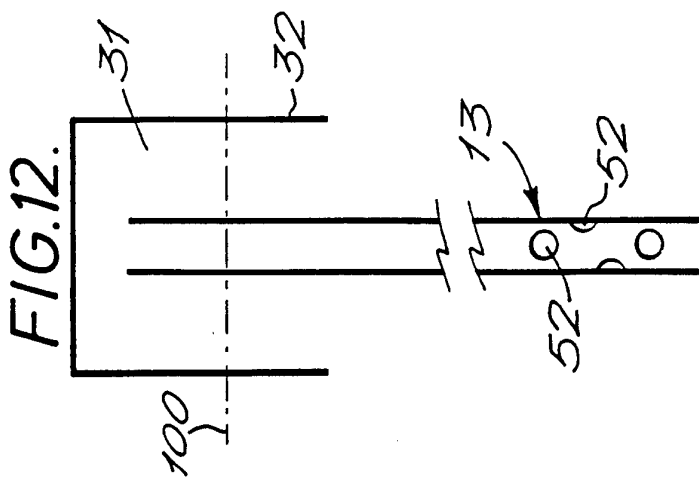


FIG. 6(b).

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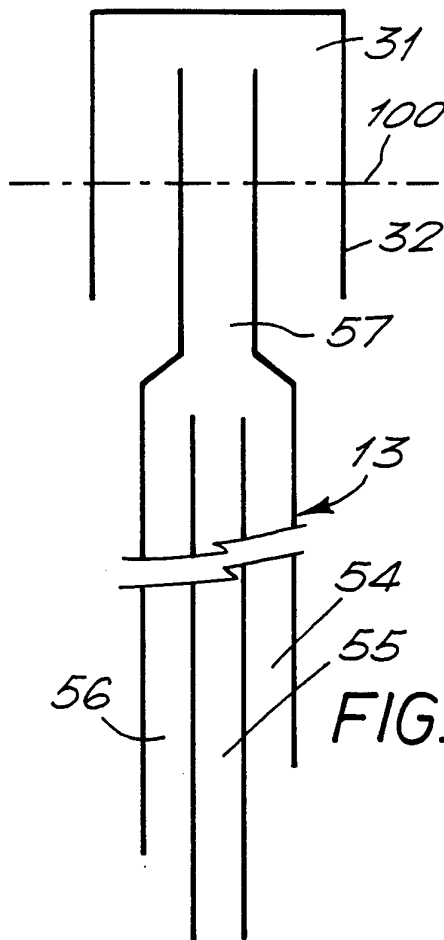


FIG. 13.

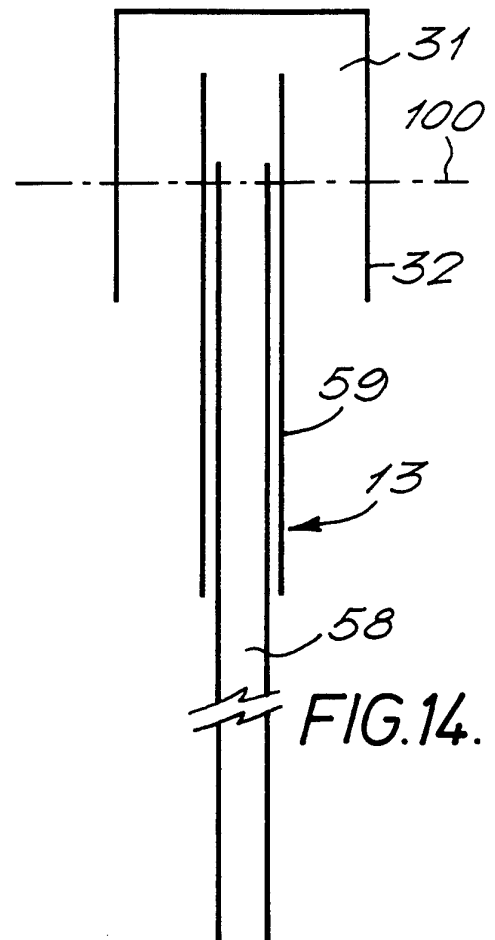


FIG. 14.

