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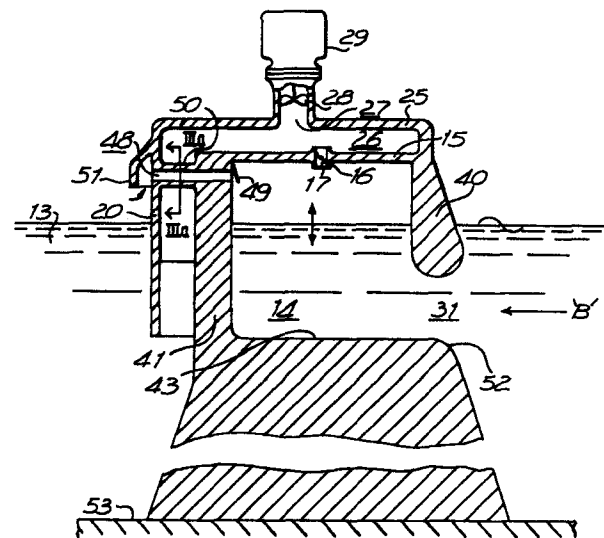
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54 Improvements in or relating to devices for extracting energy from wave power.

57 The invention provides a device for extracting energy from waves on a liquid, the device having a chamber (14) with an opening for the flow of liquid into and out of the chamber to provide a quantity of the liquid which is arranged to oscillate in the chamber to provide energy from these oscillations. In order to maximise the energy absorption efficiency of the device, that portion of the device to be submerged and lie in a vertical plane aligned in the direction of propagation of the waves is of asymmetric shape, and the device is arranged to be held in a manner to inhibit movement of the device itself in response to the waves.



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Improvements in or relating to devices for extracting energy from wave power.

This invention relates to devices for extracting energy from waves.

5 An example of a device adapted to generate electricity from energy extracted from waves is provided by the buoy device invented by Yoshio Masuda and described in British Patent Specification No. 1,014,196, in which the oscillation of a column of water in a chamber is arranged to drive air through
10 an air turbine.

A breakwater is another example of a device intended to extract energy from waves but so as to provide calmer regions on its leeward side.

15 According to the present invention, there is provided a device adapted to be partially submerged in a liquid and extract energy from waves thereon, wherein that portion of the device adapted to be below the surface of the liquid is of asymmetric shape in a vertical plane aligned in a direction of propagation of the incoming waves, and the device is
20 adapted to be held by means for inhibiting movement of the device in the liquid so that in operation waves generated by the device itself are substantially unidirectional and in a direction towards the incoming waves.

The device may be of buoyant construction, and adapted to

be held below its natural level of floatation in the liquid by mooring means so as to inhibit said movement of the device. Alternatively, the device may be of non-buoyant construction and adapted to be held by a submerged support means which may
5 include the sea bed.

In yet a further alternative, the device may be held by being adapted for incorporation in a barrier means arranged to be incident to incoming waves, for example a coastal sea wall.

10 The asymmetric shape may be provided by having the front of the device upon which the waves are intended to be incident, arranged so as to be immersed less deeply in the liquid than the rear of the device. In a device having a chamber in which a column of water is arranged to oscillate, the asymmetric
15 shape may be provided by closing the bottom of the chamber, and providing a port means at the incoming wave side of the chamber positioned so as to be immersed in the liquid.

A stationary partially submerged device which has a symmetrical underwater shape in a vertical plane aligned in
20 the direction of incoming waves will have a theoretical maximum power absorption of about 50% of the energy of the incoming waves, the remaining wave energy being lost and distributed equally between reflected and transmitted waves. By adopting an asymmetric underwater shape as required by the
25 invention, by which waves generated by the device itself in extracting energy from the incoming waves are unidirectional and towards the incoming waves, the energy absorption efficiency of the device is increased. This is because a device which generates and radiates waves preferentially in a cer-
30 tain direction when in forced oscillation will also absorb that frequency preferentially from the same direction, so that theoretically in an idealised condition there will be no reflected and transmitted waves through which energy may be lost. In practice, however, this condition is unlikely to be
35 realised but energy extraction efficiencies above 50% should

be attainable by devices incorporating the invention.

