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(71) Applicant and
(72) Inventor: SALT, Anthony [GB/GB]; 89 Jackroyd Lane, Newsome, Huddersfield HD4 6RB (GB).

(74) Agents: NEILL, Alastair, William et al.; Appleyard Lees, 15 Clare Road, Halifax HX1 2HY (GB).

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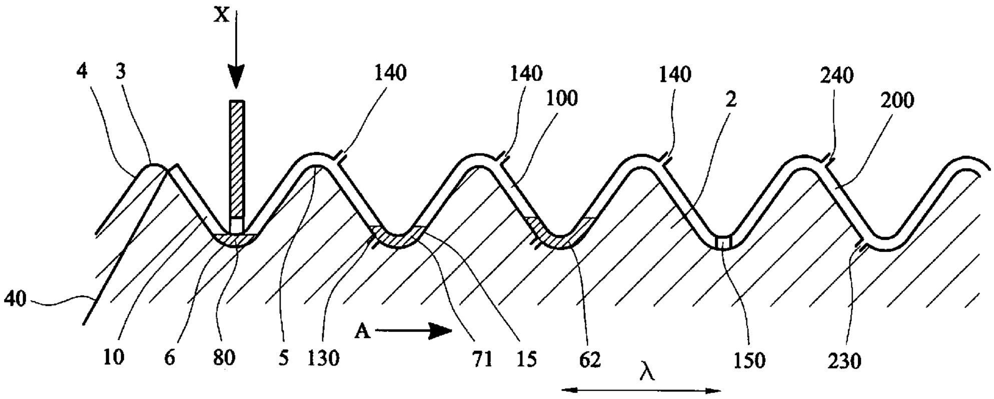
(54) **Title:** ENERGY EXTRACTION APPARATUS AND METHOD



(57) **Abstract:** A method of extracting energy from waves in a body of water comprises (a) locating a flexible pipe such that it floats on a body of water in a substantially fixed position relative to the direction of wave travel and such that at least an initial part of the pipe extends substantially in line with the direction of wave travel, wherein the pipe is arranged to flex up and down with the waves such that the pipe has a wave form corresponding to the surface of the body of water; (b) allowing water into the pipe such that it can be caused to advance along the pipe as the pipe flexes with an advancing wave front; (c) allowing said water to be advanced along the pipe by a wave front; and (d) employing water which has travelled along the pipe in an application which requires the use of water having kinetic energy. The invention provides a simple method for use in extracting energy from waves which overcomes at least one problem associated with known methods. The invention also provides an apparatus for carrying out the method.

WO 2006/067421 A1

ENERGY EXTRACTION APPARATUS AND METHOD

The present invention relates to apparatus for extracting energy from waves.

There exist a number of devices for generating power and in particular electrical power, from the energy of waves. For example, it is known to employ a partially submerged chamber, vented to the atmosphere via a pneumatic turbine, sea water being free to enter and leave the chamber. As waves pass by water rises and falls in the chamber causing air to flow through the turbine.

However, known devices for converting the energy of waves into useable power can be complex and costly to construct and operate.

Accordingly, the present invention aims to provide a simple method and apparatus for use in extracting energy from waves which overcomes at least one problem associated with known devices whether discussed herein or otherwise.

According to a first aspect of the present invention there is provided a method of extracting energy from waves in a body of water, said method comprising:

(a) locating a flexible pipe such that it floats on a body of water in a substantially fixed position relative to the direction of wave travel and such that at least an initial part of the pipe extends substantially in line with the direction of wave travel, wherein the pipe is arranged to flex up and down with the waves such that the pipe has a wave form corresponding to the surface of the body of water;

(b) allowing water into the pipe such that it can be caused to advance along the pipe as the pipe flexes with an advancing wave front;

(c) allowing said water to be advanced along the pipe by a wave front; and

(d) employing water which has travelled along the pipe in an application which requires the use of water having kinetic energy.

Preferably, step (b) comprises supplying water into the pipe. Water may be injected into the pipe. Water may be injected into the pipe such that the water is moving at the same velocity as the waves.

Preferably, in step (d) water which has travelled along the pipe is employed to drive an electrical turbine or other water powered device.

Prior to the commencement of the method the flexible pipe is suitably filled with air.

Preferably, the method comprises:

(i) locating a flexible pipe such that it floats on a body of water in a substantially fixed position relative to the direction of wave travel and such that at least an initial part of the pipe extends substantially in line with the direction of wave travel, wherein the pipe is arranged to flex up and down with the waves such that troughs, whose bases are separated from adjacent trough bases by a wavelength, are formed in the pipe, said pipe having a first inlet and an outlet, the outlet being spaced from the first inlet in the direction of wave travel;

(ii) allowing a first initial quantity of water into the first inlet of the pipe, said quantity being less than that required to fill a trough section of the pipe, such that said water can be advanced through the pipe as the pipe flexes with an advancing wave front;

(iii) waiting while a wave front travels a wavelength such that said first initial quantity of water is advanced along the pipe by a wavelength;

(iv) allowing a further initial quantity of water into the first inlet of the pipe, said quantity being less than that required to fill a trough section of the pipe;

(v) waiting while a wave front travels a wavelength such that the water within the pipe is advanced along the pipe and supplying a further initial quantity of water into the first inlet of the pipe in the same manner as step (iv);

(vi) optionally repeating step (v) one or more times; and

(vii) employing water which has travelled along the pipe in an application which requires the use of water having kinetic energy.

Preferably, steps (ii) and (iv) comprise supplying water into the pipe. Water may be injected into the pipe. Water may be injected into the pipe such that the water is moving at the same velocity as the waves.

Preferably, in step (vii) water which has travelled along the pipe is employed to drive an electrical turbine or other water powered device.

Suitably, according to the method, a plurality of discrete quantities of water travel along the pipe. Suitably, a mid part of each quantity of water is separated from a mid part of an adjacent quantity by a wavelength.

Suitably, the pipe is located such that substantially the only movement thereof is in a vertical plane. The pipe may thus move up and down with the waves but substantially does not move in any other way.

By “trough section” it is meant a section of pipe lying between the peaks of two wave crests.

Preferably, the first and further initial quantities of water supplied into the pipe are each of an amount less than that required to fill a lower trough section.

By "lower trough section" it is meant the section of pipe extending from the base of a wave to half the height of the wave peak above the base.

Suitably, the first and further initial quantities of water are each of an amount less than half that required to fill a lower trough section, more preferably less than a quarter, for example a tenth or less.

Suitably, the flexing of the pipe to adopt the form of the surface of the body of water on which it floats is such that the inlet of the pipe alternates between being at a trough and at a crest in the pipe as troughs and crests move along the pipe with passing wavefronts.

Preferably, water is supplied into the inlet when the inlet is within a trough section of the pipe. Suitably, water is carried along the pipe in the trough section into which it is supplied as that trough section advances along the pipe with an advancing wavefront.

Preferably, water is supplied into the inlet when the inlet is within a lower trough section of the pipe.

Suitably, water is carried along the pipe in the lower trough section into which it is supplied as that lower trough section advances along the pipe with an advancing wavefront.

The water may be collected from the outlet of the pipe by collection means and may then be employed to drive an electrical turbine or other water powered device.

Suitably, the method comprises locating a plurality of pipes such that they float on the body of water. The method may comprise locating a plurality of pipes such that they supply water to a common collection means.

Suitably, the method comprises locating a pipe comprising a web of pipe portions such that they float on the body of water. Suitably, the web comprises a first pipe portion having a first inlet in communication with a water supply and between two and five downstream pipe portions each having first inlets communicating with an outlet of the first pipe portion. Suitably, the web comprises second and third pipe portions each having first inlets communicating with an outlet of the first pipe portion. Water carried by the first pipe portion may thus be split and carried by the second and third pipe portions. The web may comprise only second and third pipe portions having inlets connected to the first pipe portion. Alternatively, the web may further comprise a fourth or a fourth and fifth, or fourth, fifth and sixth pipe portion each having first inlets communicating with an outlet of the first pipe portion. Water carried by the first pipe portion may thus be split and carried by the second, third, fourth and, if employed, fifth and sixth pipe portions.

Preferably, the water is split equally and equal volumes are carried by each of the pipe portions into which water is split. For example, if only second and third pipe portions are employed the water may be split equally between the second and third pipe portions. The second and third pipe portions and, if employed, the fourth, fifth and sixth pipe portions, may have outlets communicating directly with a collection means. Alternatively, the second and third pipe portions and, if employed, the fourth, fifth and sixth pipe portions, may have outlets communicating with inlets of further like pipe portions.

Suitably, the pipe or if the method employs a web of pipe portions at least the first pipe portion comprises one or more second water inlets arranged along its length. Suitably, when more than one is employed the second water inlets may be spaced from adjacent inlets by one wave length. The water inlets may be spaced along the pipe at intervals of between 0.5 and 1 meter to allow for changing wave conditions such that there are always inlets separated from one another by approximately one wave length. Suitably, those inlets employed in the method are spaced from one another by a distance of approximately one wave length in the direction of wave travel. Suitably, only one or more of those second inlets which lie an integer number of wavelengths from the first inlet are employed in the method. Suitably, external water is added to the water in the pipe through one or more second inlets as the water travels along the pipe. According to the method, the first of the second inlets through which water is allowed to enter suitably lies at one or more wavelengths, from the first inlet. The first of the second inlets through which water is allowed to enter according to the method may lie two wavelengths from the first inlet, for example three wavelengths from the first inlet.

