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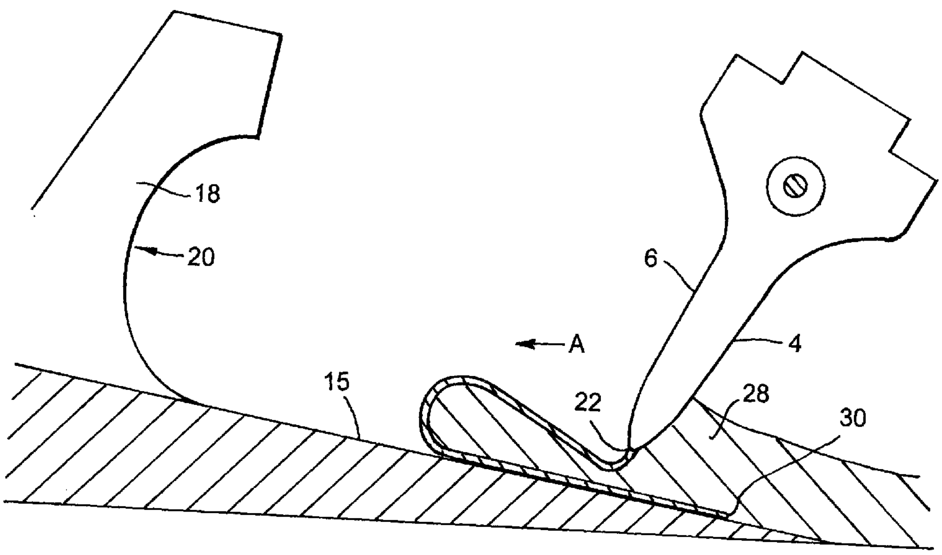

(57) Abstract: A water wave driven device (1) suitable for use in extracting energy from waves. The device comprises a paddle (2) pivotally mounted (10) for cyclic movement about a neutral position between a first, forwardly displaced, position and a second, rearwardly displaced, position under the influence of wave action acting onforwardly and rearwardly directed wave engagement faces (4, 6). A wave reflector (18) is mounted opposite the rearwardly directed face (6) of the paddle (2) for reflecting an incident water wave (28) which has passed the paddle (2), back onto the rearwardly directly wave engagement face (6). The paddle (2) is provided with a flexible skirt (24) depending therefrom so that at least a distal edge (30) is maintained in contact with the bottom (15) of a water wave passage (16) extending under the paddle (2) as it moves between its first and second positions, whereby the flexible skirt (24) harnesses energy from that part of the wave (28, 32) passing below the paddle (2) to exert additional displacement force on the paddle (2).

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WAVE POWERED ENERGY CONVERTER

The present invention relates to a water wave powered device for driving an energy-generating device.

Energy production, particularly electricity production is increasingly undergoing closer scrutiny by today's environmentally conscious consumers. This is particularly the case where nuclear fuels and petrochemical fuels are used to generate electricity.

The use of nuclear fuels is deemed by many to be too dangerous as the by-products of the nuclear processes are generally extremely toxic in addition to being highly radioactive with isotope half-lives of many thousands of years in some cases.

Petrochemical fuels such oil are not a renewable resource and supplies of such fuels are expected to expire in the not too distant future. Additionally, the use i.e. by combustion, of these fuels produces several undesirable effects such as atmospheric pollution and is believed to contribute to the global warming phenomenon.

Many efforts have been made to utilise renewable energy resources such as wind power, solar energy and wave power.

Various types of wave powered devices have been proposed for use in driving energy generating means. One type of known device utilised a float means attached to a pump (hydraulic or pneumatic), wherein, in use, the float rises and falls as waves pass underneath and the rising and falling action of the float drives the pump of the power generating means. Such devices generally require to be located far from the shore and could not be used within the inter-tidal zone of a sea/ocean or other bodies of water where the water level may vary substantially over time. Such remote location makes these devices difficult to maintain and access. Additionally, the devices must be anchored to the seabed and as such may become vulnerable during adverse weather conditions such as during storms and high winds.

Another type of device is a reciprocating paddle type device (as disclosed in US 4 580 400 Watabe et al), where an incident wave strikes and moves a pivotally mounted paddle rearwardly. The paddle or the pivot are attached to and drives a power generating means. Devices of this type have found to be generally quite inefficient as much of the potential energy stored in an incident wave is not passed on to the paddle as it impinges thereon.

It is an object of the present invention to minimise and/or obviate one or more of the abovementioned disadvantages of the devices of the prior art.

The present invention provides a water wave driven device suitable for use in extracting energy from waves, for example for driving a power generating means, which device comprises:
- a paddle pivotally mounted for cyclic movement about a neutral position between a first, forwardly displaced, position and a second, rearwardly displaced, position under the influence of wave action acting on forwardly and rearwardly directed wave engagement faces provided on said paddle;
- a wave reflector mounted opposite the rearwardly directed face of the paddle in proximity to but spaced apart therefrom for reflecting an incident water wave which has passed the paddle, back onto said rearwardly directly wave engagement face;

- characterised in that: the paddle is provided with a flexible skirt depending therefrom with an extended depth so that at least a distal edge portion thereof is maintained substantially in contact with the bottom of a water wave passage extending under the paddle as the paddle moves between said first and second positions, whereby the flexible skirt harnesses energy from that part of the wave passing below the paddle to exert additional displacement force on the paddle as a said incident wave or reflected incident wave passes the paddle.

The neutral position may be defined as a point mid-way between the first and second positions. The neutral point may also be referred to as top dead centre (TDC).

The device of the present invention is suitable for use with various water wave sources including tidal seas, lochs/lakes and reservoirs, etc. where waves are present. The device can be adapted to operate fixed to, for example, a breakwater, any shoreline or afloat, for example, on a pontoon, a floating type of arrangement being preferred in areas of greater tidal range, for example a tidal range which normally exceeds 300 mm. Such floating devices are generally located "very near shore", for example, within 100 metres, in order to *inter alia* facilitate transfer of extracted energy on-shore and benefit from increased wave height. The energy extraction capability of the device may be used not only for power generation purposes but also (or instead of) to aid the prevention of coastal erosion (with the additional benefit of driving power generation means); for sea calming, for example, around a harbour entrance; or for protecting HEP dams. Thus, for example, the reflector could form part of a coastal sea-wall, and be constructed from a durable material(s) such as concrete or reinforced concrete, whereby the provision of a number of devices according to the present invention along the extent of a said sea-wall thereby reduces and/or eliminates destructive wave-action thereon. The device may moreover also be used with artificially induced "waves", for example, in the form of periodic releases of water from a reservoir directed at the device, or other pulsed flow water supply arrangements.

The first and second positions may generally each be between 5° and 60° relative to the vertical. Preferably the first and second positions are at from 10° to 55°, and most preferably at from 15° to 50°, to the vertical. Desirably the first and second positions are at from 30° to 50°. In particular, 45° has been found to be particularly preferred. Stop means may be provided on the device of the present invention which are formed and arranged to restrict the degree of rotation to the abovementioned angle ranges of the first and second positions. It will of course be appreciated that the stop means are used essentially for defining displacement limit positions, the deceleration or "stopping" of the paddle being essentially effected by the kinetic energy extraction means driven by the paddle in use thereof as further discussed hereinbelow.

The forwardly and rearwardly directed wave engagement faces may be either substantially planar or curved to receive a said incident or reflected wave thereon. Preferably the wave engagement faces are of a generally concave configuration. The degree of curvature of the forwardly and rearwardly directed wave engagement faces need not be the same for each said wave engagement face. Additionally, each said wave engagement face may comprise a combination of curved and substantially planar portions to maximise the transfer of momentum from a water wave impinging thereon in use of the device of the present invention.

The reflector may be a wall or other generally upright, for example, substantially vertical structure which is formed and arranged to reflect an incoming incident wave onto said rearwardly facing wave engagement face of the paddle. Preferably the reflector has a curved profile to facilitate redirection of a said incident wave with a minimum of loss in momentum of said incident wave. Desirably the reflector means is concave and/or parabolic in section.

The flexible skirt depends from the paddle substantially below the forwardly and rearwardly directed wave engagement faces thereof.

The paddle generally has a width of at least 50cm, preferably from 50cm to 5 metres, more preferably from 1 metre to 3.5 metres and most preferably from 1.5 metres to 3.5 metres.

The paddle typically has a length (or height) of at least 20cm, preferably from 20cm to 4.5 metres, more preferably from 50cm to 1.5 metres and most preferably from 1 metre to 3.5 metres, although other sizes may be used depending on the average wave heights in the area.

The extended depth (or length) of the skirt is in part dependent upon the distance between the bottom of the wave passage means and the lower-most edge of the paddle from which the skirt depends. The lower-most edge of the paddle when in the neutral position may be more or less adjacent and extend parallel to the bottom of the wave passage means, or it may be vertically displaced therefrom by up to about 1.5 metres or more depending on *inter alia* the size of the paddle in use of the device.

Additionally, the angle of rotation of the paddle from the neutral position between the first and second positions has a direct bearing on the length of the flexile skirt. Where there is a small angle of rotation e.g. 5° then the length of the skirt does not require to be as great as that for a greater angle of rotation e.g. 45°, at a given distance between the lowermost edge of the paddle and the bottom of the wave passage means, in order to ensure that the bottom edge of the skirt maintains contact with the bottom of the wave passage substantially throughout the whole range of movement of the paddle, in the case of a substantially horizontally extending passage bottom, or other configuration, for example, inclined, or arcuate section, which has increasing separation from the paddle pivotal axis away from the neutral position thereof.

As previously stated, the distal edge portion of the flexible skirt should generally be maintained in contact with the bottom of the water wave passage means as the paddle moves between the first and second positions, whereby there will be defined a minimum length. Desirably, the skirt has an extended depth or length of from 1 to 4 times the minimum length, preferably from 1 to 2.5 times the minimum length and most preferably from 1.5 to 2 times the minimum length thereof.

The water wave passage means is generally 'U'-shaped and is defined by two laterally spaced apart and opposed walls and a bottom wall. The paddle is pivotally mounted to extend across the width of the wave passage means and between said opposed walls, being a substantially close fit therebetween to minimise leakage therearound.

The flexible skirt is generally formed from a durable flexible material designed to withstand more or less continual movement without material fatigue, in addition to use in adverse weather conditions (e.g. storms, high winds, direct sunlight, freezing winter conditions, etc.) and hostile environments (e.g. sea water). Suitable materials would include plastics materials such as polymers, co-polymers, etc. which may be derived from natural and/or synthetic sources, which may be strengthened by the incorporation of reinforcing materials, typically in the form of a carrier mesh or fabric of a suitable material, for example, cotton or a carbon fibre material such as Kevlar ™. Suitable materials include rubber, especially a synthetic rubber such as Neoprene (Polychloroprene). It will be appreciated that the effective density of the skirt will depend on the materials and form of construction used therein. In general it is preferred that the skirt will have slightly negative buoyancy in sea water (for coastal applications), for example, a relative density of at least 1.1.