To enable the present invention to be more readily understood attention is directed by way of example only to the accompanying drawings, in which:-

- 5 Figure 1 shows a diagrammatic sectional representation of a buoyant device having one asymmetric shape and for generating electrical energy from wavepower;
- 10 Figure 1a shows a view in the direction of arrow 'A' in Figure 1;
- Figure 1b shows a view in the direction of arrow 'C' in Figure 1a;
- 15 Figure 2 shows a diagrammatic sectional representation of a device similar to that shown in Figure 1 but having an alternative asymmetric under-water shape;
- Figure 3 shows a diagrammatic sectional representation of a device similar to that shown in Figure 2 but of non-buoyant construction;
- 20 Figure 3a shows a fragmentary sectional view to an enlarged scale on the line IIIa-IIIa of Figure 3;
- Figure 4 shows a diagrammatic sectional representation of a device similar to those shown in Figure 2 and Figure 3 but incorporated in a sea barrier;
- 25 Figure 5 shows a fragmentary view to a reduced scale in the direction of arrow X of Figure 4;
- Figure 6 shows a diagrammatic model of part of a device similar to that of Figure 1; and
- 30 Figure 7 shows a diagrammatic model of part of a device similar to that of Figure 2.

In the above Figures, like parts have like numerals.

Referring now to Figure 1, the device shown has a forward buoyancy tank 10 and a rear buoyancy tank 11 for supporting the

device in a liquid 13 (e.g. seawater), the forward buoyancy tank 10 being immersed less deeply in the liquid 13 than the rear buoyancy tank 11. The forward and rear buoyancy tanks 10 and 11 respectively define between them the front and rear walls of a chamber 14 in which a column of the liquid 13 oscillates as indicated by the arrows as a result of wave motion of the incoming waves in the direction of arrow 'B'. The chamber 14 has a roof 15 with an air outlet 16 having a non-return valve 17, and an air inlet 18 having a non-return valve 19. The air inlet 18 is connected at its other end to the rear wall 20 of the device where it is protected against spray by a shroud 21.

The rear wall 20 and a cover 25 define a duct 26 for air between the aft buoyancy tank 11 and the roof 15 as described in Offenlegungsschrift 27 37 143, to interconnect the air discharged from adjacent chambers 14.

An orifice 27 in the cover 25 directs air from the duct 26 through an air turbine 28 which is arranged to drive an electric generator 29.

As shown in Figure 1a several chambers 14 having side walls 24 are connected in parallel by the duct 26 to drive the single air turbine 28, the generator 29 of Figure 1 being omitted for clarity. The device is held as shown in Figure 1b, to which reference is made by mooring means in the form of cables 22 each attached at one end to a respective winding gear 23 (only two are shown) on the device, and to a respective anchorage 24 in the sea bed to inhibit movement of the device. The cables 22 are kept taut by constructing the device to have excess buoyancy and hauling on the cables 22 with the winding gear 23 to pull the device downwardly below its natural floatation level in the liquid 13 to a required mean depth of immersion. Such cables 22 may be supplied by British Ropes Limited, Doncaster, England.

In operation, energy is extracted from the incoming waves

by the oscillation of the liquid 13 in the chamber 14 drawing air into the chamber 14 through inlet 18 and expelling air from the chamber 14 through the outlet 16 and into the duct 26. The pressure of the air in the duct 26 depresses the liquid level at the rear of the rear buoyancy tank 11 to provide a restoring force acting on the air and tending to maintain a substantially uniform air pressure in the duct 26. Air from the duct 26 escapes through the orifice 27 and drives the air turbine 28 which drives the electric generator 29. Because of the asymmetric underwater shape of the device, the energy extracted from the waves is greater than that extracted by a similar device but having a symmetric underwater shape.

In the alternative asymmetric shape shown in Figure 2 to which reference is now made, the chamber 14 is closed at the bottom by a baseplate 30 which defines a front entry port 31 for the chamber 14 below the buoyancy tank 10. In other respects the device shown in Figure 2 is identical to that shown in Figures 1 and 1a, and its asymmetric underwater shape increases its energy absorption efficiency in the same way compared with a device having a symmetric underwater shape.

The device of Figure 2 may be held by mooring means (not shown) similar to those described in relation to Figure 1b.

As an alternative to the buoyant devices shown in Figures 1, 1a, 1b and 2, a non-buoyant device may be used as shown in Figure 3, to which reference is now made, for applications where tidal movement is relatively limited.

The device of Figure 3 is similar in most respects to the device of Figure 2 except that the use of buoyancy tanks has been dispensed with to provide the non-buoyant construction required. The device is provided with a solid forward wall 40, a solid rear partition 41, and a solid base portion 43, which define the corresponding portions of a chamber 14 similar to that of Figure 2. An air inlet 48 having a non-return valve 49 extends from the chamber 14 through the rear

partition 41, a boss 50 extending in the duct 26, and the rear wall 20 where the air inlet 48 is protected by a shroud 51. The boss 50 is also shown in fragmentary sectional view in Figure 3a to which reference can be made.