Suitably, the entry of external water through the or each second inlet is valve controlled. Suitably, according to the method of the invention, entry of water through the or each second inlet is controlled such that once the volume of a quantity of water in a section of the pipe is approximately equal to the volume of air in said pipe section then no more water is permitted to enter that pipe section.

The second inlet valves may be computer controlled. Alternatively, the second inlet valves may be arranged to operate between open and closed configurations depending on the flexure of the pipe and whether they lie at troughs or crests therein. Alternatively, the second inlet valves may be arranged to open automatically when water flows past them within the pipe.

Suitably, the or each second inlet employed in the method is arranged such that as water passes through the pipe and past the inlet a quantity of external water enters into the pipe and combines with the water passing the inlet to form a combined quantity of water in the pipe section comprising said second inlet.

Suitably, the or each second inlet employed in the method is arranged such that as water passes through the pipe and past the inlet it creates a venturi effect and draws a quantity of external water into the pipe which combines with the water passing the inlet to form a combined quantity of water in the pipe section comprising said second inlet.

Suitably, the pipe or if the method employs a web of pipe portions at least the first pipe portion comprises one or more air vents arranged along its length. Suitably, when more than one is employed the air vents may be spaced from adjacent air vents by one wave length. The air vents may be spaced along the pipe at intervals of between 0.5 and 1 meter to allow for changing wave conditions such that there are always air vents separated from one another by approximately one wave length. Suitably, only those air vents which lie an integer number of wavelengths from one another are employed in the method. Suitably, the ingress and egress of air through the or each air vent is valve controlled.

Suitably, one or more valves may comprise a sensor arranged to provide signals to a controlling computer to indicate when the second inlet valves should be opened.

Suitably, the first inlet has an air vent lying downstream of it. Suitably, said air vent lies upstream of any second inlets. Suitably, each second inlet employed in the method has an air vent lying between it and any downstream second inlets. Suitably, each air vent employed in the method lies approximately half a wavelength downstream of an inlet employed in the method. Thus, at any given time, when the inlet lies in a trough section of the pipe the air vent may lie at a crest.

Suitably, the or each air vent employed in the method is arranged such that as water is allowed into the pipe immediately upstream of the air vent a volume of air is expelled through the vent. Suitably, the volume of water allowed into the pipe and the volume of air expelled through the vent are equivalent. The or each air vent may thus prevent the build up of air pressure within the pipe and ensure that water can travel along the pipe.

Suitably, according to the method external water is allowed into the or each inlet as water in the pipe passes the inlets such that the external water is added to form a combined quantity of water in the pipe section which is not in equilibrium. By this it is meant that water on the trailing side of the trough section of the pipe lies at a higher level than that on the leading side. The combined quantity of water is thus accelerated as it moves with the wave to correct this and return to an equilibrium in which water on the trailing and leading sides of the trough section is at the same level.

Suitably, the combined quantity of water in a pipe section after the or each addition of external water is less than that required to fill a trough section of the pipe. The combined quantity of water in the pipe section is suitably less than that required to fill a lower trough section.

Suitably, at least two quantities of external water are added to the water in the pipe. Preferably, at least two quantities of external water are added to the water in each pipe portion.

Suitably, once the combined quantity of water in a pipe section of the first pipe portion is approximately equal to the volume of air in the pipe section the water is removed from the first pipe portion and divided between second and third, and if employed, fourth, fifth and sixth pipe portions connected to an outlet of the first pipe portion.

Suitably, once the combined quantity of water in a pipe section of the first pipe portion is approximately equal to the quantity of the initial or further quantity of water multiplied by the number of pipe portions into which water from the first pipe portion is split then the water is removed from the first pipe portion and divided between those pipe portions connected to an outlet of the first pipe portion. For, example, when the water is split into only a second and third pipe portion then once the combined quantity of water in a pipe section of the first pipe portion is approximately equal to double the quantity of the initial or further quantity of water the water is removed from the first pipe portion and divided between second and third pipe portions connected to an outlet of the first pipe portion.

The water from the first pipe portion may thus provide initial quantities of water to the first inlets of the pipe portions to which it's outlet is connected. For example, initial quantities of water may be provided to the first inlets of second and third pipe portions.

Suitably, the water is spilt equally between the pipe portions to which the outlet of the first pipe portion is connected. For example, water may be split equally between second and third pipe portions.

Suitably, water advances through the second and third pipe portions and, if employed, fourth, fifth and sixth pipe portions as the pipe portions flex with an advancing wave front.

Suitably, the second and third pipe portions and, if employed, fourth, fifth and sixth pipe portions each comprise one or more second inlets arranged to allow external water to be drawn into the pipe portions and combined with the water within the pipe portion to form a combined quantity of water in the section of pipe comprising said second inlet.

Suitably, the second inlets are substantially the same as those described in respect of the first pipe portion.

Suitably, external water is drawn into the second and third pipe portions, and, if employed, fourth, fifth and sixth pipe portions in the same manner as that described in respect of the first pipe portion. Suitably, a combined quantity of water in a pipe section is formed in the same manner as that described in respect of the first pipe portion.

The method may further comprise splitting the combined quantity of water in a pipe section of the second pipe portion into two or more further pipe portions. The method may further comprise splitting the combined quantity of water in a pipe section of the third pipe portion into two or more further pipe portions. Suitably, if fourth or fourth and fifth or fourth, fifth and sixth pipe portions are employed in the method then the method may further comprise splitting the combined quantity of water in a pipe section of those pipe portions into two or more further pipe portions.

Suitably, the water from each pipe portion is split into no more than five further pipe portions. Suitably, the water from each of the second and third and, if employed, fourth, fifth and sixth pipe portions, need not be split into the same number of pipe portions as that from the first pipe portion.

Suitably, the combined quantity of water in each of the second and third pipe portions and, if employed, fourth, fifth and sixth pipe portions is split when the combined quantity of water in a pipe section is approximately equal to the volume of air in the pipe section.

Suitably, the combined quantity of water in each of the second and third pipe portions and, if employed, fourth, fifth and sixth pipe portions is split when the combined quantity of water in a pipe section is approximately equal to the quantity of water introduced from the first pipe portion multiplied by the number of pipe portions into which the water is to be split. For example, if the second pipe portion has it's outlet connected to the inlets of two further pipe portions then the combined quantity of water in the second pipe portion is split when the combined quantity of water in a pipe section is equal to double the quantity of water introduced from the first pipe portion.

The splitting process may comprise several further stages of dividing the water from one pipe portion into a plurality of subsequent pipe portions and adding external water thereto. Suitably, each initial quantity of water supplied to the first pipe portion may, after external water has been added thereto, be split at between 1 and 5 stages, for example at between 2 and 3 stages. Suitably, the web may comprise between 2 and 3125 pipe portions at an outlet end thereof, preferably between 2 and 100.

Suitably, the pipe portions at the outlet end of the pipe web (final pipe portions) each comprise an outlet connected to a collection means. Suitably, the collection means comprises a collection conduit arranged to carry water from the outlets of the final pipe portions in the web. Suitably, the collection conduit is further arranged to carry air from the outlets of the final pipe portions in the web.

Suitably, the collection conduit is connected to the final pipe portions such that it lies a different distance along the wave path of each pipe portion. While water is discharged from one pipe portion into the conduit, it may be that no water may be discharged from an adjacent pipe portion. As a result, the pipe portions may be sequenced according to the method such that water enters the collection conduit from at least one pipe portion during any given time period.

Suitably, the conduit is arranged to carry air in one direction and water in another following their discharge from the final pipe portions. The air and water may thus be carried to be employed for separate uses. Suitably, at least some of the water is taken to be employed in an application, such as the generation of electricity, which requires the use of water having kinetic energy. Some of the water may be carried by a return pipe to an inlet of the flexible pipe. Suitably, the return pipe is filled with water. The return pipe may be in communication with the first inlet of the first pipe portion of the pipe web. Alternatively, the return pipe may be in communication with an inlet of a downstream pipe portion, for example the second and/or third pipe portions.

Suitably, the conduit carries water to a turbine. Suitably, the conduit carries an uninterrupted supply of water to the turbine.

The method suitably employs a flexible pipe which turns across the direction of wave travel. The velocity of water in the pipe may be increased by acceleration due to the turning of the pipe across the direction of wave travel.

Suitably, the more the pipe is turned across the direction of wave travel then the greater is the length of pipe which extends over a distance of one wavelength in the direction of wave travel.

Suitably, when the flexible pipe is arranged to turn across the direction of wave travel the position of inlet valves may be arranged such that those employed in the method are spaced from one another by approximately one wave length in the direction of wave travel. Thus, the inlets may be spaced from one another by a distance greater than that of one wavelength in the direction of the pipe.

The pipe may be arranged to turn through an angle of between 5 and 89 degrees. The pipe may turn through such an angle whilst spanning a distance of between 1 and 100 wavelengths in the direction of wave travel. Suitably, the pipe is arranged to turn gradually through an angle of between 40 and 89 degrees. For example, the pipe may be arranged to turn gradually through an angle of between 50 and 80 degrees.