Desirably the flexible skirt is sufficiently stiff to resist a wave as it impinges thereagainst to push the skirt rearwardly (when the paddle is in the first position) and thereby impart at least a portion of its momentum to the skirt, but flexible enough to allow the wave to evert at least the ground engaging portion the skirt under the paddle means and through towards the reflector of the device.

The flexible skirt may be formed and arranged to exhibit a graduated flexibility wherein, for example, the flexible skirt becomes increasingly flexible towards the distal end of the flexible skirt, for example, by means of the skirt having a progressively reducing thickness.

The flexible skirt may be rigidly attached to the paddle. Preferably at least a proximal portion of the flexible skirt adjacent the paddle is directed substantially vertically downward from the paddle when in the neutral position. Alternatively, the flexible skirt may be non-rigidly attached to the paddle. Preferably the flexible skirt is connected pivotally to the bottom edge of the paddle.

The flexible skirt may be formed as a single panel, or could be segmented i.e. made up of a plurality panel portions or strips flexibly or pivotally linked to one another. Each of the individual panel portions may be more or less rigid or flexible, with similar or different flexibility relative to that of an adjoining panel.

The use of the term "flexible" is intended to refer to the flexibility of the skirt as a whole, and is not necessarily to be restricted to referring to a property of a material from which the skirt is fabricated. For example, the skirt may be fabricated from a flexible i.e. non-rigid, rubber-like material which thereby imparts the desire flexibility to the skirt. In another aspect the skirt may be fabricated from a series of flexibly linked panels, where each panel is made from a rigid i.e. non-flexible material, but, the flexible linking (e.g. by hinges or pivots, etc.) imparts a desired flexibility, to the skirt. The skirt material may be resiliently deformable to some degree at least at an upper portion thereof, but it is generally desirable that at least the lower portion thereof is sufficiently flexible so that it can be readily everted and remain in close proximity to the water passage base throughout the paddle movement cycle.

In a preferred form of the device of the present invention, the device is provided with an over-centre toggle assist or snap through action mechanism formed and arranged so that the neutral position of the paddle is metastable and as the paddle is displaced away from the neutral position to either side thereof it is subjected to a biasing force towards the respective one of said first and second positions. In one preferred form the toggle assist mechanism comprises a mass mounted on the paddle above its pivotal axis so as to act on the paddle to bias the paddle towards said first or second positions where the paddle has moved past the neutral position under the influence of wave action thereon, wherein the mass effectively acts to raise the centre of gravity of the paddle to a point above the pivot such that when past the neutral position, the paddle will be biased towards the first or second position as appropriate, and the device is further provided with stop means to limit rotation of the paddle beyond said first and/or second positions.

Thus the mass should be sufficiently large to ensure that the centre of gravity of the "weighted" paddle is located above the pivot point thereof. The mass required to provide a useful paddle biasing or accelerating force will generally depend on the surface area of the paddle and the distance from the pivot point at which it is located. By way of example, given a distance from the paddle of typically 50cm, a suitable mass could be at least 10 kg, preferably from 10 kg to 400 kg, and most preferably from 20 kg to 500 kg. In a particularly preferred aspect, the paddle has an effective mass of about 100 kg. The ratio about the pivot may be raised to increase or decrease the lever action (movement). A ratio of 50:175 is used in DATUM MODEL (x1). This may be varied to suit prevailing wave amplitudes.

Without being bound by theory, where the paddle is moved by an incident wave from said first position to the second position, as the paddle passes through the neutral position the effective mass of the paddle accelerates downwardly under the influence of gravity. The kinetic energy produced by the paddle (and the accelerating effectiveness mass) moving downwardly may be represented by the following simple relationship:

$E_k = \frac{1}{2}(\sin \theta)mv^2$;

where θ = the angular displacement of the paddle relative to the neutral position (TDC);

m = the effective mass of the paddle moving downward; and

v = the downward velocity at angle θ.

Where the effective mass is to be taken as the difference in mass of the portion of the paddle above the pivot point relative to the mass of the portion of the (weighted) paddle (excluding the mass of the flexible skirt) located below the pivot point of the paddle when in the neutral position.

It will be appreciated therefore that use of a relatively large mass will increase the kinetic energy produced by movement of the paddle means through the neutral position to the first or second position, however in use of the device the mass should generally not be so large as to compromise the working or mechanical stability of the device. It will also be appreciated that, in general, with larger paddle sizes having larger blade areas and weight, a larger effective mass will be required.

Advantageously there is provided on the paddle a mass whose position is adjustable relative to the pivot to allow adjustment of the position of the centre of gravity and thereby the swinging period of the paddle to enable this to be substantially matched to that of various incoming incident wave frequencies. The matching of the swinging period of the paddle to the incident wave frequency has the advantage of providing a more efficient transfer of momentum from the wave to the paddle in use of the device of the present invention.

In general the amount of the mass used will be proportional to the surface area of the paddle. In locations where the incident waves tend to be relatively large, then a larger mass and paddle can be used than if the waves are relatively small.

Various other forms of over-centre toggle assist mechanism are well known in the art, such as, for example, resilient biasing means formed and arranged for biasing the paddle towards said first and second positions. Such mechanisms are also intended to be encompassed within the scope of the present invention.

The device may be provided with wave channelling means formed and arranged to direct an incoming incident wave onto the paddle in use of the device of the present invention.

The wave channelling means preferably takes the form of two laterally spaced apart opposed substantially upright wall means which extend substantially longitudinally and forwardly of the device, wherein said walls are formed and arranged to direct an incoming incident wave therebetween and onto the paddle. Conveniently the channelling means could be in the form of a standard freight container in which the device is mounted, the end doors facing the direction from which the waves are coming being held open or removed. Such an arrangement has the practical advantage of facilitating transportation of the device to an installation site.

Desirably the proximal ends of the walls of the wave channelling means, which are adjacent the paddle, are disposed closer together than the distal ends of the walls, wherein the wave channelling means substantially describe a 'V'-shape when viewed in plan. This configuration of the wave channelling means serves to generally increase the amplitude and mass of water contained in a said incident wave as a result of a so-called 'funnel effect'.

The funnel-effect is created where the width of an incident wave spanning the width of the relatively widely spaced apart distal ends of the walls of the wave channelling means is decreased progressively as the incident wave travels between the walls wherein there is a concomitant increase in the height (amplitude) of the incident wave. Subsequently, when the incident wave impinges upon the paddle, the wave contains a greater mass of water than it would normally have contained if the incident wave did not pass between the walls of the wave channelling means. As a result of the greater mass of water contained in the incident wave when it reaches the paddle means it has the potential to impart a greater momentum to the paddle.

The walls generally would have a length of at least 10 metres, preferably from 10 metres to 40 metres, more preferably from 10 metres to 20 metres.

The walls desirably are formed and arranged to have a vertical height which is not substantially greater than the pivot of the paddle means. Where for example an incident wave has an amplitude substantially greater than the height of the pivot of device, then movement of the paddle from the first to the second position may be hindered by the wave impinging upon the paddle above the pivot and thereby acting against the desired direction rotation of the paddle from the first position to the second position.

The device may also be provided with a longitudinally extending base portion projecting outwardly generally towards a said incoming incident wave. Preferably the base portion is sloped upwardly towards the paddle from said outward direction. The base portion may be sloped at an angle of between from 2° and 15° from the horizontal, preferably from 5° and 12° and desirably is sloped at an angle of approximately 8°.

Where the device of the present invention is provided with said wave channelling means, then the base and the wall means may be combined to form a trough which is formed and arranged to direct a said incident wave onto said paddle wherein, the trough has a distal end open to said incoming incident wave and a proximal end open and adjacent to said paddle.

Preferably the wave passage base extends rearwardly of the paddle up to the reflector.

Conveniently the reflector may be formed integrally with the rearward end of the wave passage. For example the wall means, wave passage base and reflector may be formed as pre-fabricated individual units or as integrated pre-fabricated units. The pre-fabricated units may be formed from, for example, concrete or other similar materials which are durable and can withstand various adverse working and weather conditions.

In a further aspect of the present invention there is provided a power generation system comprising a water wave driven device according to the present invention drivingly connected to power generating means by a fluid pump or compressor. A fluid pump or compressor may take the form of a hydraulic fluid or oil pump, or may be a gas pump such as for example an air pump. Air compression has the advantage of easy and convenient storage of potential energy. Other advantages of using a air compression system include greater flexibility by allowing the turbine or other power generation device to be located remote from the wave driven device, for example, at a convenient on-shore location, connected to the device by an umbilical or pipeline, as well as facilitating the coupling of multiple devices together by interconnecting the compressed air pipelines therefrom via suitable manifolds etc. Depending on the length and diameter of the pipelines, these may themselves have a significant energy storage capacity by means of build up of air pressure in the pipeline until it is required to be released to drive the power generation means e.g. in order to meet a peak demand level.

It will be appreciated that it is a particular feature of wave power, as with other forms of natural renewable energy source such as wind power, that the amount of energy available is subject to constant fluctuation, even to the extent that no energy can be extracted at all because there are no waves or no wind, or because the weather conditions are too violent for safe operation of the energy extraction device. Such fluctuations can present considerable problems in the supply of electricity to the National Grid including the possibility of damage thereto, and thus severely limit the amount of electricity that can be generated in this way. Another important issue for electricity suppliers, is the considerable fluctuations in demand for electricity that occur throughout the day, and from day to day.

The use of a gas compressor as a means for initially capturing energy from a natural renewable energy source and storing it in the form of compressed gas, prior to using the compressed gas for generating electricity, provides very considerable advantages in making such energy sources much more practical. A further advantage is that

Thus in a further aspect the present invention provides an electricity generating system comprising: a natural energy driven device suitable for use in extracting energy from a natural energy source, said device being drivingly coupled to a gas compressor, said compressor being coupled via a gas container to a compressed gas-driven electricity generating turbine.

Various forms of natural energy driven device may be used including water wave driven devices of the present invention as well as various other water wave driven devices, and wind driven devices such as windmills and wind turbines, especially wind turbines which directly compress air. Various kinds of pump may be used for compressing gas including positive displacement motors when operated as pumps, gear pumps, reciprocating piston and cylinder type pumps, vane pumps, and swash plate pumps. The compressed gas thus obtained will generally be transferred to a remote turbine via a pipeline, which itself can serve as a substantial reservoir of compressed gas. Nevertheless, such a pipeline may also be connected to additional compressed gas storage in the form of one or more chambers, which may, for example, be in the form of underground chambers formed in substantially non-porous strata. Whilst the system of the invention may be used with any kind of gas, most conveniently the gas medium used is air.

With a electricity generating system of the present invention, any fluctuations in the energy available from the natural energy source and/or in the demand for electricity, may be readily accommodated or buffered by the compressed gas stored in the system between the gas compressor and the electricity generating turbine, in a particularly simple and convenient manner.