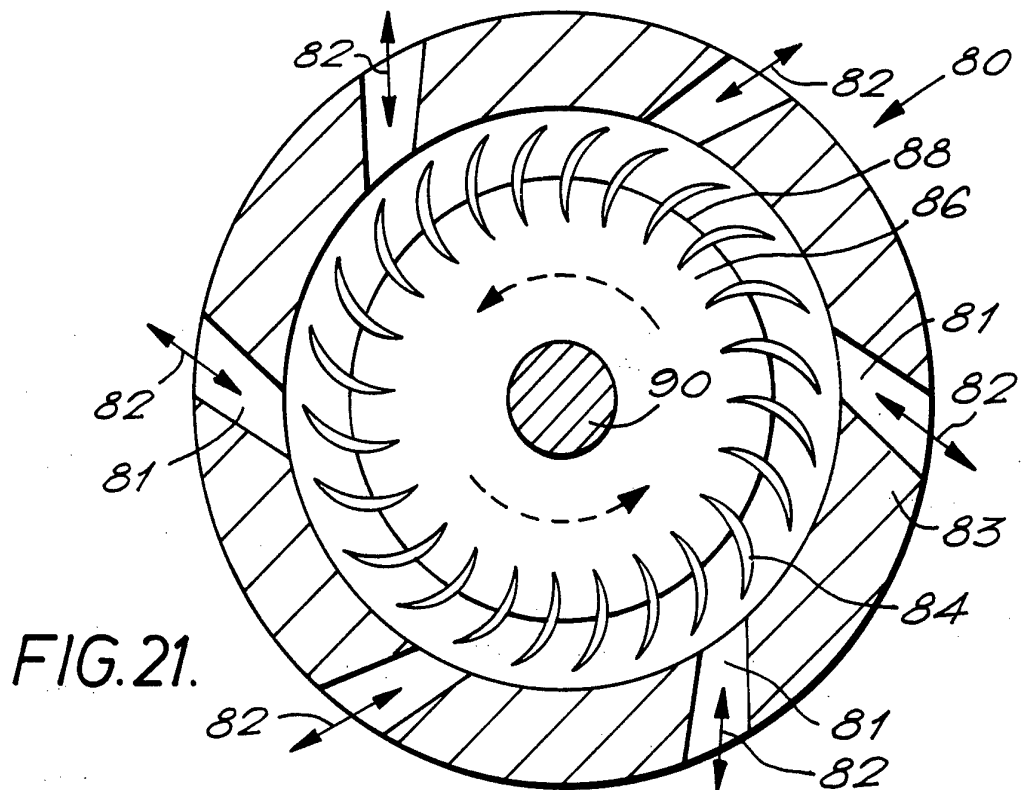
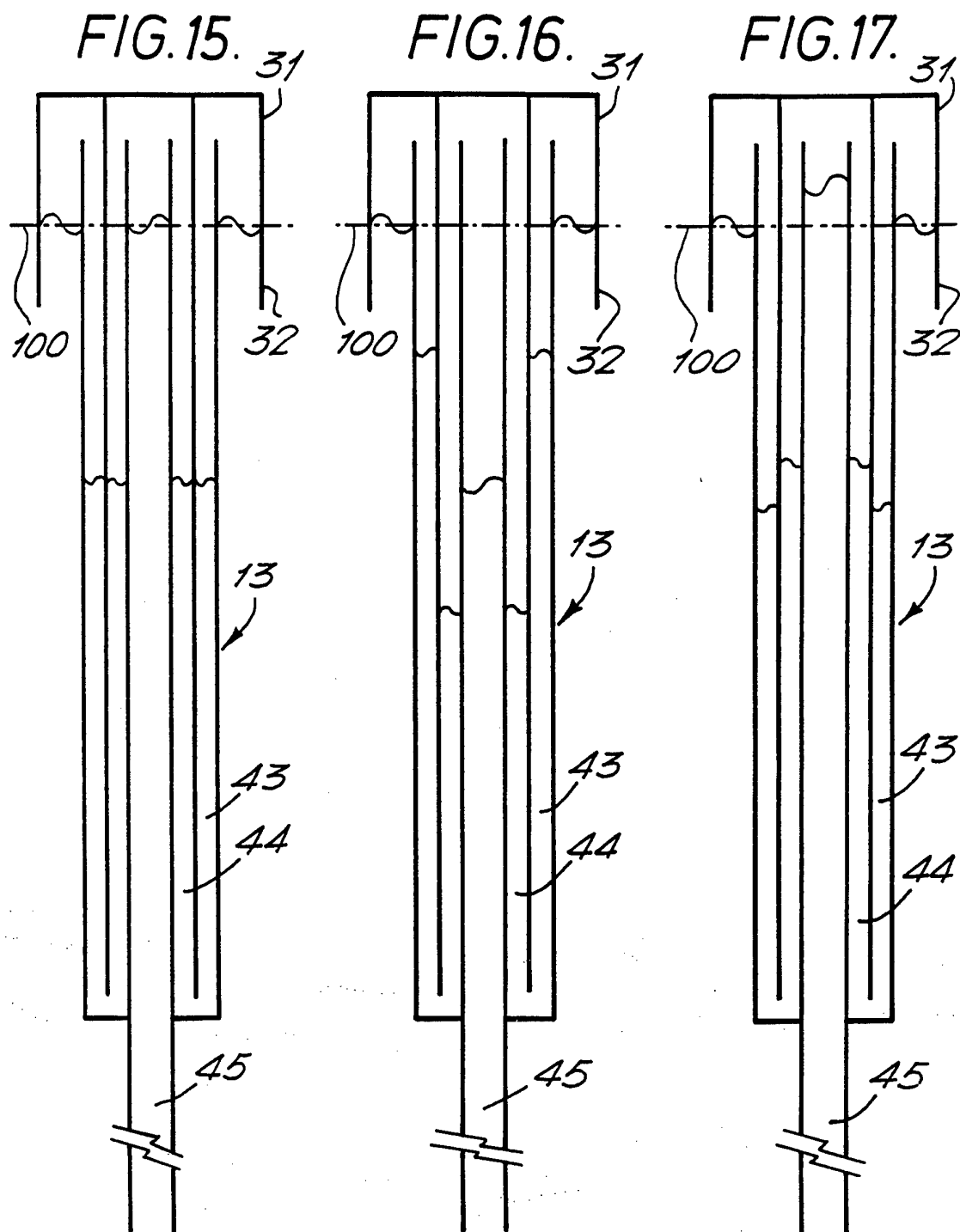
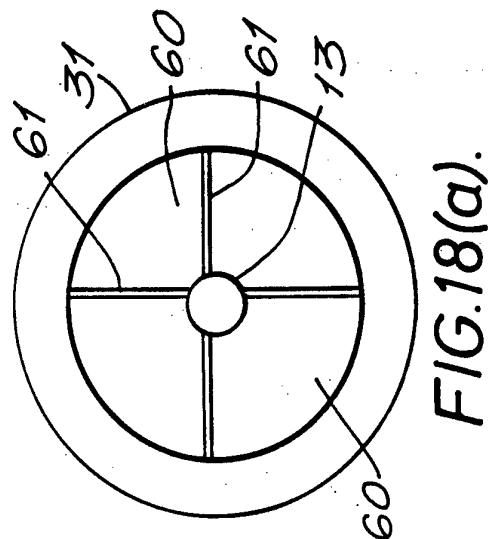