Suitably, as the pipe turns water continues to advance through the pipe with the wave front. As a consequence the water may be caused to accelerate in the direction of pipe extent each time the pipe turns relative to the direction of wave travel. Preferably, water passing through the pipe is caused to accelerate constantly in the direction of pipe extent as the pipe turns relative to the direction of wave travel. Water exiting the pipe may thus have a greater velocity than water entering the pipe.

For example, water travelling through the pipe may have a velocity V1 in the direction of wave travel and after the pipe has turned through an angle A the water may then have a velocity V2 in the direction of pipe travel. For a given value of V1 and A the velocities V2 may approach the values according to the following table though they may be limited by friction between the pipe and water:

V1/k.p.h	A/degrees	V2/k.p.h
5	30	5.75
10	30	11.5
15	30	17.25
5	40	6.18
10	40	13.1
15	40	19.65
5	50	7.27
10	50	15.6
15	50	23.4
5	55	8.23
10	55	17.4
15	55	26.1
5	60	10
10	60	20
15	60	30

5	65	11.85
10	65	23.7
15	65	35.55
5	70	14.6
10	70	29.2
15	70	43.8
5	75	19.3
10	75	38.6
15	75	57.9
5	80	28.8
10	80	57.6
15	80	86.4
5	85	57.35
10	85	114.7
15	85	172.05

Suitably, the body of water comprises an ocean or sea.

Suitably, the method comprises anchoring the pipe such that it can flex and move up and down but substantially cannot move in any other way. Suitably, the pipe is anchored such that it can rise and fall with a tide. The method may comprise anchoring each flexible pipe portion. Suitably, the method comprises anchoring the pipe to a sea or ocean bed. Suitably, the method comprises connecting the pipe to pontoons which are anchored to the sea or ocean bed.

According to a second aspect there is provided an apparatus for extracting energy from waves, said apparatus comprising a flexible pipe adapted to carry water and adapted to float on a body of water and to flex as waves travel through the body of water, said apparatus being arrangeable in use such that said waves travel substantially in the direction in which at least an initial part of the pipe extends, wherein said apparatus further comprises a supply means for supplying water into a first inlet of the pipe and a collection means for recovering water from the pipe, wherein said collection means is arrangeable to supply water for employment in an application which requires the use of water having kinetic energy.

Suitably, the collection means is arrangeable to supply water to drive an electrical turbine or other water powered device.

Suitably, the apparatus is adapted to be employed in a method according to the first aspect. The apparatus may thus comprise one or more of the features of an apparatus described in relation to the first aspect.

Suitably, the apparatus is adapted such that, in use, the flexible pipe turns across the direction of wave travel.

Suitably, the supply means of the apparatus comprises control means such that water can be supplied to the pipe at specific times. Suitably, the control means is arranged such that water is only allowed into the pipe at time intervals separated by the time taken for a wave front to travel an integer number of wavelengths, preferably one wavelength. The control means may comprise a valve. The valve may comprise a servo controlled valve. The valve may be computer controlled.

Suitably, the supply means comprises a supply pipe arranged to carry water from a point removed from the inlet of the flexible pipe. The supply pipe may be flexible.

Suitably, the collection means comprises a collection pipe. The collection pipe may be flexible. The collection means may be connected to an outlet of the pipe. The collection means may be collected to a return pipe which returns some of the collected water to the flexible pipe. The return pipe may be flexible. The return pipe may be in communication with the supply pipe. Suitably, the return pipe is in communication with the flexible pipe such that, after an initial period, it feeds water thereto such that, by employing the energy of the waves, the supply of water is self sustaining.

The collection means may also recover air from the flexible pipe. Suitably, the collection means is arranged to cause air and water recovered from the flexible pipe to exit the collection means separately from one another. The apparatus may comprise an air carrying pipe separate from the water return pipe. The air carrying pipe may carry some air from the collection means back towards the inlet end of the flexible pipe. The air carrying pipe may run alongside the flexible pipe and may be attached thereto to help keep it buoyant. There may be more than one such air carrying pipe. The apparatus may employ some of the air to drive a small electrical generator to power electrical components of the apparatus.

The apparatus may comprise a plurality of flexible pipes and the collection means may be connected to an outlet of each. Alternatively, the apparatus may comprise a single flexible pipe which may be unbranched.

The apparatus may comprise a flexible pipe comprising a web of pipe portions with a first pipe portion connected at its outlet to an inlet of at least a second and third pipe portion such that it branches out. The second pipe portion may be connected to at least a fourth and fifth pipe portion and the third pipe portion may be connected to at least a sixth and seventh pipe portion (It should be noted that those pipe portions referred to here as the fourth, fifth and sixth pipe portions do not lie at the same point in the web as those pipe portions referred to as the fourth, fifth and sixth pipe portions in the first aspect.). The fourth, fifth, sixth and seventh pipe portions may themselves branch. Suitably, the collection means is connected to an outlet of each of the final pipe portions in the web.

Suitably, when the apparatus comprises a plurality of pipes or pipe portions connected to the collection means the collection means is arranged such that in use water is removed from each consecutive pipe or pipe portion at an increasing wavelength distance from the supply means. While water exits one pipe or pipe portion it may be that there may be no water exiting one or more of the other pipes or pipe portions and vice versa. Water may thus be supplied into the collection means from at least one pipe or pipe portion at any one time. The collection means may thus be able to supply an uninterrupted stream of water to a turbine.

Suitably, the pipe comprises one or more second inlets arranged to allow external water to be drawn into the pipe. Suitably, the first pipe portion comprises one or more second inlets. Subsequent pipe portions in a web may also comprise one or more second inlets. Suitably, the or each inlet comprises a valve.

The or each second inlet valve may comprise a servo controlled valve. The second inlet valves may be computer controlled. Alternatively, the second inlet valves may be arranged to operate between open and closed configurations depending on the flexure of the pipe and whether they lie at troughs or crests therein. The valves may for example be connected to a cable at points which move longitudinal relative to the pipe as the pipe flexes. Alternatively, the second inlet valves may be arranged to open automatically when water flows past them within the pipe. The valves may then close themselves, for example they may be spring loaded valves which are only opened as water flows past within the pipe.

Each second inlet may be provided with a cover plate having a number of apertures in predetermined positions and the cover plates of the inlets may be connected so that an operator can set the inlets which are aligned with apertures in their cover plates and into which water can enter depending on the wavelength of the waves. Alternatively, the second inlets may have computer controlled valves and the computer may be programmed to only open certain valves when the waves are separated by a given wavelength.

Suitably, the pipe comprises one or more air vents arranged along it's length. Suitably, each air vent lies downstream of an inlet. Suitably, each air vent comprises a valve.

Each air vent may comprise a valve having a floating closure member arranged to cause the valve to be closed as water travels through the pipe past the valve and to open as air travels through the pipe past the valve. Alternatively, each valve may comprise a servo controlled valve. One or more air vents may comprise a valve having a sensor to indicate to a computer whether the valve is closed or open. The computer may be programmed to use that information together with other given parameters such as the wavelength of the waves and location of the inlets to determine which inlets should be opened and closed for the most effective operation of the apparatus. Suitably, each air vent comprises a sensor. Preferably at least the last air vent in each pipe portion comprises a sensor.

Suitably, the apparatus comprises a computer arranged to control the valve operation such that it adjusts the ratio of the volume of water and air in a pipe section of a pipe portion as close as possible to 1:1 before the water is split into further pipe portions or recovered by the collection means.

Suitably, the pipe comprises a pipe constructed to float on water when carrying a volume of water. Alternatively, the pipe may comprise a non-floating pipe having floats arranged along its length such that it will float. Where the apparatus comprises a plurality of pipes or pipe portions it may comprise a number of floats spaced along the length of the pipes or pipe portions and extending transverse to the wave direction between parallel pipes or pipe portions.

Suitably, the apparatus comprises anchoring means arranged to fix the pipe in position such that it may flex and move up and down but substantially not move in any other way. The anchoring means may be arranged to secure the pipe to the sea or ocean bed. Suitably, the anchoring means is arranged to take tidal movement into account. Suitably the anchoring means comprises floating pontoons to which the or each pipe is connected and which are anchored to the sea or ocean bed.

Suitably, the or each pipe has a length such that it may be arranged to span a distance of between 3 and 50 wavelengths, for example between 6 and 20 wavelengths. Suitably, the pipe has a length of between 3 and 5000 metres, for example up to 1000m. The length of the pipe may be arranged depending upon the desired output speed of the water carried by the pipe.

Suitably, the pipe, or each pipe portion where the pipe comprises a web of pipe portions has a diameter of between 1cm and 100cm. The pipe, or each pipe portion where the pipe comprises a web of pipe portions may have a diameter of around a twentieth of the wave height. The apparatus may be arranged such that, in use, the diameter of the pipe increases after the pipe has turned through an angle of greater than about 40 degrees. This may make it easier to accommodate water carried by the pipe in trough sections of the pipe.

The present invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a plan view of a first embodiment of an energy extraction apparatus;

Figure 2a is a side elevation of a section of a first embodiment of an energy apparatus at a first point in time;

Figure 2b is a side elevation of a section of a first embodiment of an energy apparatus at a second point in time;

Figure 2c is a side elevation of a section of a first embodiment of an energy apparatus at a third point in time;

Figure 2d is a side elevation of a section of a first embodiment of an energy apparatus at a fourth point in time;

Figure 2e is a side elevation of a section of a first embodiment of an energy apparatus at a fifth point in time;

Figure 2f is a side elevation of a section of a first embodiment of an energy apparatus at a sixth point in time;

Figure 3 is a plan view of a second embodiment of an energy extraction apparatus.