The use of multiple interconnected devices can be particularly advantageous in power stations in tidal locations, as this allows a series of devices to be positioned over a range of different levels relative to mean sea level or lowest astronomical tide level (LAT), so that whilst at low tide higher positioned devices may be inactive because they are out of the water and at high tide lower positioned devices may be largely ineffective because they are substantially completely submerged, there should at all tide levels be at least some devices which are still active. Of course where the devices are mounted on a floating pontoon or the like (as further described hereinbelow), the devices may be mounted at a suitable level which will be automatically maintained as the pontoon rises and falls with the tide. Conveniently also a range of different sizes of devices may be used together whereby different ones of these may operate at maximal efficiency under different wave height conditions.

Further preferred features and advantages of the present invention will appear from the following detailed description given by way of some preferred embodiments illustrated with reference to the accompanying drawings in which:

Fig. 1 is a front view of a schematic representation of the device according to one embodiment of the present application;
Fig. 2 is a plan view of the device of Fig. 1'
Figs. 3A to 3F show a sequence of movements of the paddle of the device as it moves between first and second positions thereof;

Fig. 4 is a schematic plan view of a power generating system of the invention including a further embodiment of the device of the present invention;

Fig. 5 is a schematic drawing of a reciprocating air pump and electricity generator driven by a device according to the present invention; and

Fig. 6 is a side elevation of a floating pontoon mounted device.

Fig. 1 shows a water wave driven device according to one embodiment of the present invention which is generally indicated by the reference numeral 1, wherein the device 1 is shown in a neutral position. The device 1 has a paddle 2 having a more or less planar forwardly directed engagement face 4 and a rearwardly directed engagement face 6 (see Figs. 3A-F).

The paddle 2 is mounted on a pivot 10 extending therethrough. The pivot 10 is journalled between left 12 and right 14 vertically extending walls which are mutually opposed and extend horizontally and are arranged parallel to one another. The walls 12, 14 and a base 15 extending therebetween below the paddle 2 define a channel 16 for the passage of water (see Fig. 2). The paddle 2 extends horizontally across the entire width of the channel 16 at right angles to the left and right walls 12,14.

A reflector wall 18 is located rearwardly of and faces towards the rearwardly directed engagement face 6 of the paddle 2. The reflector wall 18 has a forwardly directed concave 'C'-shaped reflecting surface 20 when viewed in side section (see Figs. 3B to E).

The paddle 2 has a lowermost edge 22 extending across the width thereof. A flexible skirt 24 is attached to and extends downwardly from the lowermost edge 22.

The skirt 24 has a length greater than the distance between the lowermost edge 22 of the paddle 2 and base 15 of the channel 16, such that most of the length of the skirt 24 extends forwardly of the paddle 2 and lies on top of the base 15.

Figs. 3A to F illustrate the movement of the paddle 2 of the device 1 in use thereof, wherein the paddle (blade) 2 in Fig. 3A is shown rotated forwardly from its neutral position, about the pivot 10, to a first, forwardly displaced position by a rear counterweight portion 26a located above and substantially rearwardly of the pivot 10. The lowermost edge 22 is shown directed substantially forwardly of the device 1 and the skirt 24 extends forwardly along the base 15 towards an incoming incident wave 28 travelling in the direction indicated by arrow A i.e. towards the forwardly directed engagement face 4 of the paddle 2.

The incident wave 28 travels over the flexible skirt 24 and impinges upon a lower portion of the forwardly directed wave engagement face 4, transferring at least some of the momentum of the incident wave 28 to the lower portion of the paddle 2 which subsequently rotates rearwardly about the pivot 10. As shown in Fig. 3B, as the paddle 2 rotates from the first position, the flexible skirt 24 is also pushed rearwardly by the wave 28 so that a proximal portion 30 thereof, located adjacent the lowermost edge 22 of the paddle 2 passes there-under thereby drawing the distal end 30 (see Fig. 3C) rearwardly thereafter.

As the lowermost edge 22 of the paddle rotates rearwardly, the paddle 2 passes through a neutral position where the paddle 2 is neither biased forwardly or rearwardly, towards a second position wherein the paddle 2 is biased by a forward counterweight portion 26b located above and forwardly of the pivot and biases the paddle 2 so that the lowermost edge 22 is directed rearwardly of the device 2 towards the reflector wall 18.

As shown in Fig. 3D, as the paddle 2 moves under the influence of both the wave 28 and the biasing effect of the forward counterweight portion 26b to the second, rearwardly displaced, position, the lowermost edge 22 is raised relative to the base 15, and the incident wave 28 continues to push the skirt 24 rearwardly until skirt 24 everts and the distal portion 30 thereof extends towards horizontally towards the reflector wall 18.

The incident wave 28 thereafter passes underneath the flexible skirt 24 and exits at the distal end 30 thereof and travels upwardly along the forwardly directed concave reflecting surface 20 of the reflector wall 18. The direction of travel of the wave is reversed as indicated by arrow B as a result of the wave being directed forwardly by the reflecting surface 20 so that the wave is now a reflected wave 32. The reflected wave 32 is directed forwardly by the reflecting surface 20 and the base 15 which is sloped forwardly at an angle of approximately 8° onto the rearwardly directed wave engagement face 6. The forwardly moving reflected wave 32 imparts at least portion of it momentum to the lowermost edge 22 of the paddle 2 and to the rearwardly directed wave engagement face 6 to rotate the paddle 2 back towards the first position. The reflected wave 32 acts to push the proximal end of the skirt 24 forwardly of the device 1 and under the lowermost edge 22 (see Fig. 3E), wherein when the paddle 2 passes through the neutral position, the mass 26a acts under the influence of gravity to bias the paddle 2 towards the first position. The lowermost edge 22 of the paddle 2 is raised as the paddle 2 moves to the first position, the reflected wave 32 continues to act upon and push the skirt 24 forwardly thereby drawing the distal end 20 of the skirt 24 forwardly (see Fig. 3F) thereafter whereupon when the skirt 24 again everts leaving the device 1 in the (starting) position as shown in Fig. 3A.

In another embodiment of the present invention as shown in Fig. 4, there is shown optional wave channelling walls 34a,b positioned for directing and funnelling an incident wave 28 towards the device 1. Each wave channelling wall 34a,b has a distal end 26a,b and a proximal end 38a,b, wherein the distal ends 26a,b are remotely located from the device 1 and the proximal ends 26a,b are located adjacent the device 1 and adjoin upright walls 14 and 12 respectively. The distance between the distal ends 36a and 36b is greater than that between the proximal ends 38a and 38b so that when viewed from above, the wave channelling walls 24a and b have a 'V'-shaped configuration, though this is of course not essential. The wave channelling walls 34a and b extend horizontally and forwardly of the device 1 and have a vertical height (not indicated) at substantially the same height as the pivot 10 of the device 1.

The pivot 10 extends beyond the left wall 12 and is arranged to drive a fluid pump 40 for providing pressurised fluid. The fluid pump 40 can be for example an oil or other non-compressible fluid pump, or preferably is a compressed gas, conveniently air, pump.

The fluid pump 40 may be drivenly connected 42 directly to an electricity generator 44 for generating electricity. In practice, though, there would normally be used a series of units 45a, b, c …, each comprising a wave powered device 1 with a fluid pump 40 drivenly connected thereto, connected 47 in parallel to a compressed air umbilical 49 connected to a remote power generating station 44. The individual units may be of different sizes to provide optimum power generation for different wave heights, and may be positioned at different levels relative to mean sea level in order to maintain power generation through a range of tidal conditions. The units 45 a, b, c … may be disposed simply along a length of shore line 51 as shown in Fig. 4 or may be mounted on floating pontoons so that the paddle is supported at an optimum level under a wide range of different tidal conditions (see Fig. 6). The units may also be arranged to face in different directions to help reduce power generation output fluctuations resulting from changes in the direction from which the waves are coming. By way of example the units could be distributed along a datum line in the form of a parabola with which they are aligned.

Fig. 5 shows a preferred form of compressed air pump 46 drivenly connected to the pivot 10 of a device 1. The pump 46 comprises two vertical cylinders 48a,b each provided with a piston 50a,b. The pistons 50a,b are pivotally 52 connected to a rocker arm 54 fixedly connected to the pivot 10 such that when the paddle 2 (not shown) moves between the first and second positions the rocker arm 54 rotates back and forth thereby raising and lowering each of the pistons 50a,b within the cylinders 48a,b respectively, and thereby compressing and pumping air through non-return valves 56a,b to a compressed air storage vessel 58 in fluid communication with each said cylinders 48a,b via tubing 60a,b. The compressed air contained within the storage vessel 58 may be used to drive a turbine driven electricity generator as indicated schematically by numeral 62.

Fig. 6 shows the principal parts of another embodiment of the device 1 mounted on a pontoon 70 so as to lie in the water at a suitable level as indicated in Fig. 6 such that the bottom edge 22 of the paddle 2 is at about sea level 71. As shown in Fig. 6 the pontoon is slidably mounted 72 on vertical piles 73 driven into the seabed 74 so that the pontoon 70 and device 1 can be maintained in a substantially horizontal attitude. If desired damper means 75 may also be provided for reducing oscillation of the pontoon due to wave action. Other forms of pontoon anchoring means could nevertheless also be used if desired.

Table 1 shows a series of calculated energy outputs for various sizes of device according to the present invention scaled up from a working model (model x1) as it is driven by a wave between its first and second positions, suitable for use with different wave heights and tidal ranges.

It should be noted here that the figures provided are purely for illustrative purposes. The effective mass used in the working prototype corresponding to Model x 1 was experimentally found to provide a useful degree of toggling assistance while at the same time allowing the paddle to be readily raised up over TDC by an average wave under normal or light swell conditions - in the case of the prototype Model x 1, there was used a wave height of 100 mm which readily toggled the paddle. It will of course be appreciated that in practice a wide variety of wave conditions can be encountered and even for a given wave height there may be significant variations in energy content and energy extractable due to, for example, differences in speed, shape etc. Thus the shape and geometry (including the distance of the centre of gravity from the pivot etc) of the above described paddle can be varied significantly without departing from the scope of the present invention. Thus, for example where the paddle rotates between the first and second positions (at $\pm 45^\circ$ to the neutral position) passing though said neutral position for a device having an effective mass of 100kg, the device is calculated using ($E_k = \frac{1}{2} \sin\theta$, where $\theta = 45^\circ$) to be able to produce 15.5kJ of energy per wave cycle i.e. movement from the first to the second and a return to the first position again, and assuming an incident wave frequency of 10 waves per minute, this is the equivalent of 11.2MWh.