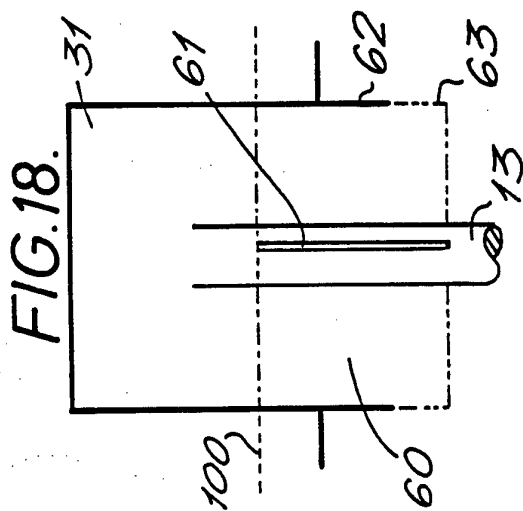
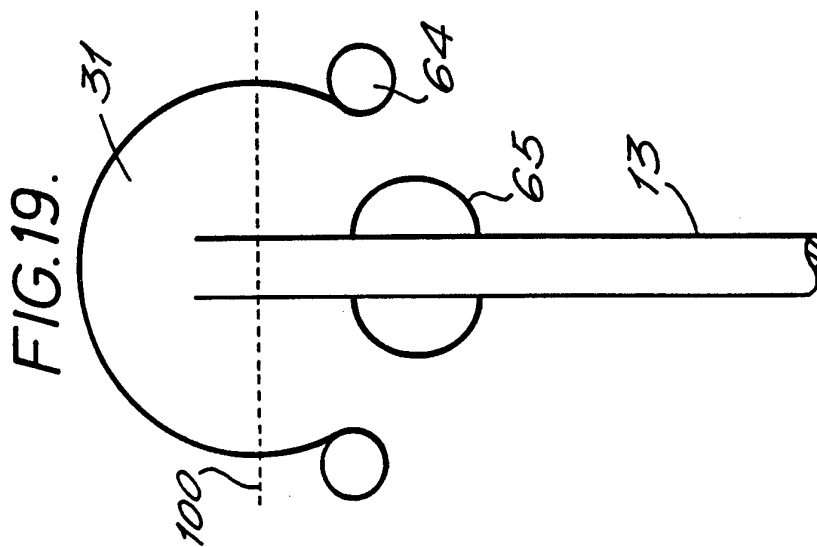
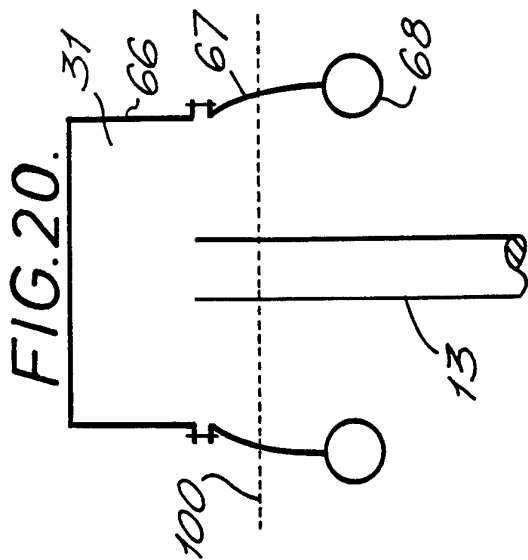