5 The base portion 43 has a rounded corner 52 at a front entry port 31 to the chamber 14, and is shown resting on a submerged surface 53, such as the sea bed, to present the device at the required partially submerged depth in the liquid 13. In all other respects, the device of Figure 3
10 is essentially the same as the device of Figure 2 and extracts energy from waves on the liquid 13 in an identical manner.

It will be understood that cables (not shown) may be attached to the device of Figure 3 to retain it in its
15 required position on the submerged surface 53, and weights (not shown) provided to increase the inertia of the device.

The invention may also be incorporated in a barrier as shown in Figure 4, to which reference is now made, for installations subject to relatively limited tidal movement.

20 In Figure 4 a portion of a coastal sea wall 59 of ferro-concrete construction is shown, and is shaped to provide the essential features of a device similar to that of Figure 3 for extracting energy from incoming waves on the sea 13. In more detail the device of Figure 4 has a forward wall 60, a
25 rear wall 61, and a base portion 63, which define the corresponding portions of a chamber 14 having a front entry port 31 similar to that of Figures 2 and 3.

An air inlet 65 having a non-return valve 66 extends upwardly from the chamber 14 to the top of the device where
30 it is protected from spray by a shroud 67. The device has a duct 26 into which air from the chamber 14 enters through the outlet 16 and non-return valve 17 in a similar manner to that described in relation to Figures 1 to 3. The duct 26

is shown unpressurised, but may be arranged to be pressurised as described in Offenlegungsschrift 27 37 143. In all other respects, the device of Figure 4 is essentially the same as the devices of Figures 2 and 3 and extracts energy from the incoming waves in an identical manner.

The device of Figure 4 may be of considerable length broadside to the incident waves, and arranged as a multiplicity of chambers 14, as shown in Figure 5 to which reference is now made. In Figure 5 sets of three chambers 14a, 14b, 14c are shown connected by a common duct 26 to a single orifice 27 and air turbine 28 along the length of the device, the generator 29 of Figure 4 being omitted for clarity. The chambers 14a and 14b, and 14b and 14c are separated by side walls 70 below the duct 26 but the chambers 14c and 14a are separated by side walls 71 which extend into the duct 26 to separate the air flow in one set of chambers 14a, 14b, 14c from that in another set. If desired a similar arrangement of sets of chambers 14 may be used in relation to the devices of Figures 1 to 3, and it will be understood that a set of chambers 14 may comprise more than three chambers 14, or two such chambers 14.

Referring now to Figure 6 the essential features of a device similar to that of Figure 1 are shown in a vertical plane aligned with the incoming wave for the purpose of establishing the dimensions thereof for maximum power absorption efficiency. These features are represented by:

- L = distance in the chamber 14 between the forward buoyancy tank 10 and the rear buoyancy tank 11
- x = width at the bottom and maximum width of the forward buoyancy tank 10
- y = distance between the bottom of the forward buoyancy tank 10 and mean sea level

s = vertical distance between the bottom of the forward buoyancy tank 10 and the bottom of the rear buoyancy tank 11

w = width at the bottom of the rear buoyancy tank 11

5 fo = frequency of the incoming waves.

For maximum power absorption efficiency:

$$f_o = \frac{1}{2\pi} \sqrt{\frac{g}{y + \frac{\pi L}{4}}} \quad \text{where } g = \text{acceleration due to gravity}$$

$$L \leq s \leq 2L$$

$$0.25L \leq y \leq 0.5L$$

10 $0.5y \leq x \leq y$

$$L \leq W \leq 3L$$

The essential features of a device similar to that of Figure 2 in a vertical plane aligned in the direction of propagation of the waves are shown in Figure 7 to which
15 reference is now made.

The features are represented by:

L = distance in the chamber 14 between the forward buoyancy tank 10 and the rear buoyancy tank 11

20 x = width at the bottom and maximum width of the forward buoyancy tank 10

y = distance between the bottom of the forward buoyancy tank 10 and mean sea level

s = height of the front entry port 31.

For maximum power efficiency:

$$L = 0.1 \lambda_0$$

where $\lambda_0 = \frac{g}{2\pi f_0^2}$ = wavelength of the incoming waves
corresponding to the natural frequency,
 f_0 , of the water column in the chamber
14.

$$\begin{aligned} s &= 0.67 L) \\ y &= 0.4 L) \quad \text{approximately} \\ x &= 0.25 L) \end{aligned}$$

The devices of Figures 1 to 5 may be provided with means for changing the resonant frequency of the liquid 13 in the chamber 14, for example as described in UK Application No. 19199/77, to optimise the device for maximum energy absorption efficiency over a range of incoming wave frequencies.