TABLE 1 - Energy Output Calculations

Description	Model x 1	Model x 2	Model x 3	Model x 4	Model x 5	Model x 6	Model x 7	Model x 8	Model x 9	Model x 10
Effective mass @ COG & TDC in kg	1	4	9	16	25	36	49	64	81	100
Radius of mass @ COG & TDC	50	100	150	200	250	300	350	400	450	500
Radius of Blade Section	125	250	375	500	625	750	875	1000	1125	1250
Blade Ramp clearance @ perpendicular	11	22	33	44	55	66	77	88	99	110
Overall height to COG on centre line	175	350	525	700	875	1050	1225	1400	1575	1750
Blade Height	110	220	330	440	550	660	770	880	990	1100
Blade Width	160	320	480	640	800	960	1120	1280	1440	1600
Blade Area cm2	176	704	1584	2816	4400	6336	8624	11264	14256	17600
Skirt length	170	340	510	680	850	1020	1190	1360	1530	1700
Skirt width	160	320	480	640	800	960	1120	1280	1440	1600
Skirt area cm2	272	1088	2448	4352	6800	9792	13328	17408	22032	27200
Skirt thickness	0.4	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Distance to reflector	240	480	720	960	1200	1440	1680	1920	2160	2400
Wave height minimum	80	160	240	320	400	480	560	640	720	800
Wave height maximum	100	200	300	400	500	600	700	800	900	1000
Tide Max (relative to pivot)	-100	-200	-300	-400	-500	-600	-700	-800	-900	-1000
Tide Min (relative to pivot)	-175	-350	-525	-700	-875	-1050	-1225	-1400	-1575	-1750
Stop Angle (degs) from TDC	45	45	45	45	45	45	45	45	45	45
Newtons required to lift from stop	6.9	27.7	62.4	111.0	173.4	249.7	339.9	443.9	561.9	693.7
min applied blade force N/cm2	**0.0394**	**0.0394**	**0.0394**	**0.0394**	**0.0394**	**0.0394**	**0.0394**	**0.0394**	**0.0394**	**0.0394**
Output/stroke in kJoules (term. vel =15m/s)	0.08	0.32	0.72	1.27	1.99	2.86	3.90	5.09	6.44	7.95
Output/ double stroke in kJoules	0.14	0.57	1.29	2.29	3.58	5.15	7.02	9.16	11.60	14.32
Output/hour in MJoules (5 sec interval)	**0.10**	**0.41**	**0.93**	**1.65**	**2.58**	**3.71**	**5.05**	**6.60**	**8.35**	**10.31**

Note - all measurements in mm unless otherwise indicated

TABLE 1 - Energy Output Calculations (continuation)

Description	Model x 11	Model x 12	Model x 13	Model x 14	Model x 15	Model x 16	Model x 17	Model x 18	Model x 19	Model x 20
Effective mass @ COG & TDC in kg	121	144	169	196	225	256	289	324	361	400
Radius of mass @ COG & TDC	550	600	650	700	750	800	850	900	950	1000
Radius of Blade Section	1375	1500	1625	1750	1875	2000	2125	2250	2375	2500
Blade Ramp clearance @ perpendicular	121	132	143	154	165	176	187	198	209	220
Overall height to COG on centre line	1925	2100	2275	2450	2625	2800	2975	3150	3325	3500
Blade Height	1210	1320	1430	1540	1650	1760	1870	1980	2090	2200
Blade Width	1760	1920	2080	2240	2400	2560	2720	2880	3040	3200
Blade Area cm2	21296	25344	29744	34496	39600	45056	50864	57024	63536	70400
Skirt length	1870	2040	2210	2380	2550	2720	2890	3060	3230	3400
Skirt width	1760	1920	2080	2240	2400	2560	2720	2880	3040	3200
Skirt area cm2	32912	39168	45968	53312	61200	69632	78608	88128	98192	108800
Skirt thickness	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Distance to reflector	2640	2880	3120	3360	3600	3840	4080	4320	4560	4800
Wave height minimum	880	960	1040	1120	1200	1280	1360	1440	1520	1600
Wave height maximum	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
Tide Max	-1100	-1200	-1300	-1400	-1500	-1600	-1700	-1800	-1900	-2000
Tide Min	-1925	-2100	-2275	-2450	-2625	-2800	-2975	-3150	-3325	-3500
Stop Angle (degs) from TDC	45	45	45	45	45	45	45	45	45	45
Newtons required to lift from stop	839.3	998.9	1172.3	1359.6	1560.8	1775.8	2004.7	2247.5	2504.2	2774.7
min applied blade force N/cm2	**0.0394**	**0.0394**	**0.0394**	**0.0394**	**0.0394**	**0.0394**	**0.0394**	**0.0394**	**0.0394**	**0.0394**
Output/stroke in kJoules (term. vel =15m/s)	9.63	11.46	13.44	15.59	17.90	20.36	22.99	25.77	28.72	31.82
Output/ double stroke in kJoules	17.33	20.62	24.20	28.07	32.22	36.66	41.38	46.39	51.69	57.28
Output/hour in MJoules (5 sec interval)	**12.47**	**14.85**	**17.42**	**20.21**	**23.20**	**26.39**	**29.79**	**33.40**	**37.22**	**41.24**

A preferred form of floating device of the present invention is generally in the form of a catamaran-like vessel with an artificial beach or ramp set connecting its twin hulls below the water-line, (although multi-hull devices with up to 5 or more hulls and four or more ramps therebetween, could also be used). The ramp is set at about 8 degrees to the horizontal, approximately 12 metres long and 2 metres wide with the toe of the ramp 3 metres below the mean surface level of the water. At the head of the ramp there is a "C" or parabola section wall to reverse the direction of the wave. Approximately, 3 metres down from this concrete parabola, a 2 metre wide paddle is placed. The paddle's shaft is on mountings on the head of the two flume walls so that a clearance of 1100mm between the bottom of paddle and the ramp is maintained when the paddle is perpendicular to the ramp. The paddle is designed to balance on its shaft when horizontal before the skirt is fitted. A 2 metre wide fabric reinforced neoprene/rubber skirt extends from the tip of the paddle so that the end of the skirt lies flat on the polished concrete ramp when the paddle is lying at 45 degrees to the horizontal in its "receive position". During final fitting out, an effective mass of 400kg is attached to the top of the paddle with its centre of gravity approximately 1000mm above the shaft.

The device is deployed so that the ramp faces the prevailing waves. The twin hulls are shaped to capture a 3 metre wide wave front which is funnelled down to two metres and rushes up the ramp at, say 7m/s, and drives into the paddle and skirt combination in its first forwardly displaced position in which it faces forward at 45° to the vertical with the gap below its tip filled with the skirt.

If the effective mass of the wave is 3000kg we can say, using the conservation of linear momentum rule that:

(mw x uw) + (mp x up) = (mw x vw) + (mp x vp)

where u is the initial velocity (before) and v is the post collision velocity (after), and w and p refer to the wave and paddle respectively.

Substituting, we then get: (3000 x 7) + (400 x 0) = (3000 x 4) + (400 x vp)

vp "flip" = (21000-12000)/400 = 22.5m/s

If we assume that the wave's velocity is slowed by 3m/s as it passes under the paddle and streamed skirt the velocity of the 400kg mass (vp) will be accelerated from standstill towards 22.5m/s. However, this velocity will probably never be attained as it accelerates through just 70° or 1222mm of arc freely before it decelerates to zero through the remaining 20° or 349mm of arc. The likely maximum velocity at +70° in this example will be in the order of 20m/s. An equal and opposite force of $(400 \times 20^2)/2$ = 80kJ (ie 80kiloNewtons of Torque @ one metre radius) must be applied to stop the 400kg mass on top of the paddle as it travels through 20° to the end of its quadrant.

The opposing force is applied by compressing air in a piston - cylinder device. The cylinder has holes drilled into along its length between 0° and 70° to allow the piston to accelerate freely. Between 70° and 90° the cylinder has no holes apart from the outlet set at 90° with a non return valve fitted. Between 90° and the internal face of the stop end at 94° there are no apertures at all.

A crank 1000mm long fitted and keyed onto the main shaft has a connecting rod fitted. This in turn has a piston fitted so that it can travel freely along the guide/cylinder. In operation the piston accelerates along the shaft to a velocity of 20m/s where it starts to compress air. Air is forced through the outlet's non-return valve until the piston passes this point. With the valve closed by the piston the remaining air trapped between 90° and 94° pressurises towards infinity. When two forces equalise a "pneumatic bounce" is created and the direction of the piston's travel is reversed. In the meantime the flow of the wave has also been reversed, crashes down on the leeward side of the paddle and skirt, and the paddle accelerates back towards its first, forwardly displaced, position.

This time the equation is slightly different because the pneumatic bounce has increased the velocity from zero to, say, 1m/s. We now have:

(mw x uw) + (mp x up) = (mw x vw) + (mp x vp)

(3000 x 4) + (400 x 1) = (3000 x 2) + (400 x vp)

vp = ((12000 +400) - (6000))/400

vp "flop" = 16m/s

wherein m, u, v, w, p have the same meaning as before (except when m indicates metres).

Again, this velocity is unlikely to be reached, but a velocity in order of 14m/s is achievable on the flop stroke. An equal and opposing force of $(400 \times 14^2)/2 = 39.2$kJ is required to stop the piston on the flop stroke.

We can thus say that mechanical energy totalling 119.2kJ from both strokes was available to compress a predetermined volume of air into the system.

With a 1000mm crank the distance the piston travels between 70° and 90° is around 350mm. A piston-cylinder device with an internal diameter of 600mm will compress $0.396m^3$ of air on every flip and flop stroke. A total of $0.792m^3$ or 28 cubic feet of air per wave is forced through two separate non-return valves into a common manifold. From the manifold the air is pumped via a high-pressure hose to an on-shore umbilical pipe. This umbilical pipe can be fed with any number of devices of the invention and can be any diameter or any length and could conceivably form part of a national grid of compressed air. If, in this example, the high-pressure hose is 100 metres long with an internal diameter of 30mm and the common umbilical pipe is 1km long with an ID of 300mm, then the total storage volume available is $70.8m^3$.

The internal length from the outlet at 90° and the internal face of the stop end determines the system's maximum attainable pressure. The equivalent length at 94° gives 6 Bar, 95° gives 5 Bar 100° gives 3 Bar whereas 110° gives a maximum of just 2 Bar. Since temperature changes are negligible, these have been ignored here.

We can deduce that 90 waves are required to raise system pressure by 1 Bar. We will assume that the desired system pressure in this example is 6 Bar. With the air to the pneumatic motors regulated to 4 Bar the system has 2 Bar or 21.5 MJ available in the form of compressed air. With the motors running and drawing off 125kJ/s or 125kW, with no input at all from the wave energy extracting device, it would take seventeen hours for the system's pressure to drop to 4 Bar, this backup offers continuous supply during periods of calm weather.

Further variations and modifications of the device will be apparent to the skilled person and are intended to be encompassed in the scope of the present invention.

CLAIMS

1. A water wave driven device suitable for use in extracting energy from waves, for example for driving a power generating means, which device comprises:
- a paddle pivotally mounted for cyclic movement about a neutral position between a first, forwardly displaced, position and a second, rearwardly displaced, position under the influence of wave action acting on forwardly and rearwardly directed wave engagement faces provided on said paddle;
- a wave reflector mounted opposite the rearwardly directed face of the paddle in proximity to but spaced apart therefrom for reflecting an incident water wave which has passed the paddle, back onto said rearwardly directly wave engagement face;
- characterised in that: the paddle is provided with a flexible skirt depending therefrom with an extended depth so that at least a distal edge portion thereof is maintained substantially in contact with the bottom of water wave passage extending under the paddle as the paddle moves between said first and second positions, whereby the flexible skirt means harnesses energy from that part of the wave passing below the paddle to exert additional displacement force on the paddle as a said incident wave or reflected incident wave passes the paddle.