Figure 4 is a schematic cross-sectional view of an air vent.

An energy extraction apparatus 1 according to a first embodiment comprises a flexible pipe 10 which comprises a branched web of connected pipe portions. The pipe 10 is arranged to float on a body of water 2, more specifically the sea and to flex to conform to the shape of the waves 3 on the surface 4 thereof.

For simplicity, the illustrated apparatus is shown extending in the direction of wave travel. However, in an alternative embodiment (not shown) an apparatus having a similar construction to that illustrated in Figure 1 can be arranged to turn across the direction of wave travel.

The apparatus further comprises a water supply means 20 for feeding water into the flexible pipe 10 and a collection means 30 for carrying water from the pipe 10 to a turbine (not shown).

The pipe 10 comprises a first portion 100 having a first inlet 110 connected to the supply means 20 and an outlet 120 connected to a second pipe portion 200 and a third pipe portion 300. The second pipe portion 200 has an inlet 210 connected to the first pipe portion 100 and an outlet 220 connected to a fourth pipe portion 400 and a fifth pipe portion 500. The third pipe portion has an inlet

310 connected to the first pipe portion and an outlet 320 connected to a sixth pipe portion 600 and a seventh pipe portion 700. The fourth and fifth pipe portions 400, 500 each comprise an inlet 410, 510 connected to the second pipe portion 200 and an outlet 420, 520 connected to the collection means 30. The sixth and seventh pipe portions 600, 700 each comprise an inlet 610, 710 connected to the third pipe portion 300 and an outlet 620, 720 connected to the collection means 30. Each pipe portion comprises air vents 140, 240, 340, 440, 540, 640, 740 downstream of each of the inlets.

The first pipe portion 100 comprises second inlets 130 arranged to draw water from the body of water 2 on which the pipe 10 floats (external water) into the pipe 10 as water carried by the pipe 10 passes the second inlets 130. The flow of water through these inlets is controlled by valves (not shown). As water enters the pipe through either the first or second inlets the air within the pipe immediately in front of that water is vented via the air vent downstream of the inlet. Thus air can be allowed to egress from the pipe to prevent pressure build up and allow the apparatus to function.

The second, third, fourth, fifth, sixth and seventh pipe portions 200, 300, 400, 500, 600 and 700, each also comprise second inlets 230, 330, 430, 530, 630 and 730, which are valve controlled.

The supply means 20 comprises a pipe 21 connected to a water source (not shown). The supply means includes a control means 22 arranged to ensure water is only supplied to the flexible pipe 10 at specific times. The control means 22 comprises a valve (not shown). Water travels in the pipe 21 in the direction shown by arrow X.

The collection means 30 comprises a collection pipe 31 having openings in communication with the fourth, fifth, sixth and seventh pipe portions 400, 500, 600 and 700 of the pipe 10. The collection pipe 31 is angled relative to the direction of wave travel in the body of water 2 (indicated by arrow A) such that the outlet of each pipe portion lies a different distance from the supply means in the direction of wave travel. Water is carried by the collection pipe in the direction indicated by arrow Y.

The apparatus further comprises anchoring means comprising tethers 40, 50 attached as required to the pipe 10 which secure it via floating pontoons to the sea bed.

In use, the pipe 10 is located on the sea such that it adopts the surface configuration of the sea and has crests 11 and troughs 12 corresponding to crests 5 and troughs 6 of the sea waves.

As illustrated by Figure 2a the pipe 10 thus comprises trough sections 13 lying below the level of line B-B. The base 14 of each trough being separated from adjacent trough bases by one wavelength λ. Within the trough sections 13 are lower trough sections 15. The lower trough sections 15 are those pipe sections lying below the level of line C-C which is the centre-line of the wave, i.e. the equilibrium position. As a wavefront travels through in the direction of arrow A the pipe 10 flexes and the trough sections advance along the pipe 10 towards the collection means 30. Water within the pipe 10 moves with advancing troughs towards the collection means 30.

The operation of the apparatus is illustrated by figures 2a to 2f.

A first initial quantity of water 60 is supplied into a lower trough section 15 of a first portion 100 of the flexible pipe 10 (illustrated by Figure 2a)

The supply of water is then stopped while the first initial quantity of water 60 is advanced along the pipe. The water 60 remains within the lower trough section 15 of the pipe 10 and thus as the lower trough section 15 is caused to advance along the pipe 10 so too is the water 60. After the wavefront has travelled half a wavelength the pipe 10 is in the configuration shown by figure 2b.

When the wavefront has travelled a wavelength (i.e. at time t = λ/c after the first initial quantity of water is supplied into the pipe, where λ = wavelength and c = wave velocity) (as illustrated by figure 2c) a further initial quantity of water 70 is supplied into a lower trough section 15 of the pipe via inlet 110. Air lying between the first and further initial quantities of water in the pipe is vented via the air vent 140 immediately downstream from the first inlet 110. The first initial quantity of water 60 passes a second inlet 130 drawing external water into the pipe 10 to form a first combined quantity of water 61. At first this is not in equilibrium as the trailing edge 61a is higher than the leading edge 61b, however the combined quantity of water 61 adjusts to an equilibrium whilst subsequently advancing along the pipe.

When the wavefront has travelled a further wavelength (i.e. at time t = 2λ/c after the first initial quantity of water is supplied into the pipe) (illustrated by Figure 2d) a further initial quantity of water 80 is supplied into a lower trough section 15 of the pipe via inlet 110. Air lying between the second and further initial quantities of water in the pipe is vented via the air vent 140 immediately downstream from the first inlet 110.. The first combined quantity of water 61 passes another second inlet 130 drawing external water into the pipe 10 to form a greater combined first quantity of water 62. The second initial quantity of water 70 passes a second inlet 130 drawing external water into the pipe 10 to form a second combined quantity of water 71. Air lying between the first and second initial quantities of water in the pipe is vented via the air vent 140 immediately downstream from the second inlet 130 lying closest to the inlet 110. The process being the same as that to form the first combined quantity 61 (at time t = λ/c after the first initial quantity of water was supplied into the pipe).

Each time the wavefront advances a wavelength, further initial quantities of water are supplied into the first inlet 110 of the first pipe portion and external water is drawn into the second inlets 130 as quantities of water previously introduced into the pipe advance, thus forming combined quantities of water which then progress along the pipe. At the same time, air is vented via the air vents.

When a combined quantity of water 90 is such that the volume of water in a pipe section is approximately equal to the volume of air therein the volume of water is a multiple of the initial quantity. The combined quantity of water then reaches a junction 150 of the first pipe portion 100 with the second and third pipe portions 200, 300 as shown in Figure 2e (at time t = $3\lambda/c$ after the first initial quantity of water is supplied into the pipe) and is split in two to provide an initial quantity into each of the second and third pipe portions (only second pipe portion 200 and quantity of water 91 therein shown in Figure 2e).

The water then travels along the second and third pipe portions in the same manner as in the first and additional external water is drawn in through second inlets 230, 330. Thus, as illustrated by Figure 2f (at time t = $4\lambda/c$) quantities of water in the second and third pipe portions 200, 300 (only second pipe portions 200 and quantity of water 91 therein shown) advance and grow in substantially the same manner as that described for the first pipe portion 100. Once the quantity of water in a pipe section of each pipe portion has increased, and the ratio of air to water in the pipe section is 1:1, the water is split into the fourth and fifth and sixth and seventh pipe portions 400, 500, 600, 700. Again, the splitting operation is computer controlled. The water then once more advances and grows in the same manner before being supplied into the collection pipe.

The collection pipe is arranged such that it lies a different distance along the wave path of each of the fourth, fifth, sixth and seventh pipe portion. Consequently, water may be supplied to the collection pipe sequentially from each pipe portion. Thus, one or more of the pipes may always be supplying water into the collection pipe at any given time. This may provide a steady flow of water to a turbine.

According to a second embodiment a single flexible pipe is located on the surface of a body of water 2, in particular the sea.

The apparatus is substantially the same as that of the first embodiment with the single pipe replacing the pipe web. Thus, the apparatus comprises supply means 20 and collection means 30 as well as tethers 40, 50.

The flexible pipe is located and anchored as shown in figure 3 such that after an initial portion extending in line with the direction of wave travel (shown by arrow A) it curves across the direction of wave travel.

First and further initial quantities of water are supplied into the pipe 10 as described in the first embodiment and are advanced along the pipe in the same manner. An air vent 140 is provided downstream of the inlet 110 to vent air lying between successive initial quantities of water supplied into the pipe to prevent pressure build up.

The pipe is provided with second inlets 130 to allow external water to be drawn into the pipe. Further air vents 140 are provided to allow air to be vented from the pipe as external water is drawn in. The method of adding water is substantially as described in the first embodiment. As the initial quantity of water passes a first second inlet 130a it draws external water into the pipe to form a first combined quantity of water. As the first combined quantity of water passes the second second inlet 130b it draws further external water into the pipe to form a second combined quantity of water and so on. Thus the initial quantities are added to as they advance through the pipe 10. The water in the pipe is not split into further pipes but suitably the addition of water is controlled such that once the ratio of air to water in a pipe section is approximately 1:1 no further water is added to the water in that pipe section.