It will be appreciated that other asymmetric underwater shapes may be used in accordance with the invention, and asymmetric underwater shapes may be incorporated in alternative devices for extracting energy from wavepower to those shown in the Figures, for example a breakwater. Such a breakwater might be provided by the devices shown in the Figures but with the air turbine 28 and electric generator 29 dispensed with and the dimensions of the orifice 27 selected to maximise the energy loss as air is driven therethrough.

The devices shown in Figures 1 to 3 may be made from materials conventionally used by those skilled in the art of designing devices for extracting energy from wavepower depending on the chemical properties of the liquid and the forces to which the device is likely to be subjected in use (e.g. metals, or ferro-concrete). Although alternative materials can be used for the device of Figure 4, ferro-concrete is likely to be the preferred material.

It will be understood that although the invention has been described in relation to a device having several chambers in which the oscillation of a column of liquid in each chamber is used to discharge air into a common duct, 5 the invention may also be incorporated in a device having at least one such chamber from which air is discharged directly to an air turbine.

The invention may also be incorporated in devices having alternative means for rectifying the air discharged 10 from adjacent chambers before the air is directed to an air turbine, and also in devices having alternative means of deriving mechanical power from the oscillations of a column of liquid in a chamber of the device.

Claims:

1. A device for extracting energy from waves on a liquid in which the device is adapted to be partially submerged, the device having a chamber with an opening for the flow of the liquid into and out of the chamber to provide a quantity of the liquid which is arranged to oscillate in the chamber from the motion of the waves, and means arranged to use or dissipate at least some of the energy of the oscillating liquid in the chamber, characterised by,

- a) an asymmetric shape of that portion of the device adapted to be submerged and lie in a vertical plane aligned in the direction of propagation of the waves; and
- b) means (22, 23, 43, 59) for holding the device in said partially submerged position and inhibiting movement of the device in response to said waves, so that in operation waves generated by the device itself are substantially unidirectional and in a direction towards the incoming waves.

2. A device as claimed in Claim 1, further characterised by the asymmetric shape being provided by,

- a) a forward wall (10, 40, 60) of the chamber (14) with respect to waves incoming towards the device;
- b) a rear wall (11, 41, 61) of the chamber (14), said forward wall (10, 40, 60) being shorter than the rear wall (11, 41, 61) so as to be immersed less deeply in the liquid than the rear wall (11, 41, 61); and
- c) an open lower end of the chamber (14) to provide said opening.

3. A device claimed in Claim 1, further characterised by the asymmetric shape being provided by,

- a) a closed lower end (30, 43, 63) of the chamber (14); and
- b) a forward wall (10, 40, 60) of the chamber (14), with respect to waves incoming towards the device, and shaped to define at least in part said opening (31).

4. A device as claimed in Claim 2, further characterised by the device being arranged so that in a vertical plane aligned in the direction of propagation of the waves:

- a) the difference (S) between the mean depth of immersion of the forward wall (10, 40, 60) and the rear wall (11, 41, 61) of the chamber (14) with respect to incoming waves is not less than the distance (L) in the chamber (14) between said walls (10, 40, 60 - 11, 41, 61) and not greater than twice said distance (L) between said walls (10, 40, 60 - 11, 41, 61);
- b) the mean depth (y) of immersion of said forward wall (10, 40, 60) of the chamber (14) is not less than one quarter of the distance (L) in the chamber (14) between said forward wall (10, 40, 60) and said rear wall (11, 41, 61) of the chamber (14) and not greater than one half of said distance (L) between said walls (10, 40, 60 - 11, 41, 61);
- c) said rear wall (11, 41, 61) of the chamber (14) has a thickness at the lower end thereof in said vertical plane not less than the distance (L) in the chamber between said forward wall (10, 40, 60) and said rear wall (11, 41, 61) of the chamber (14) and not greater than three times said distance (L) between said walls (10, 40, 60 - 11, 41, 61); and
- d) said forward wall (10, 40, 60) of the chamber (14) has a thickness (x) at the lower end thereof in said vertical plane not less than one half the mean depth (y) of immersion of said forward wall (10, 40, 60) and not greater than said mean depth (y) of immersion of said forward wall (10, 40, 60).