2. An apparatus according to claim 1 wherein the skirt has a length of from 1 to 4 times the maximum separation of a lower edge of the paddle at which said skirt is connected thereto, from said bottom of the wave water passage, between said first and second positions of the paddle.

3. A device according to claim 1 or claim 2 wherein said water wave passage is of generally 'U'-shaped section so that

said paddle and skirt are maintained in generally close interengagement between said first and second positions of the paddle, so as to minimize leakage therebetween.

4. A device according to any one of claims 1 to 3 wherein said skirt is of a fabric reinforced rubber.

5. A device according to any one of claims 1 to 4 wherein said skirt is of progressively increasing flexibility towards its distal edge portion.

6. A device according to any one of claims 1 to 5 wherein said paddle is provided with an over-centre toggle assist or snap through action mechanism formed and arranged so that the neutral position of the paddle is metastable and as the paddle is displaced away from the neutral position to either side thereof it is subjected to a biasing force towards the respective one of said first and second positions.

7. A device according to claim 6 wherein the toggle assist mechanism comprises a mass mounted on the paddle above its pivotal axis so as to act on the paddle to bias the paddle towards said first or second positions when the paddle has moved past the neutral position under the influence of wave action thereon, wherein the mass effectively acts to raise the centre of gravity of the paddle to a point above the pivot such that when past the neutral position, the paddle will be biased towards the first or second position as appropriate.

8. A device according to any one of claims 1 to 7 wherein the device is further provided with direct or indirect stop devices to limit rotation of the paddle beyond said first and/or second positions.

9. A device according to any one of claims 1 to 8 wherein said bottom of the wave water passage is inclined upwardly towards said wave reflector at an angle of from 2 to 15° to the horizontal.

10. A device according to any one of claims 1 to 9 wherein said wave reflector has a curved profile to facilitate redirection of a said incident wave with a minimum of loss in momentum of said incident wave.

11. A device according to claim 10 wherein the wave reflector is concave and/or parabolic in section.

12. A device according to any one of claims 1 to 11 wherein said skirt is fixedly connected to the lower edge of the paddle.

13. A device according to any one of claims 1 to 12 wherein is provided a convergent channel at a forward end portion of the wave water passage for funnelling waves into said paddle.

14. A device according to any one of claims 1 to 13 which is in the form of a floating vessel, provided with at least one anchor, for anchoring thereof in an off-shore location.

15. A device according to claim 14 wherein said vessel is a multi-hull vessel with the hulls being interconnected below the water-line so as to define at least one said wave water passage therebetween.

16. A power generation system comprising at least one water wave driven device according to claim 1 drivingly connected to a power generating device via a fluid pump or compressor.

17. A system according to claim 16 wherein is used a gas compressor.

18. A system according to claim 17 wherein is included a gas pipeline extending between said gas compressor and said power generating device.

19. A system according to claim 17 or claim 18 wherein said gas compressor is selected from positive displacement motors when operated as pumps, gear pumps, reciprocating piston and cylinder type pumps, vane pumps, and swash plate pumps.

20. A system according to any one of claims 17 to 19 wherein said power generating device comprises a compressed gas-driven electricity generating turbine.

21. A system according to any one of claims 17 to 20 wherein is provided a multiplicity of said one water wave driven devices with respective gas compressors coupled to a gas pipeline via a manifold.

22. An electricity generating system comprising: a natural energy driven device suitable for use in extracting energy from a natural energy source, said device being drivingly coupled to a gas compressor, said compressor being coupled via a gas container to a compressed gas-driven electricity generating turbine.

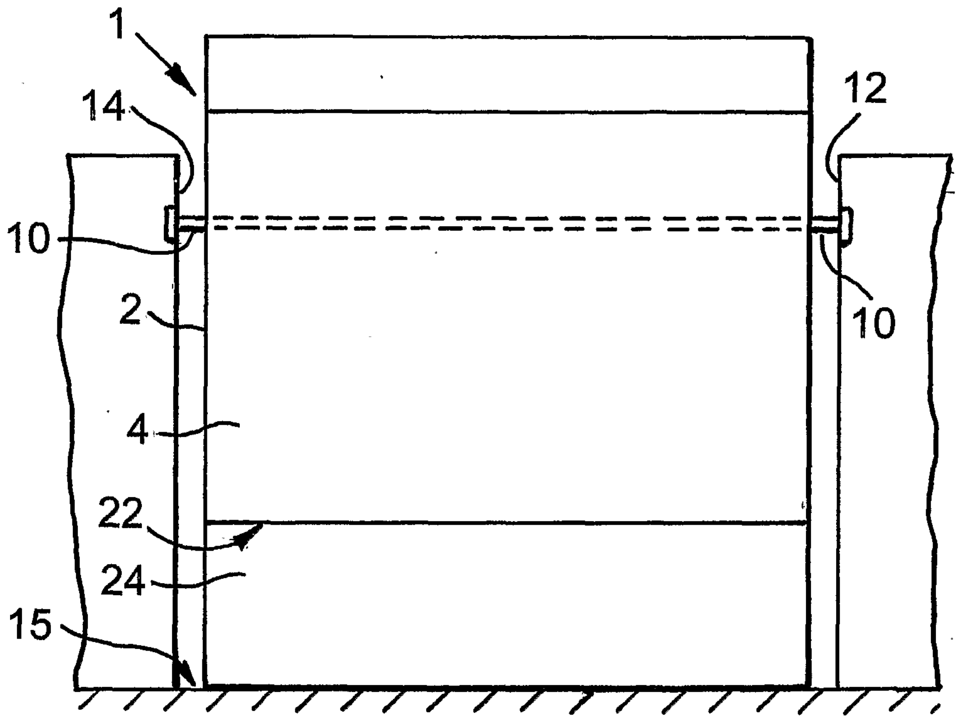


Fig.1

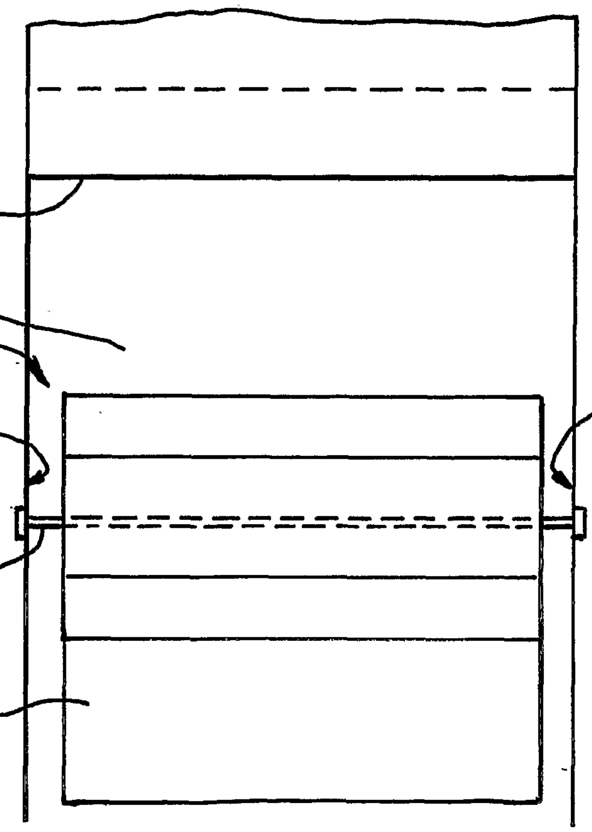
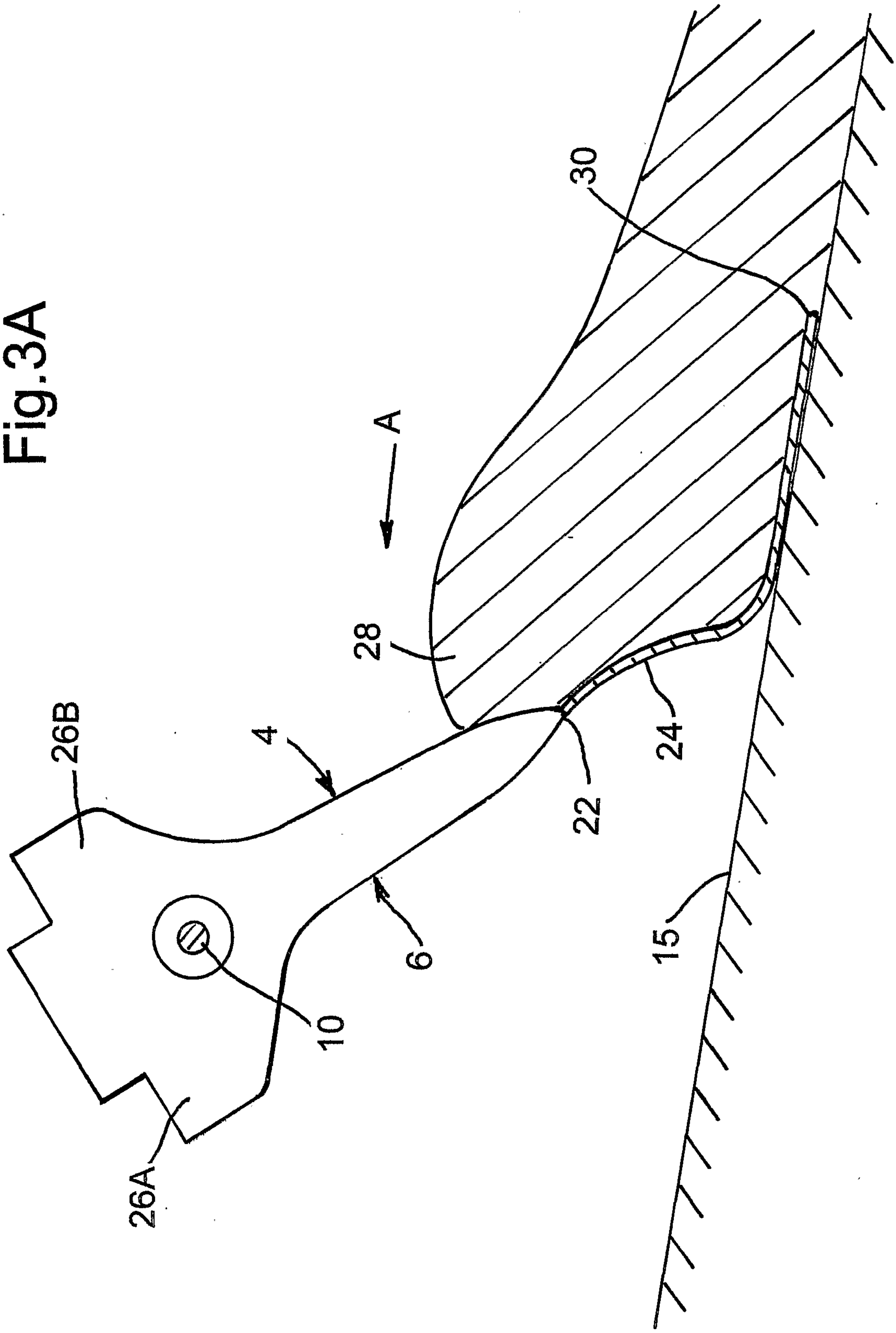