As the pipe 10 turns across the direction of wave travel the water within the pipe 10 is still caused to travel in the wave direction at the same speed. Whilst doing this the water thus travels with a greater speed in the direction of pipe travel. For example, a quantity of water travels between points D and E, which are separated by a wavelength, in a time of λ/c and between points F and G, also separated by a wavelength, in a time of λ/c but the distance between points F and G is greater than that between points D and E in the direction of pipe travel.

The water thus exits the pipe 10 into the collection means 30 with an increased velocity and is then used to power a turbine.

As mentioned, a pipe web similar to that of Figure 1 can be arranged to turn across the direction of wave travel and may combine the beneficial effects discussed in relation to the pipe of Figure 3 with those of the pipe web of Figure 1. Such a pipe web differs from that of Figure 1 in that the more the web is turned across the direction of wave travel the further the valves must be spaced from one another along the pipe length in order that they remain separated by an appropriate distance in the direction of wave travel.

Figure 4 illustrates an air vent 140 suitable for employment in the present invention. The air vent comprises a valve comprising a floating ball 141 secured within a housing 142 defining entrance and exit apertures 143, 144 through which air can egress. As water flows past the vent the ball 141 floats (shown in solid line) and blocks the exit of the aperture. When water is not flowing past the ball 141 it drops down (shown in broken line) and provides a flow path to the exit through which air can travel. The vent further comprises a sensor 145 to indicate to a computer whether the valve is open or closed.

The pipework may be coated with low friction material, for example polytetrafluoroethylene.

It will be understood that the present invention may thus provide a simple apparatus for converting energy of waves into a useable form and which has few moving components requiring maintenance.

Attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

Each feature disclosed in this specification (including any accompanying claims, abstract and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

CLAIMS

1. A method of extracting energy from waves in a body of water, said method comprising:

(a) locating a flexible pipe such that it floats on a body of water in a substantially fixed position relative to the direction of wave travel and such that at least an initial part of the pipe extends substantially in line with the direction of wave travel, wherein the pipe is arranged to flex up and down with the waves such that the pipe has a wave form corresponding to the surface of the body of water;

(b) allowing water into the pipe such that it can be caused to advance along the pipe as the pipe flexes with an advancing wave front;

(c) allowing said water to be advanced along the pipe by a wave front; and

(d) employing water which has travelled along the pipe in an application which requires the use of water having kinetic energy.

2. A method of extracting energy from waves in a body of water, the method comprising:

(i) locating a flexible pipe such that it floats on a body of water in a substantially fixed position relative to the direction of wave travel and such that at least an initial part of the pipe extends substantially in line with the direction of wave travel, wherein the pipe is arranged to flex up and down with the waves such that troughs, whose bases are separated from adjacent trough bases by a wavelength, are formed in the pipe, said pipe having a first inlet and an outlet, the outlet being spaced from the first inlet in the direction of wave travel;

(ii) allowing a first initial quantity of water into the first inlet of the pipe, said quantity being less than that required to fill a trough section of the pipe, such that said water can be advanced through the pipe as the pipe flexes with an advancing wave front;

(iii) waiting while a wave front travels a wavelength such that said first initial quantity of water is advanced along the pipe by a wavelength;

(iv) allowing a further initial quantity of water into the first inlet of the pipe, said quantity being less than that required to fill a trough section of the pipe;

(v) waiting while a wave front travels a wavelength such that the water within the pipe is advanced along the pipe and supplying a further initial quantity of water into the first inlet of the pipe in the same manner as step (iv);

(vi) optionally repeating step (v) one or more times; and

(vii) employing water which has travelled along the pipe in an application which requires the use of water having kinetic energy.

3. Apparatus for extracting energy from waves, said apparatus comprising a flexible pipe adapted to carry water and adapted to float on a body of water and to flex as waves travel through the body of water, said apparatus being arrangeable in use such that said waves travel substantially in the direction in which at least an initial part of the pipe extends, wherein said apparatus further comprises a supply means for supplying water into a first inlet of the pipe and a collection means for recovering water from the pipe, wherein said collection means is arrangeable to supply water for employment in an application which requires the use of water having kinetic energy.

4. Apparatus as claimed in claim 3, adapted such that, in use, the flexible pipe turns across the direction of travel.

5. Apparatus as claimed in claim 3, comprising control means such that water can be supplied to the pipe and specific times.

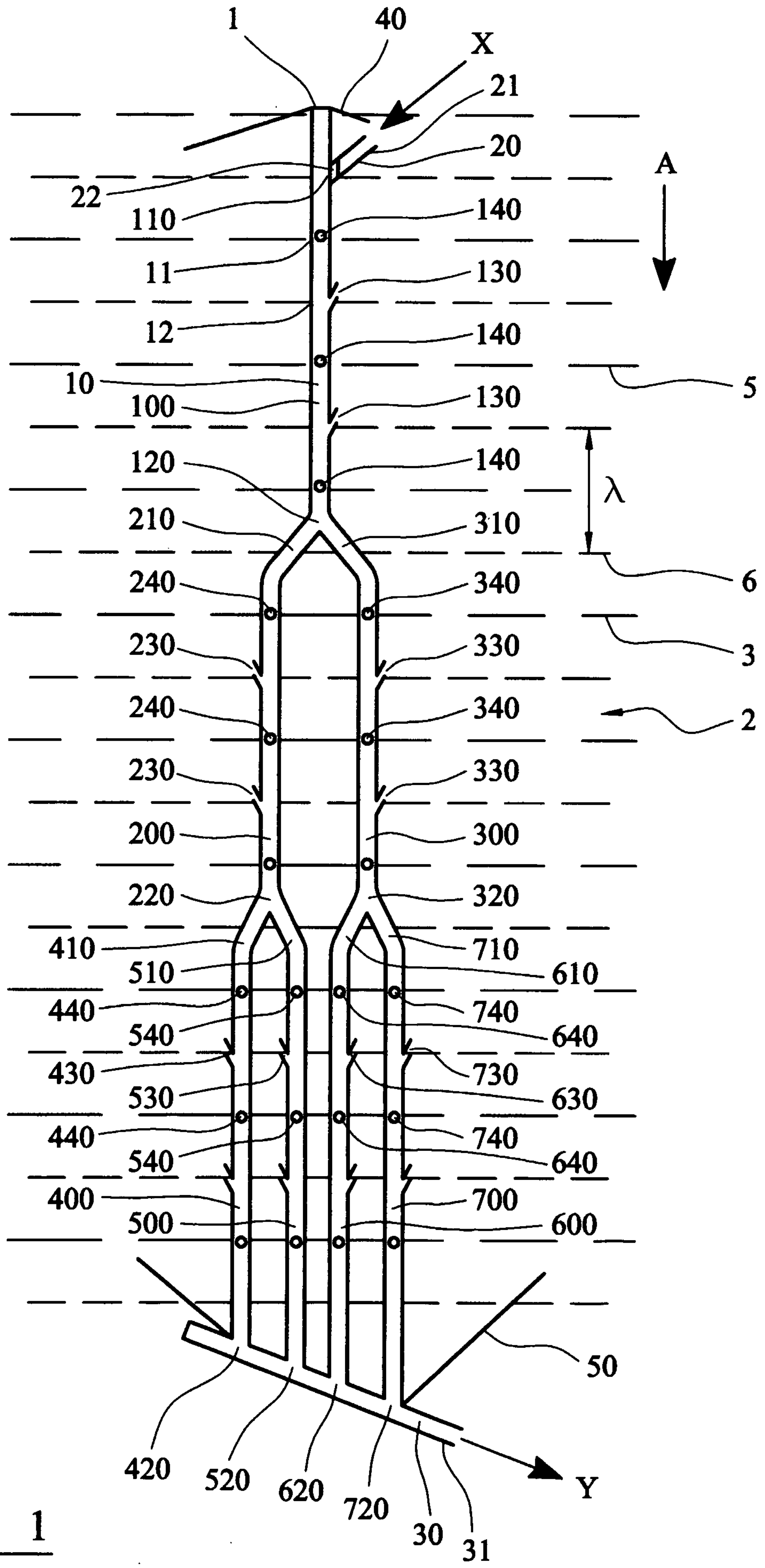
6. Apparatus as claimed in claim 5, in which means is arranged such that water is only allowed into the pipe at time intervals separated by the time taken for a wave front to travel an integer number of wavelengths, preferably one wavelength.

7. Apparatus as claimed in any one of claims 3 to 6, in which the collection means comprises a collection pipe.

8. Apparatus as claimed in any one of claims 3 to 7, comprising a flexible pipe comprising a web of pipe portions with a first pipe portion connected at its outlet to an inlet of at least a second and third pipe portion such that it branches out.

9. Apparatus as claimed in any one of claims 3 to 8, comprising a computer arranged to control valve operation of the apparatus such that it adjusts the ratio of the volume of water and air in a pipe section of a pipe portion as close as possible to 1:1 before the water is split into further pipe portions or recovered by collection means.

