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(54) Remotely operated submersible vehicle with adjustable tether mounting terminal

(57) A remotely operated submersible vehicle (100) is disclosed. The vehicle (100) comprises a housing (102), positioning means (104, 106, 108, 110, 112, 114, 120, 122) adapted to control a position and/or orientation

of the remotely operated submersible vehicle and a mounting apparatus (116) adapted to be connected to a tether cable (118) to enable a position at which a towing force is applied from the cable (118) to the apparatus to be adjusted.

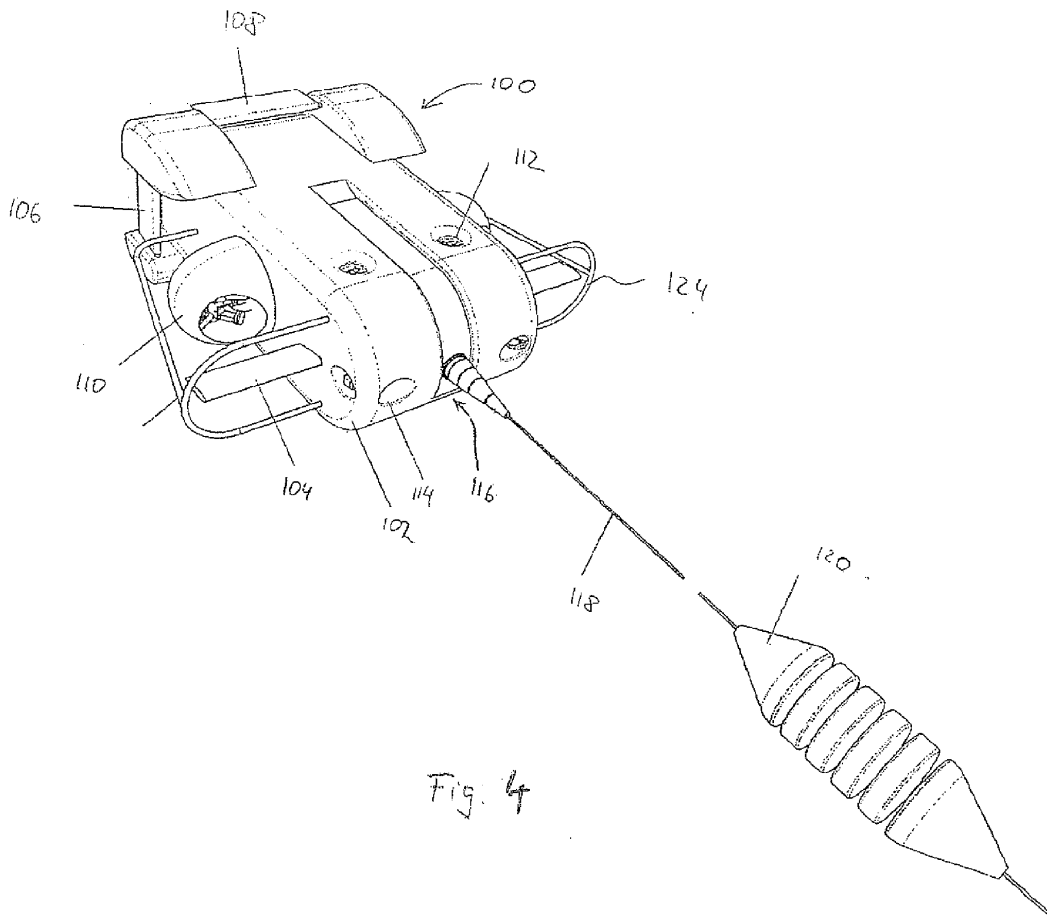


Fig. 4

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Description

FIELD OF THE INVENTION

[0001] The present invention generally relates to underwater vehicles such as remotely operated vehicles (ROVs) for underwater applications, and relates particularly, but not exclusively, to a remotely operated vehicle having an adjustable tether mounting terminal for operation in high-speed and low-speed water flows.

BACKGROUND OF THE INVENTION

[0002] Remotely operated vehicles, generally referred to as ROVs, are tethered underwater robots mainly used in the offshore industry and for marine research. ROVs are unoccupied, maneuverable and operable by a user aboard a vessel or platform.

[0003] Typical work-class ROVs have a buoyancy block or system that is mounted to a rigid frame to which several independently driven and controlled thrusters are attached. The ROV is connected to the vessel or platform by means of a tether or umbilical cable through which power, information signals and control signals are passed. Some tethers or umbilicals may also contain hoses for delivery of hydraulic or pneumatic services etc. ROVs may be equipped with cameras, lights, sonars, magnetometers, tooling manipulators and/or cutting arms, water samplers and other instruments for measuring, for example, water clarity, light penetration and temperature.