Fig.2

Fig.3A



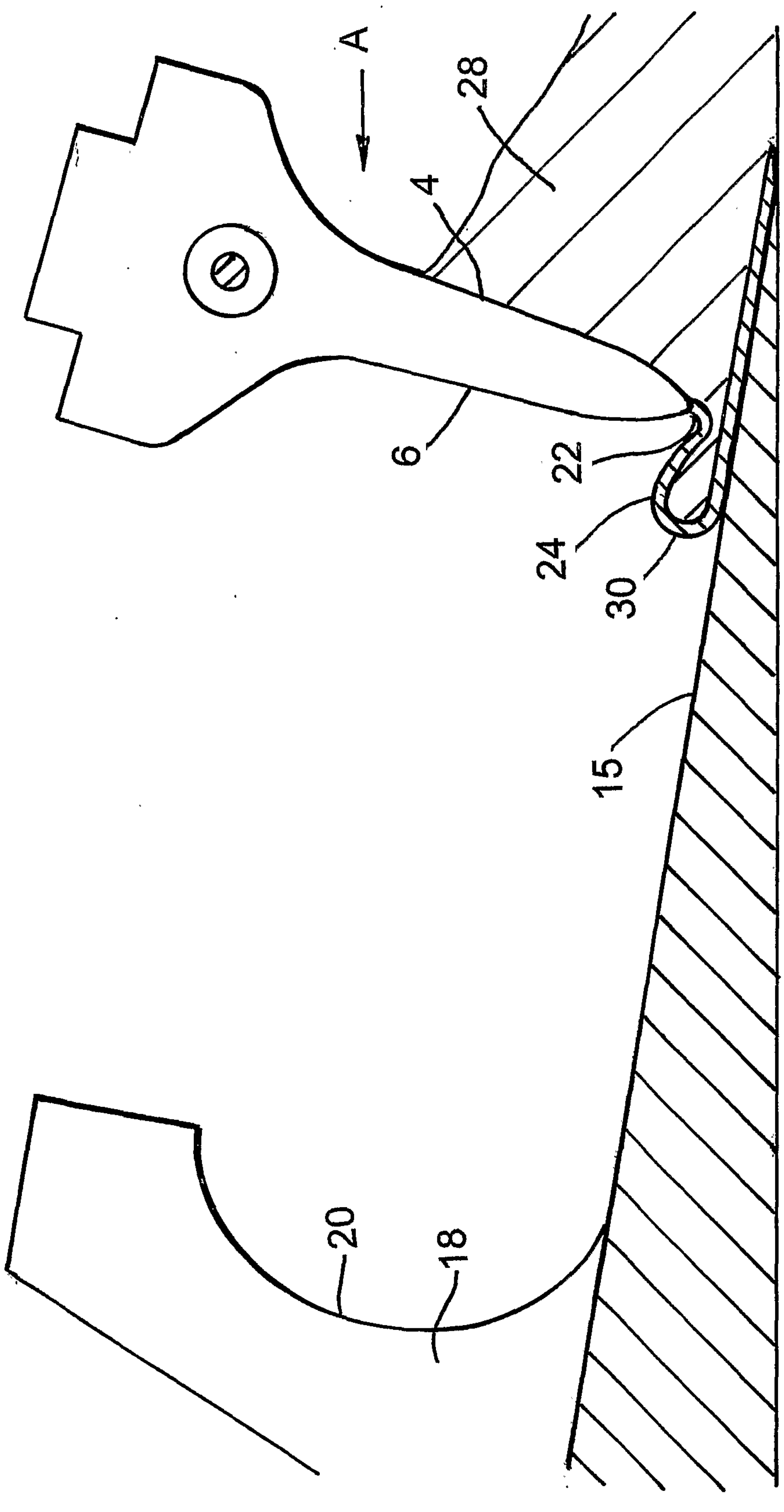
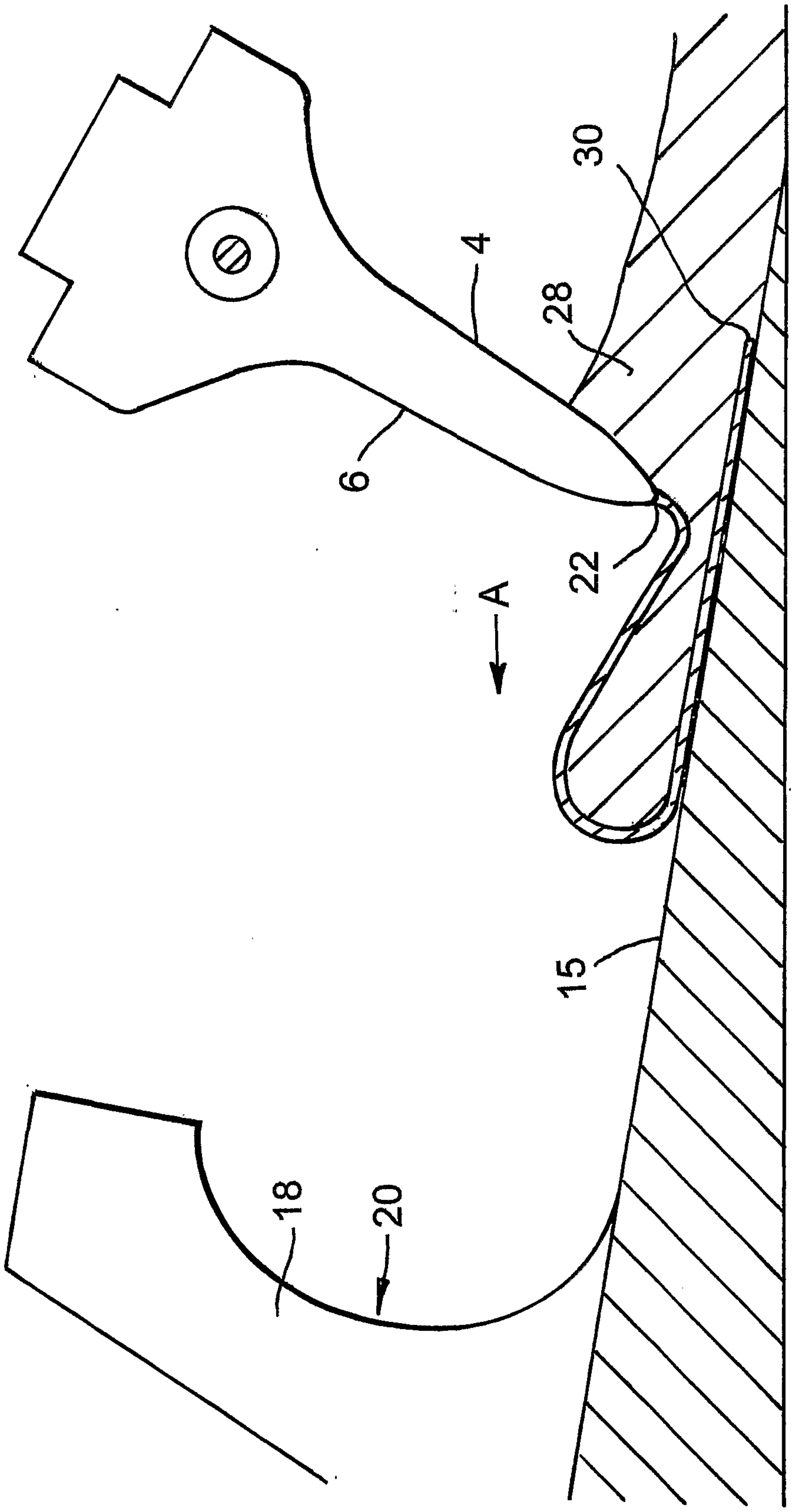