10. Apparatus as claimed in any one of claims 3 of 9, comprising anchoring means arranged to fix the pipe in position such that it may flex and move up and down but substantially not move in any other way.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Y

FIG. 1

FIG. 2a

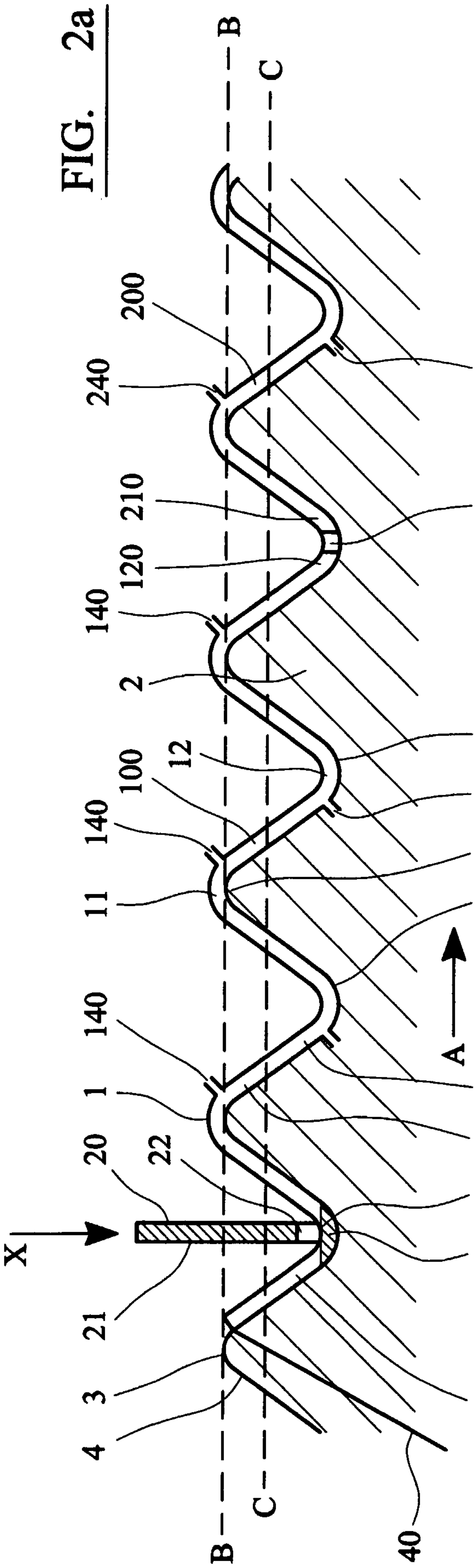
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FIG. 2b

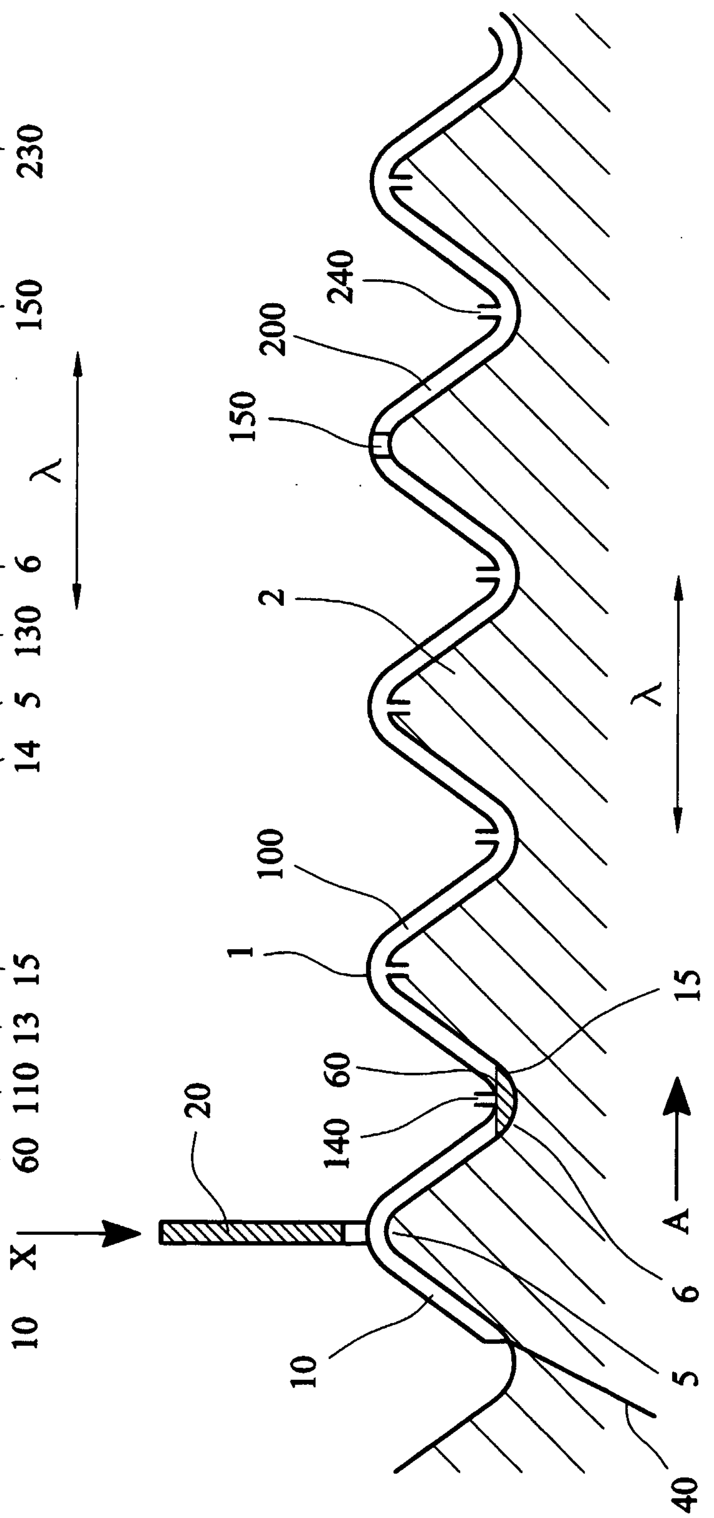
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FIG. 2c

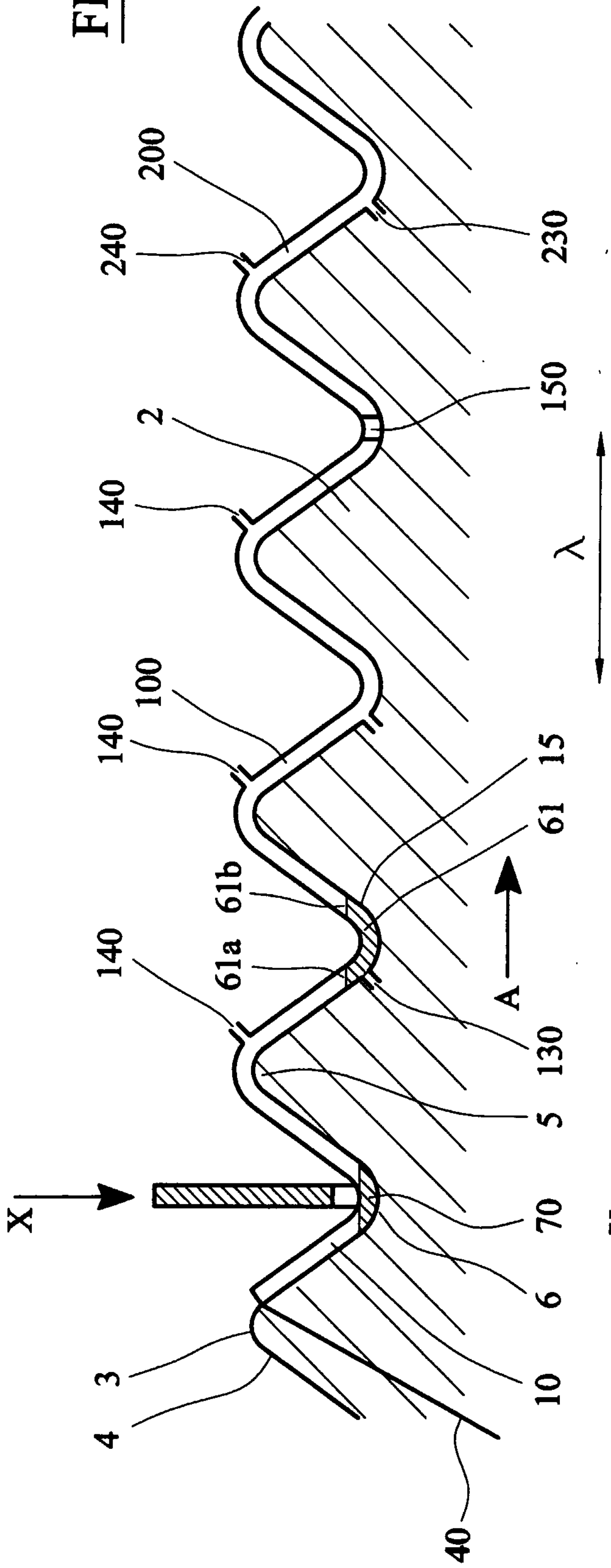
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FIG. 2d