5. A device as claimed in Claim 3, further characterised by the device being arranged so that in a vertical plane aligned in the direction of propagation of the waves:

- a) the height (S) of the opening (31) is about 0.67 of the distance (L) in the chamber (14) between the forward wall (10, 40, 60) and the rear wall (11, 41, 61) with respect to incoming waves;
- b) the mean depth (y) of immersion of the forward wall (10, 40, 60) is about 0.4 of the distance (L) in the chamber (14) between the forward wall and the rear wall (11, 41, 61); and

c) said forward wall (10, 40, 60) of the chamber (14) has a thickness (x) at the lower end thereof in said vertical plane about 0.25 of the distance (L) between said forward wall (10, 40, 60) and said rear wall (11, 41, 61).

6. A device as claimed in any one of Claims 1 to 5, further characterised by the device being of buoyant construction, and the holding means (22, 23) being adapted for holding the device below the natural level of floatation of the device in the liquid so as to inhibit said vertical movement of the device.

7. A device as claimed in any one of Claims 1 to 5, further characterised by the device being of non-buoyant construction, and the means comprising a submerged support (43, 53).

8. A device as claimed in any one of Claims 1 to 5, further characterised by the device being adapted for incorporation in a barrier means (59) arranged to be incident to incoming waves.

On behalf of the Applicants

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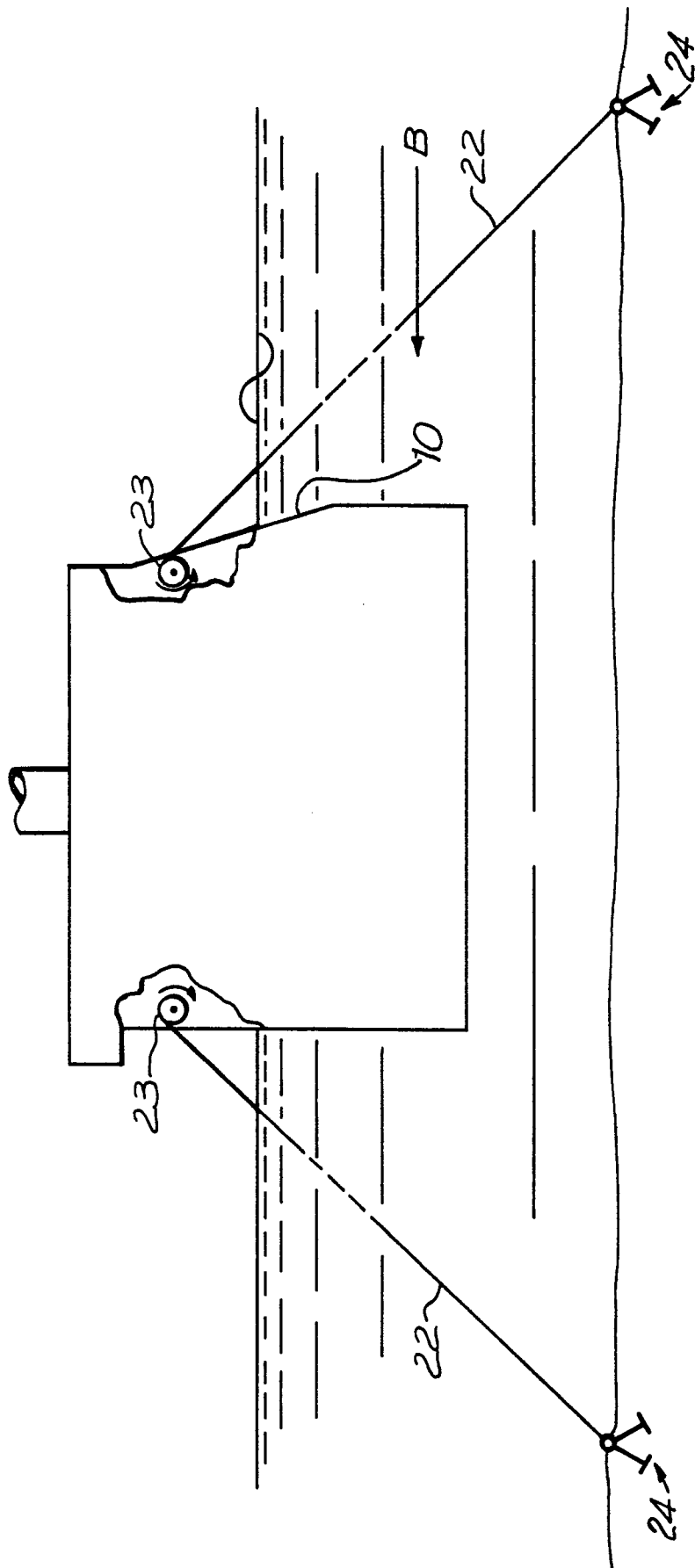


FIG. 1a.