Fig.3B

Fig.3C



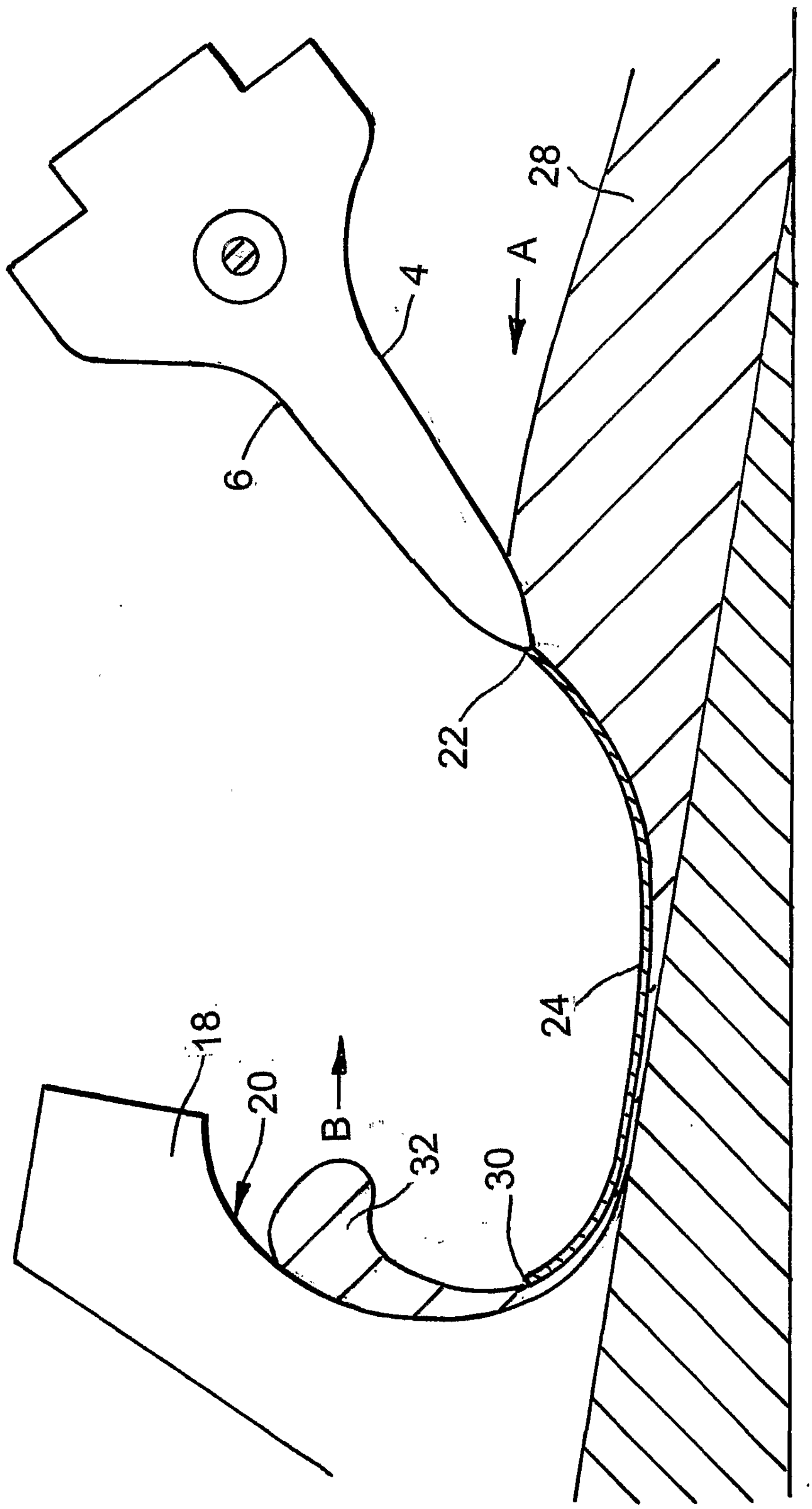
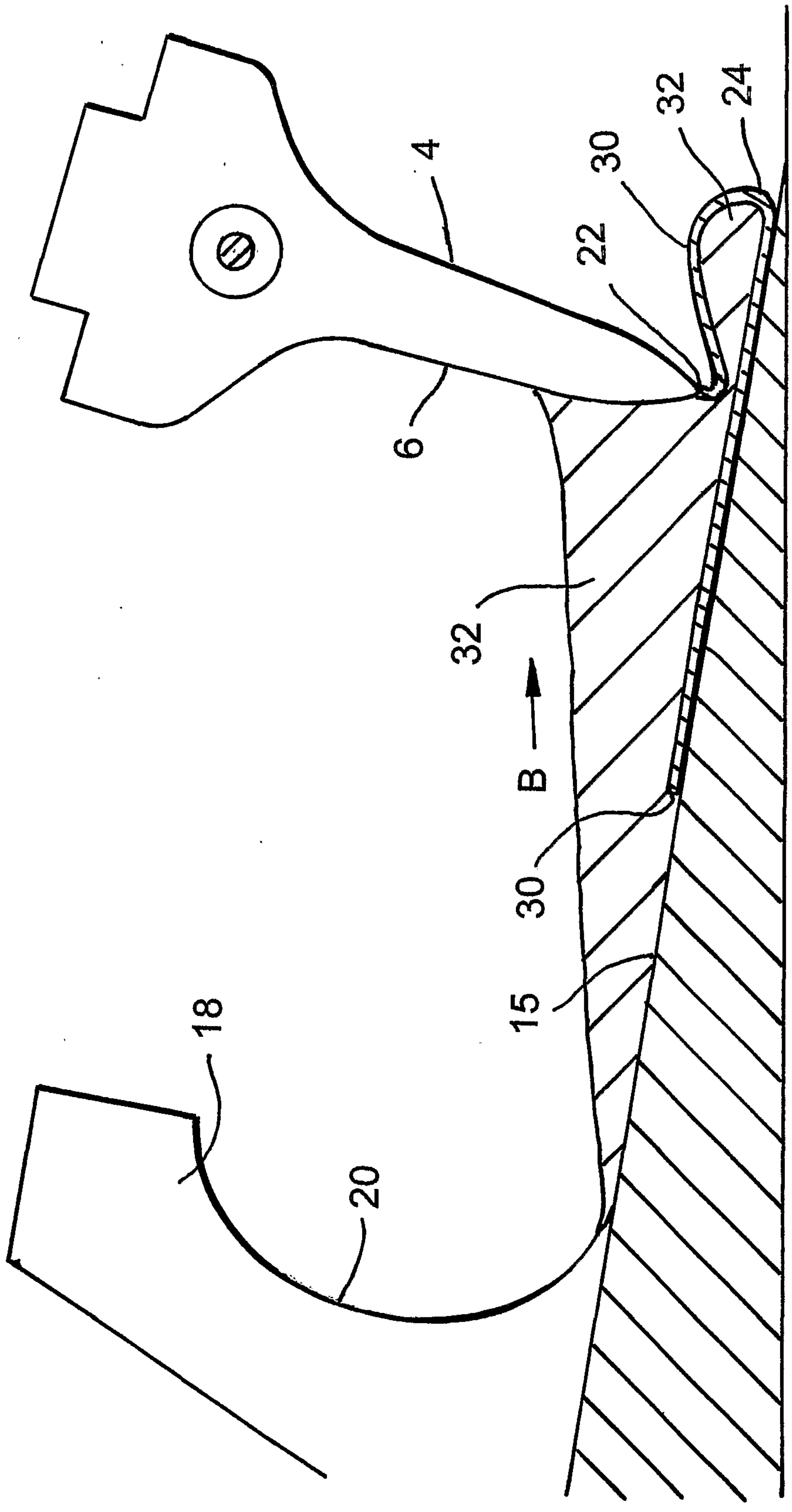


Fig.3D

Fig.3E



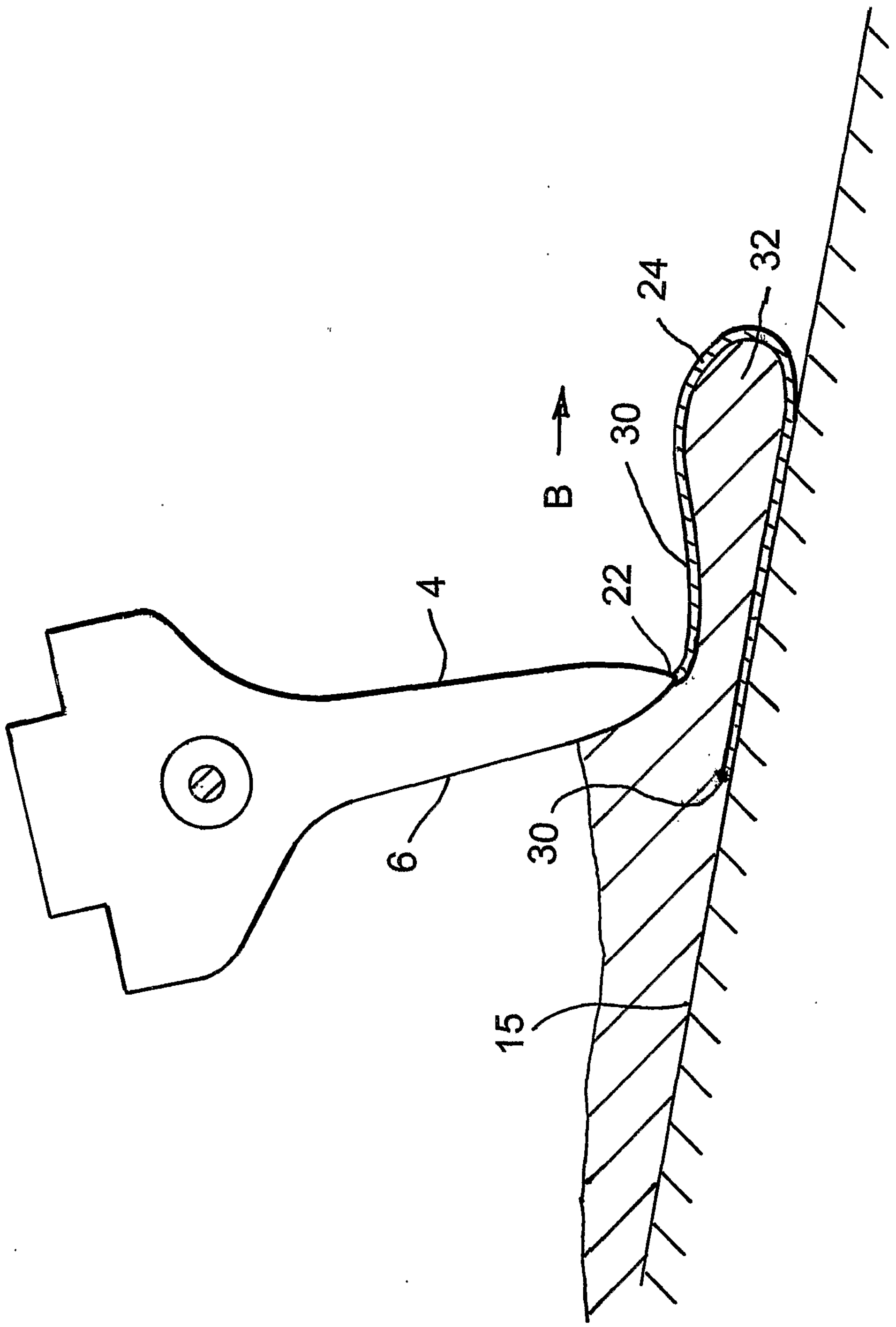
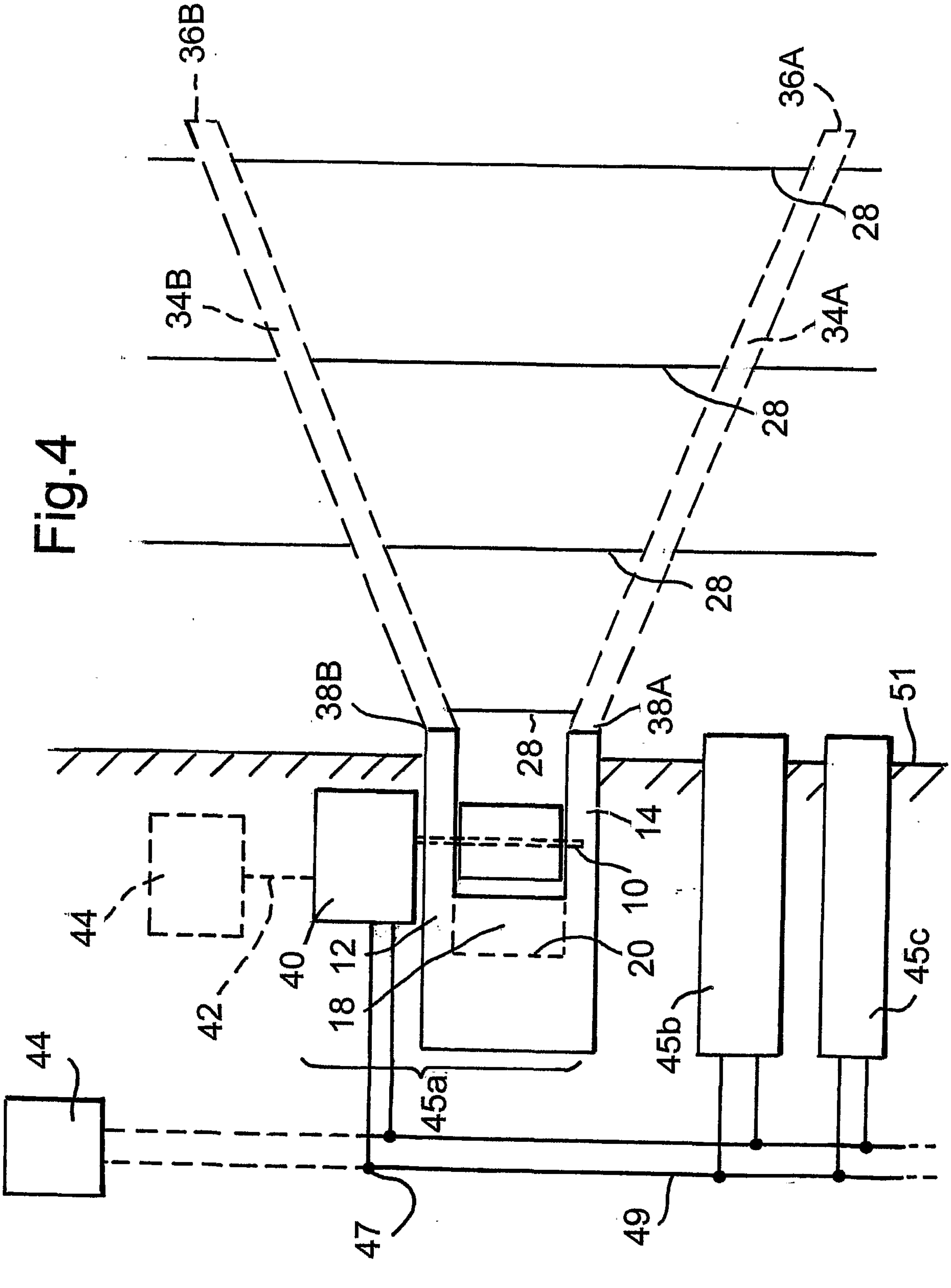