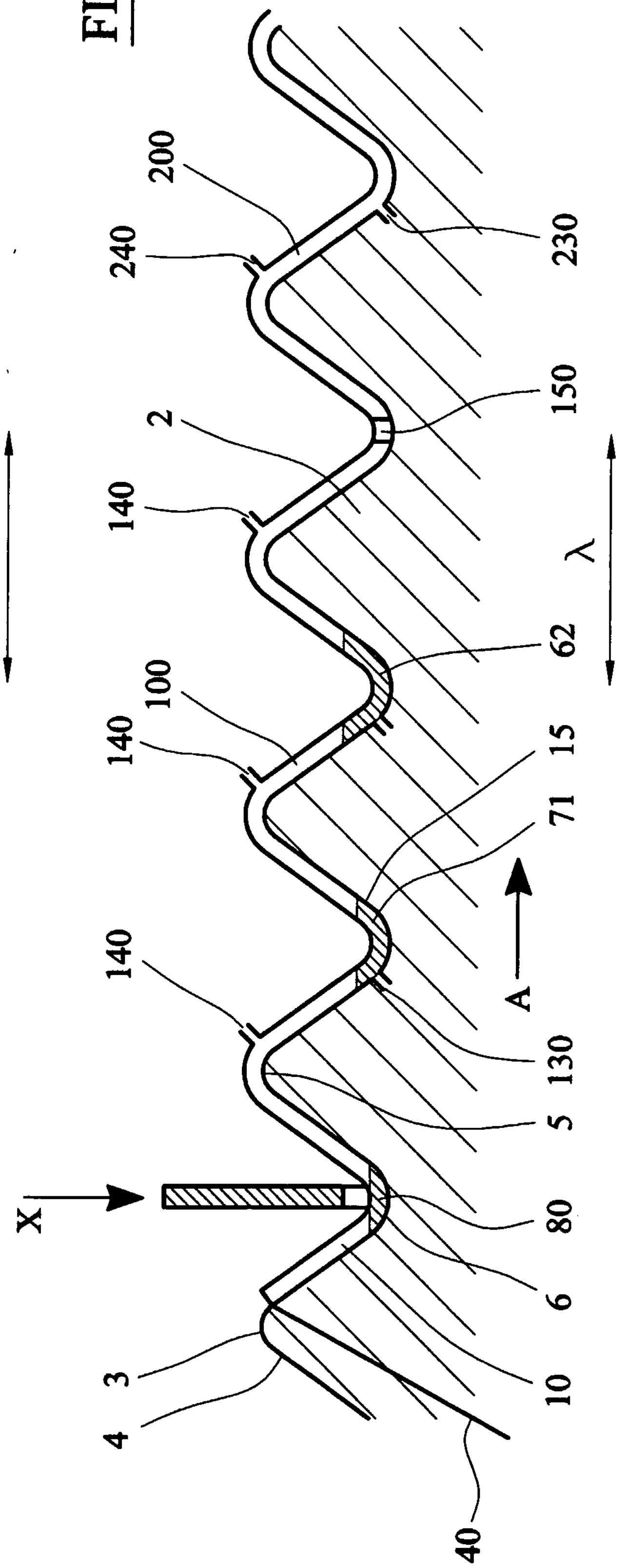
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FIG. 2e

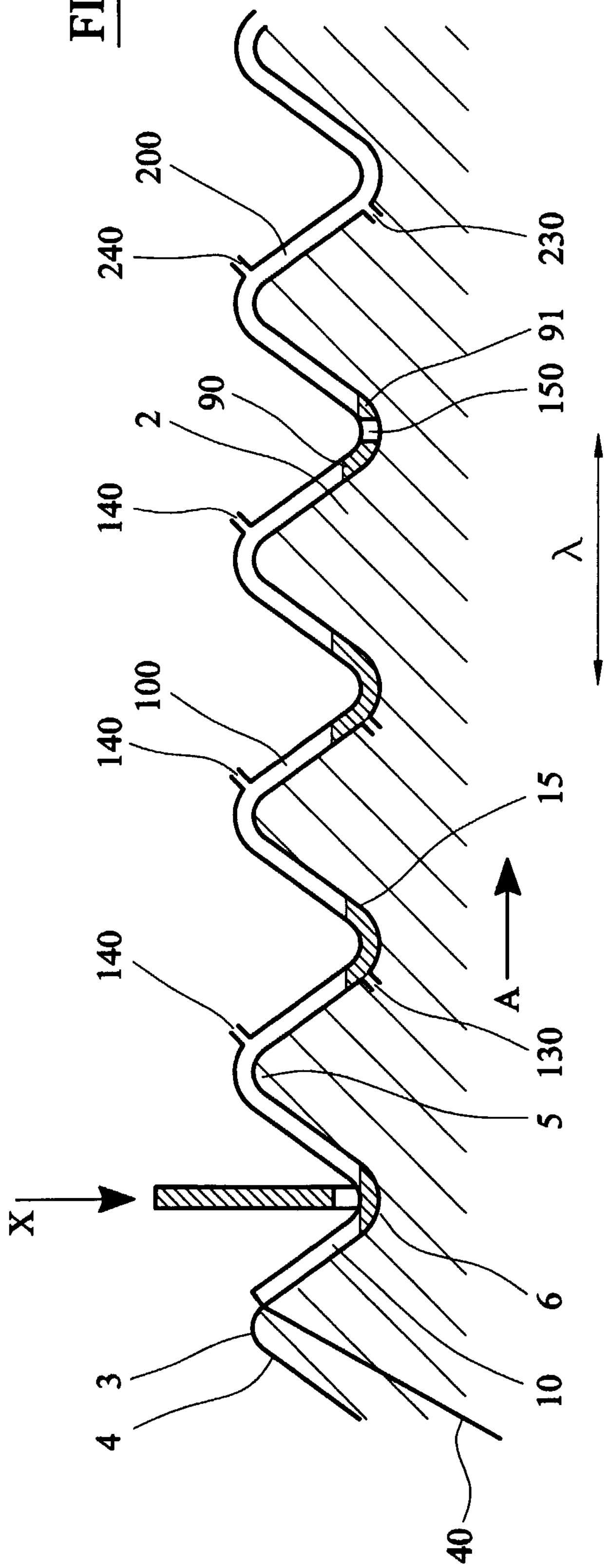

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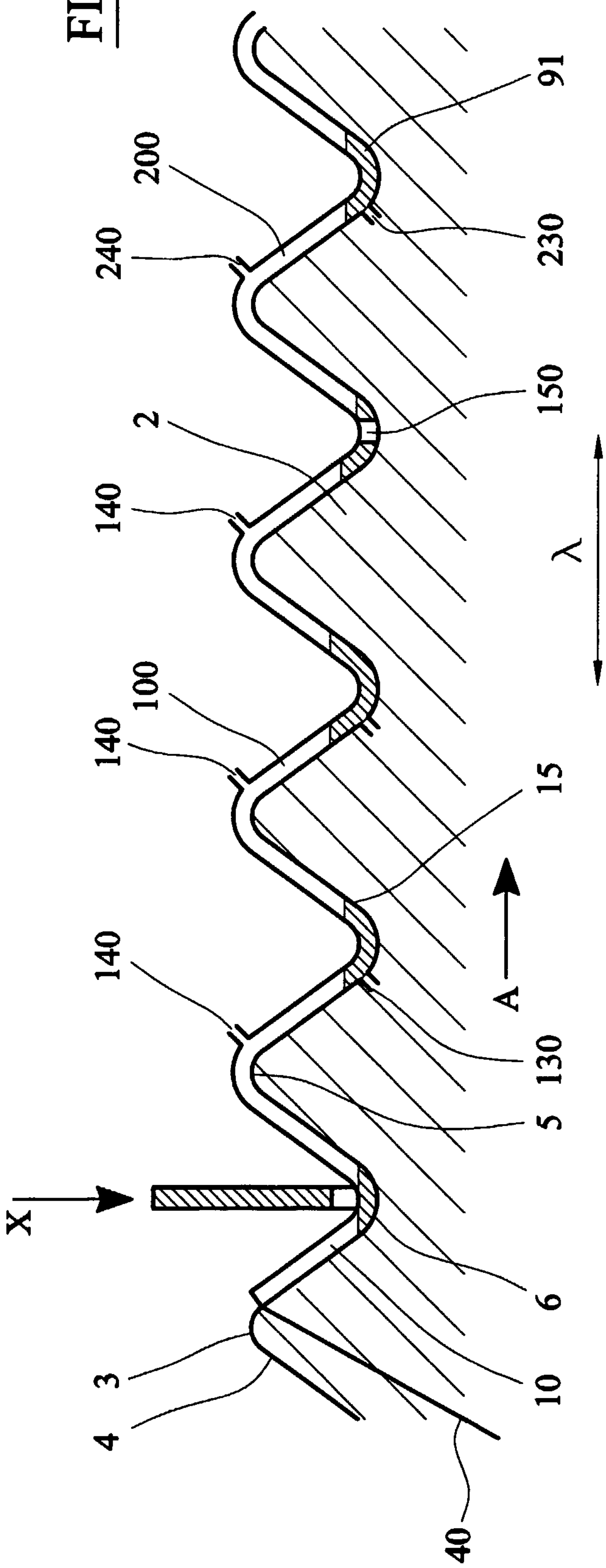
FIG. 2f