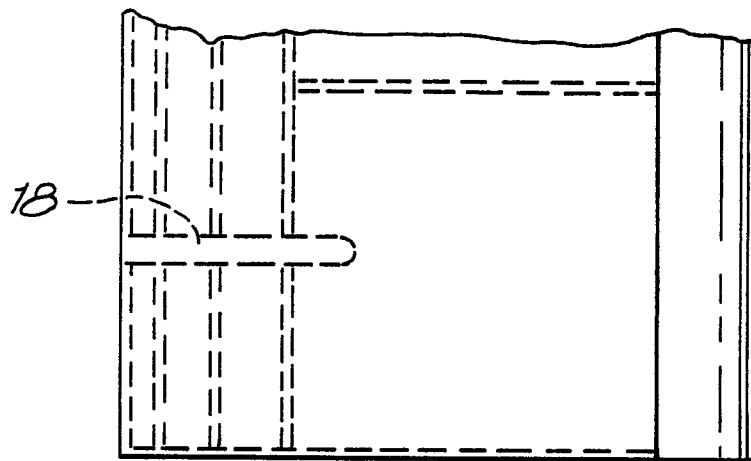
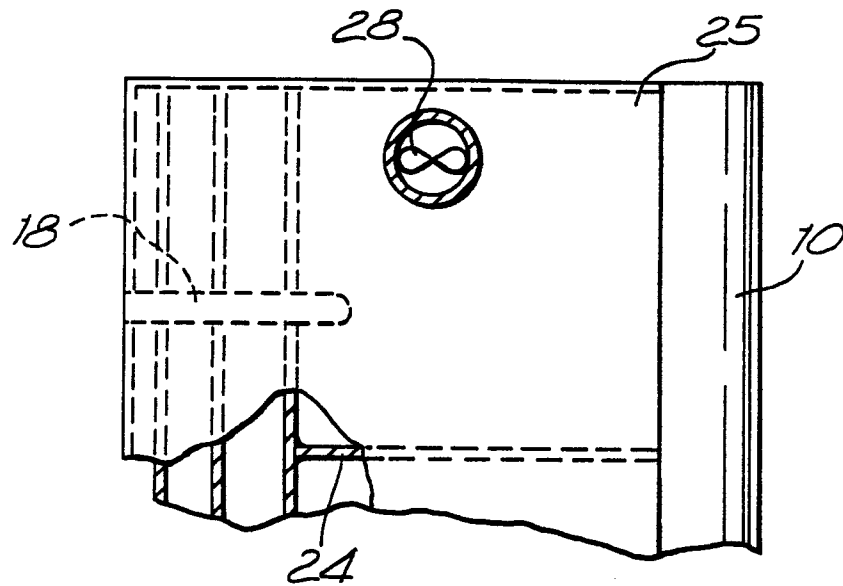