Fig.3F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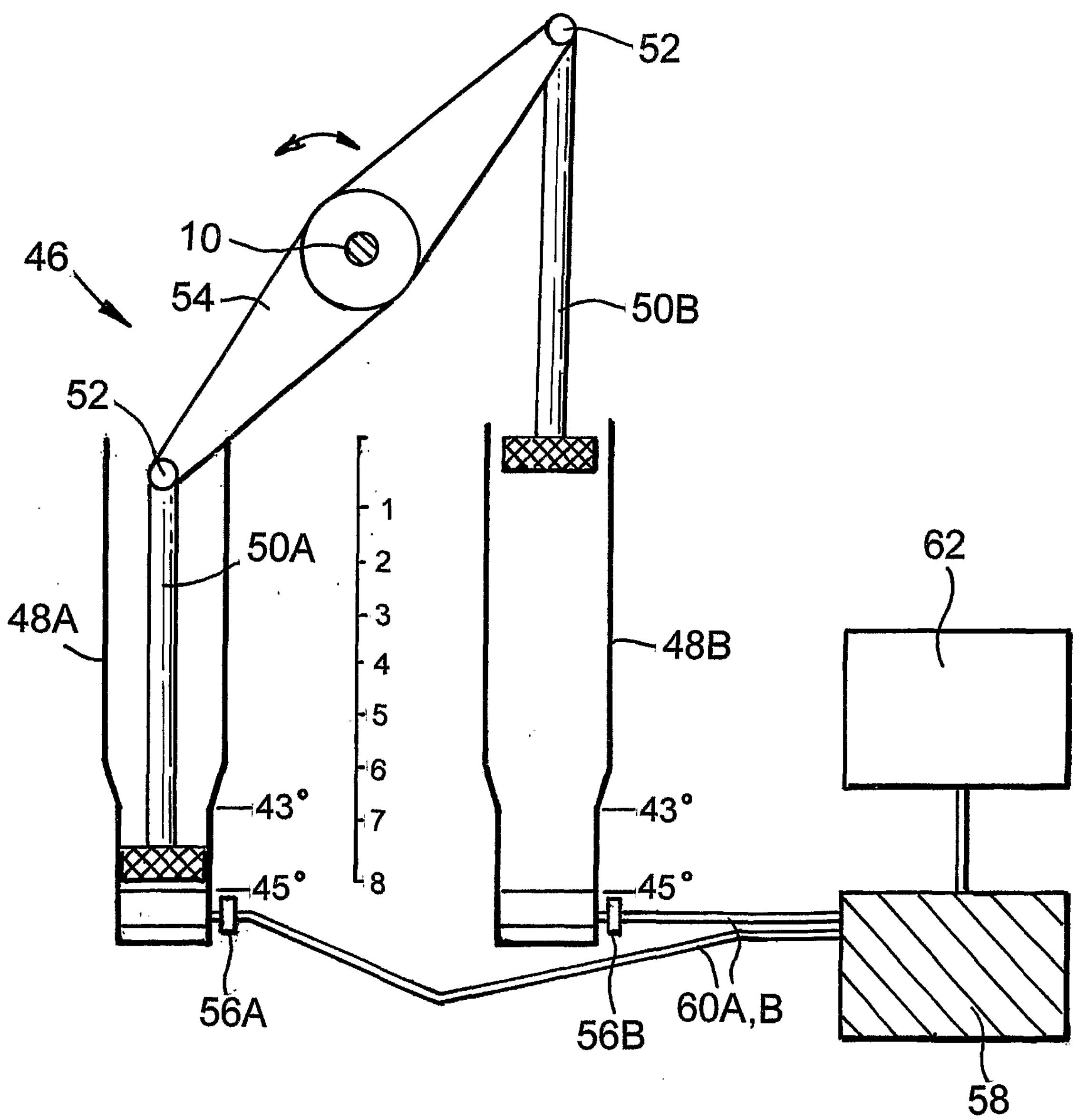
49

Fig.4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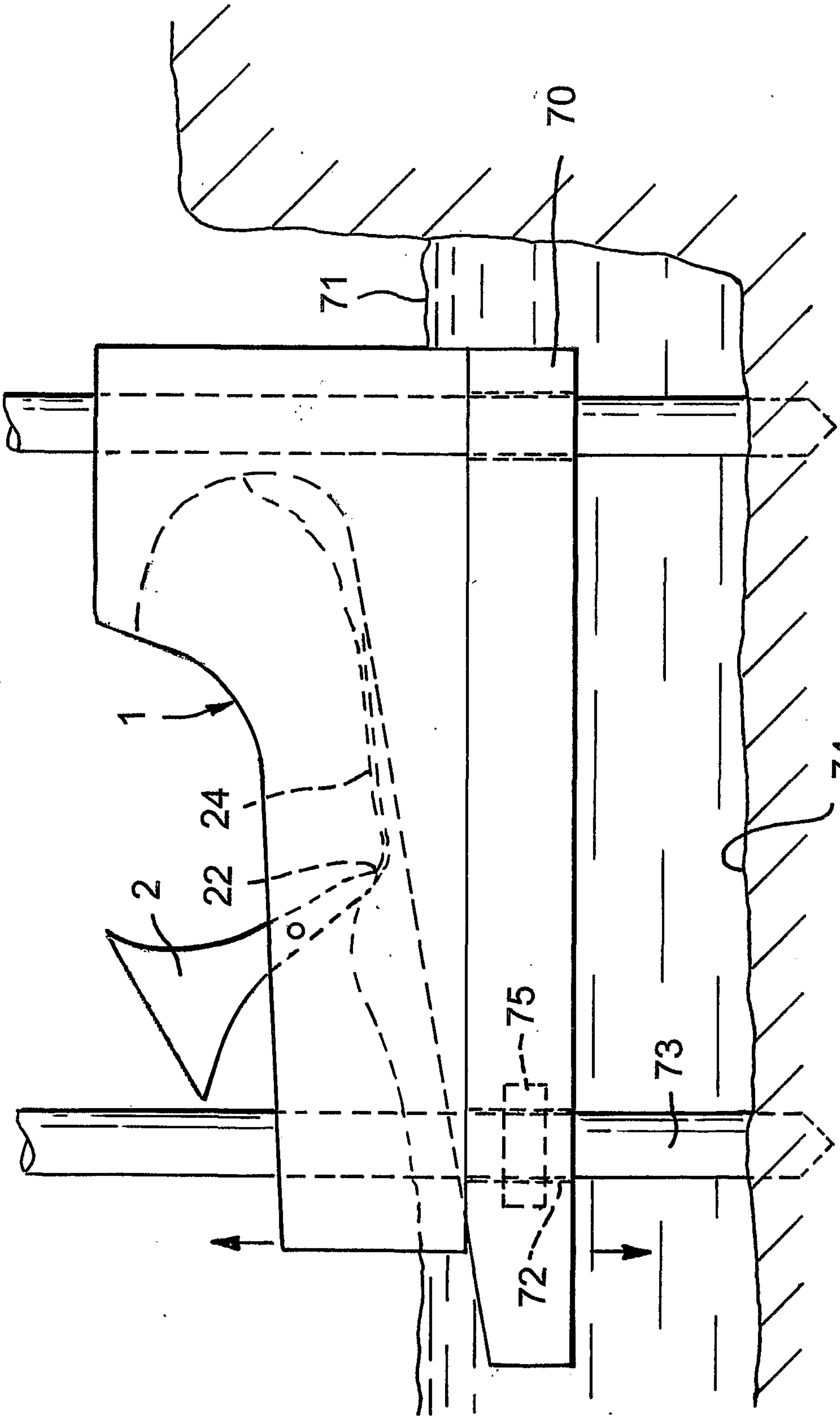
8
45°
56A
60A,B
56B
58

Fig.5

Fig.6



INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/04179

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F03B13/18

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 7 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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4 580 400 A (WATABE TOMIJI ET AL) 8 April 1986 (1986-04-08) cited in the application	1-15
X		16,22
Y	column 4, line 1 - line 18; figures 3,4 column 7, line 4 - line 30	17-21
Y	DE 196 47 102 A (ARRIBI PHILIPPE) 20 May 1998 (1998-05-20) abstract claims 1-3	1-3,5,8, 12
Y	US 4 782 663 A (BELLAMY NORMAN W) 8 November 1988 (1988-11-08) abstract column 11, line 56 - line 68	4

-/--

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

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
26 November 2001	03/12/2001

Name and mailing address of the ISA	Authorized officer
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	Criado Jimenez, F

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4 718 231 A (VIDES MAX M) 12 January 1988 (1988-01-12) column 4, line 23 - line 27; figure 2	6,7
Y	FR 2 548 739 A (LIAUTAUD JEAN) 11 January 1985 (1985-01-11) abstract; figures	9,13-15
Y	GB 2 283 265 A (KOREA OCEAN RES DEV INST) 3 May 1995 (1995-05-03) abstract; figures	10,11
Y	US 4 332 506 A (ANDREWS OTTIE H) 1 June 1982 (1982-06-01) abstract; figures	13
Y	GB 2 026 621 A (SEA ENERGY ASSOCIATES LTD) 6 February 1980 (1980-02-06) page 1, line 67 - line 74	17-21
A	abstract; figure 1	1
X		22
A	US 4 441 030 A (BELLAMY NORMAN W) 3 April 1984 (1984-04-03) column 2, line 64 -column 3, line 2; figure 2	1
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