FIG. 21.

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INTERNATIONAL SEARCH REPORT

Int. Application No

PCT/GB 95/00793

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 F03B13/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 F03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB-A-2 028 929 (ENGLISH ELECTRIC CO LTD) 12 March 1980	1-5, 7, 9, 10, 22, 24, 30-32, 34
Y		6
Y		8, 14, 16
Y		13, 15
Y		17
Y		19
Y		20, 29
Y		21
Y	see page 2, line 52 - line 58 see page 3, line 101 - line 108 see the whole document	28
Y	US-A-3 922 739 (BABINTSEV IVAN ANDREEVICH) 2 December 1975 see figure 1	6

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

4 July 1995

Date of mailing of the international search report

18.07.95

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Criado Jimenez, F

INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 95/00793

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	GB-A-1 014 196 (KABUSHIKI KAISHA RYOKUSEISHA) 22 December 1965 see page 2, line 28 - line 58; figures 2,3 ---	8,14,16
Y	US-A-3 912 938 (FILIPENCO GREGORY D) 14 October 1975 see column 2, line 15 - line 26; figures 3,4 ---	13,15
A Y	WO-A-87 03045 (BOENKE KNUT) 21 May 1987 see abstract see page 3, line 31 - line 35 ---	1 17
Y	FR-A-2 579 681 (PILLET MARCEL) 3 October 1986 see page 4, line 6 - line 21; figure ---	19
Y	US-A-3 250 220 (C.H.ESLINGER) 10 May 1966 see column 3, line 8 - line 11; figures 2,3 ---	20,29
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A	WO-A-89 11036 (ONDE MARCEL) 16 November 1989 see the whole document ---	1
A	GB-A-1 596 636 (ENERGY SECRETARY OF STATE FOR) 26 August 1981 see page 1, line 84 - page 2, line 9; figure 1 -----	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 95/00793

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US-A-3912938	14-10-75	NONE	
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US-A-3250220	10-05-66	NONE	
GB-A-2245031	18-12-91	NONE	
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		EP-A- 0381670	16-08-90
		FR-A- 2606835	20-05-88
GB-A-1596636	26-08-81	NONE	