FIG. 3

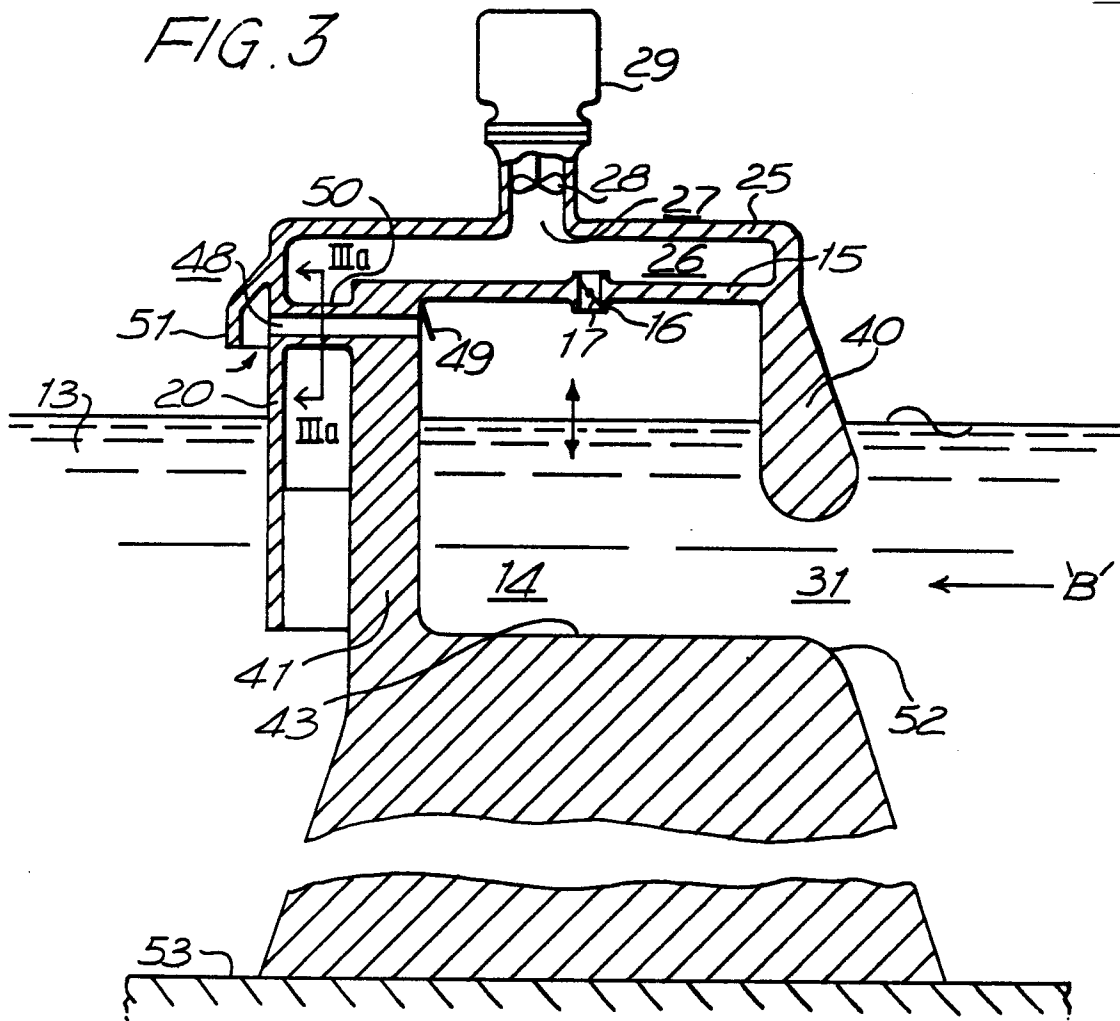


FIG. 3a.

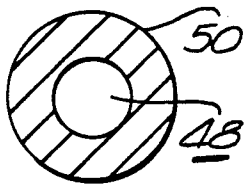


FIG. 4.