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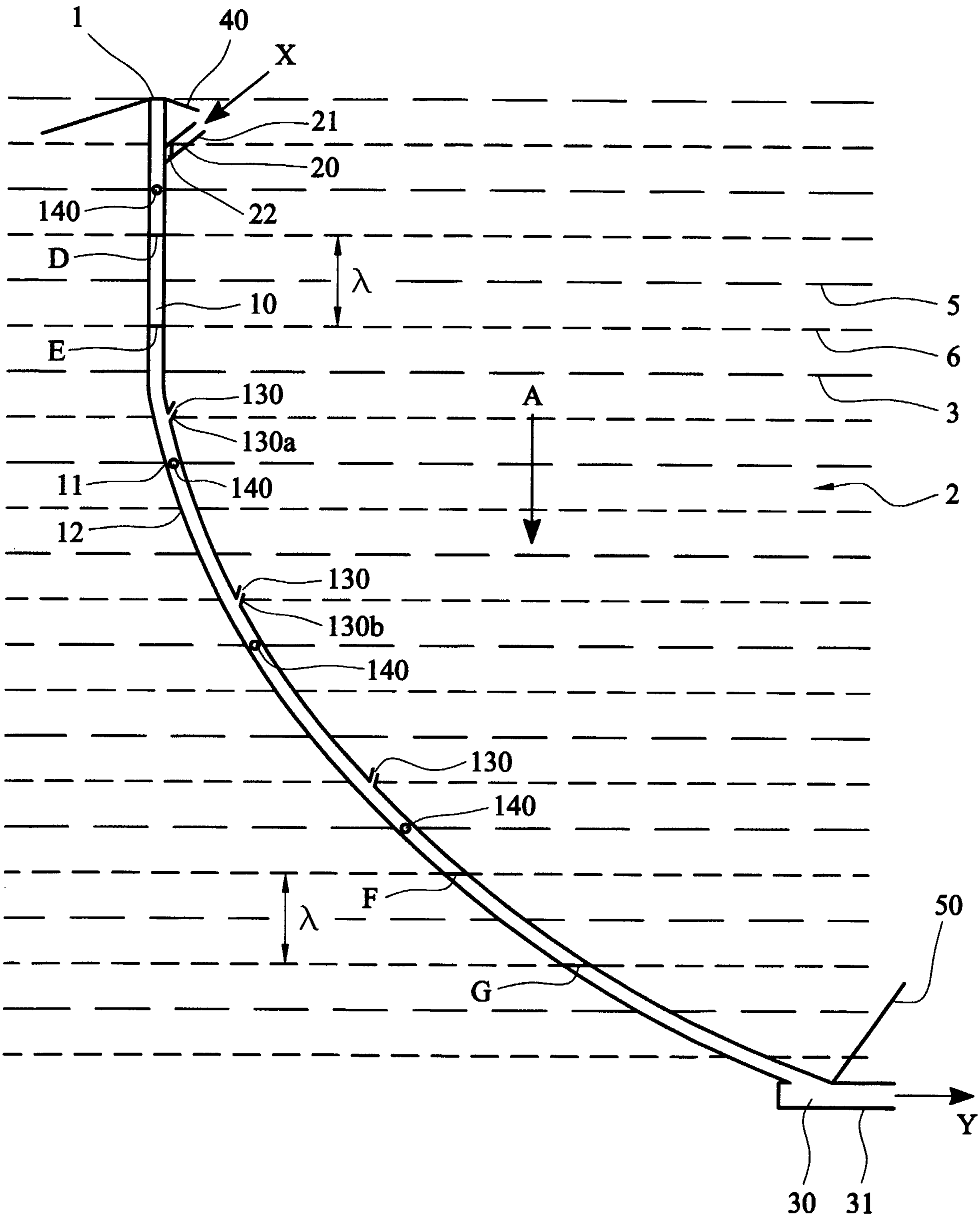
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FIG. 3

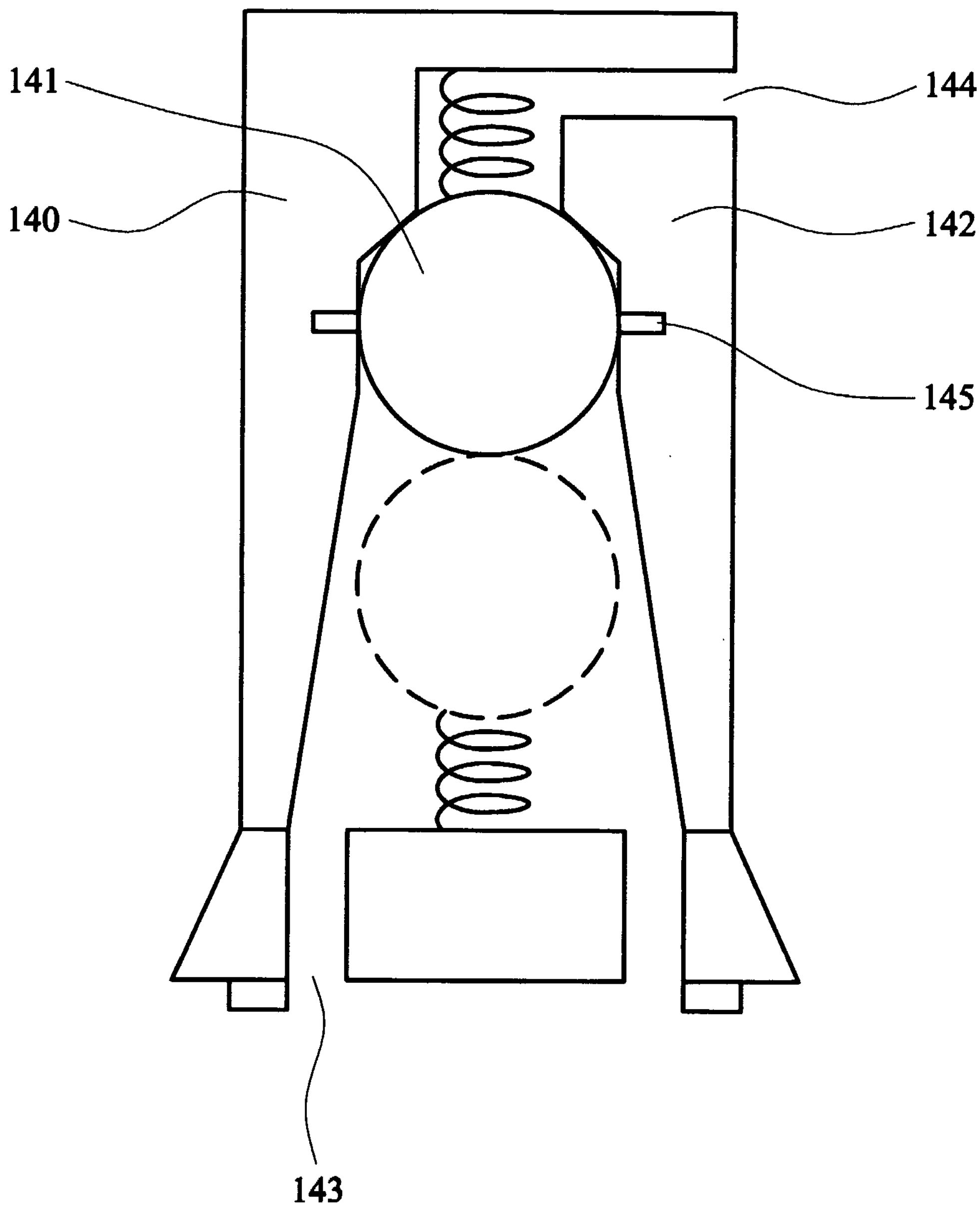

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2005/004948

A. CLASSIFICATION OF SUBJECT MATTER
F03B13/18 F03B13/22

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)
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)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DATABASE WPI Section PQ, Week 198526 Derwent Publications Ltd., London, GB; Class Q55, AN 1985-158007 XP002372600 -& SU 1 129 407 A (KIEV POLY) 15 December 1984 (1984-12-15) abstract; figure & SU 1 129 407 A1 (KI POLT I IM.50-LETIYA VELIKOJ SOTSIALISTICHESKOJ REVOLYUTSII) 15 December 1984 (1984-12-15) -----	1-3,5-7, 10
X	US 3 335 667 A (MURPHY JAMES) 15 August 1967 (1967-08-15) figures -----	1-3,5-7, 10

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search: 16 March 2006

Date of mailing of the international search report: 27/03/2006

Name and mailing address of the ISA/
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NL – 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer
Angelucci, S

INTERNATIONAL SEARCH REPORT

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 84/00583 A (HERTZ, KRISTIAN, DAHL) 16 February 1984 (1984-02-16) figures	1-3,7
X	GB 1 579 929 A (BRITISH PETROLEUM CO LTD) 26 November 1980 (1980-11-26) page 1, line 78 - line 81 page 1, line 90 - line 92 figures 4,6	1,3,7

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2005/004948

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SU 1129407	A1	15-12-1984	NONE			
US 3335667	A	15-08-1967	NONE			
WO 8400583	A	16-02-1984	AU	1824983	A	23-02-1984
			DK	347582	A	04-02-1984
			EP	0115511	A1	15-08-1984
			GB	2133477	A	25-07-1984
			JP	59501374	T	02-08-1984
			NL	8320232	A	02-07-1984
			NO	841311	A	03-04-1984
GB 1579929	A	26-11-1980	NONE			