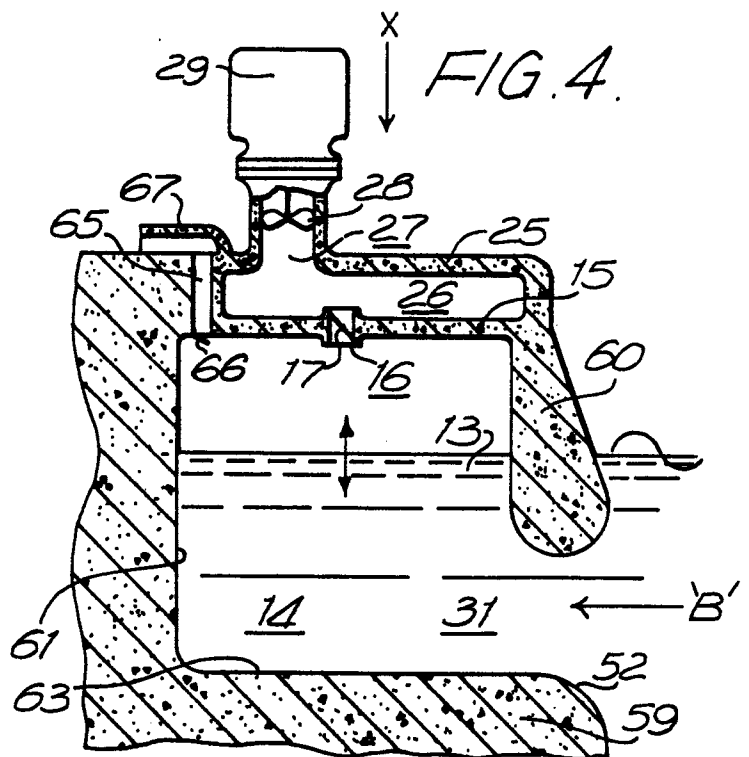
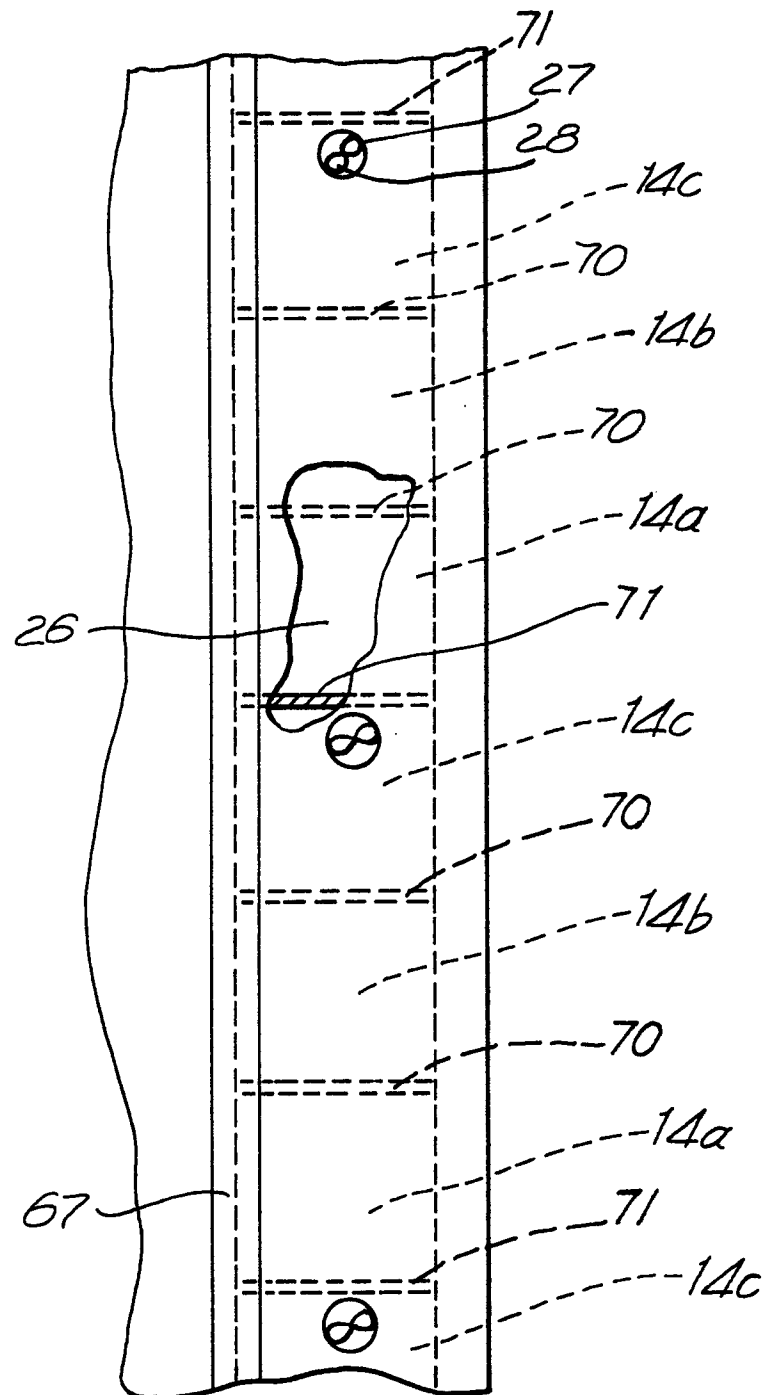


FIG. 5.





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DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
X, D P, E	<u>DE - A - 2 737 143</u> (SECRETARY OF STATE FOR ENERGY) (23-02-1978) * Page 5, first paragraph; page 6, third paragraph; page 7, line 10 to bottom of page 8, page 14 last but one paragraph; page 15, last paragraph * --	1, 2, 6	F 03 B 13/12
X	<u>DE - A - 2 507 330</u> (RICA FRANCA) * Page 3, last two paragraphs * --	1, 3, 7	
	<u>FR - A - 2 278 943</u> (GONCALVES) * Page 1, lines 20-29; figure 1 * --	1, 3, 7	TECHNICAL FIELDS SEARCHED (Int. Cl.)
P	<u>FR - A - 2 346 571</u> (WAVEPOWER) 28-10-1977 * Page 6, line 20 to page 7, line 10; figure 8 * --	1, 3, 6	F 03 B 13/12
A, P	<u>GB - A - 1 492 427</u> (MASUDA) 16-11-1977		
A	<u>FR - A - 993 678</u> (MARIJON)		
A	<u>FR - A - 761 818</u> (AUBERGER)		
A	<u>FR - A - 1 049 067</u> (ELECTRICITE DE FRANCE) ----		CATEGORY OF CITED DOCUMENTS
			X: particularly relevant A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: conflicting application D: document cited in the application L: citation for other reasons
			&: member of the same patent family, corresponding document
✓ The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 10-10-1978	Examiner DELL