[0004] An example of a typical work-class ROV is shown in **Figure 1**. A buoyancy tank or block **2** is mounted to a frame **3** and adapted to provide sufficient buoyancy for the ROV **1**. Thrusters **4** are mounted to the frame **3** allowing the ROV **1** to maneuver underwater. Tooling **5** such as manipulators and grabbers can be used for carrying equipment and for performing maintenance tasks and are located at one end of the frame **3**. The ROV **1** is connected to the vessel or platform (not shown) by means of a tether or umbilical cable **6** that is usually attached to a top-side terminal **7** of the frame.

[0005] However, as shown in **Figure 2**, these typical work-class ROVs **1** cannot operate effectively in high-flow conditions, i.e. typically in water flows of speed in excess of about 2 knots (≈ 1 m/s), because the flow resistance of the top-side tether cable **6** and the ROV **1** causes drag that may move the ROV **1** out of the desired position. Thus, thrusters and hydrofoils provide forces F_d , F_t and moment M to counteract the flow induced additional forces arising from the combination of ROV drag F_{rd} and cable force F_{ch} and F_{cv} that affect the ROV's position and maneuverability.

[0006] **Figure 3** shows a typical work-class ROV **1** when operating in low-flow conditions, i.e. substantially no water flow or water flow significantly less than 2 knots (≈ 1 m/s), with only forces F_c , F_d , F_t and F_{rd} acting on the ROV **1**.

[0007] As a result, the necessary additional compensatory maneuvers make the ROV in the configuration shown in Fig 2 sluggish and less responsive and sometimes unable to maintain position, and the additional use of thrusters and/or hydrofoils increases the power consumption of the ROV.

SUMMARY OF THE INVENTION

[0008] Preferred embodiments of the present invention seek to overcome one or more of the above disadvantages of the prior art.

[0009] According to an aspect of the present invention, there is provided a remotely operated submersible vehicle, comprising:

a housing;

positioning means adapted to control a position and/or orientation of said remotely operated submersible vehicle;

a mounting apparatus adapted to be connected to a tether cable to enable a position at which a towing force is applied from the cable to the apparatus to be adjusted.

[0010] This provides the advantage that the towing force to the tether cable is always in a hydro-dynamically optimal position for the vehicle (ROV), therefore minimizing any additional forces that may affect the position of the vehicle due to cable drag in high-flow conditions and weight/cable slack in low-flow conditions. Thus, fewer compensatory manoeuvres by the positioning means are necessary to maintain a desired vehicle position, requiring less power and therefore minimizing energy consumption of the vehicle.

[0011] A position at which a towing force is applied by a cable to the apparatus may include at least one first position above the centre of gravity of the vehicle in use.

[0012] A position at which a towing force is applied by a cable to the apparatus may also include at least one second position upstream of the centre of gravity of the vehicle when in use in the direct flow of fluid in which the vehicle is submerged

[0013] The vehicle may further comprise detachment means for enabling remote detachment of a tether cable.

[0014] This provides the advantage that the tether cable could be detached instantly in case of an emergency or to allow autonomous operations of the remotely operated vehicle.

[0015] The positioning means may comprise at least one thruster and/or at least one hydrofoil and/or at least one variable buoyancy chamber.

[0016] At least one said hydrofoil may be remotely controllable.

[0017] At least one said thruster may be positioned adjacent an edge region of the housing

[0018] A combination of advantageously positioned and remotely controllable thrusters, hydrofoils, variable buoyancy chambers and weight provide the advantage that the manoeuvrability of the remotely operated submersible vehicle is maximized allowing more accurate operations.

[0019] The remotely operated submersible vehicle may further comprise at least one tool.

[0020] At least one said tool may comprise at least one manipulator.

[0021] At least one said tool may be adapted to be located downstream of the centre of gravity of the vehicle in use in the direction of flow of fluid in which the vehicle is submerged.

[0022] This provides the advantage that a tooling package e.g. manipulators are protected from the full force of the water flow and do also not interfere with the optimized hydro-dynamic characteristics of the remotely operated submersible vehicle.

[0023] The remotely operated submersible vehicle may further comprise a protection frame adapted to provide protection to at least one hydrofoil and/or at least one thruster.

[0024] This provides the advantage that crucial parts for the manoeuvrability of the remotely operated submersible vehicle are protected from external forces making it more hardwearing and increasing its lifetime, thereby reducing cost of repairs.

[0025] The remotely operated submersible vehicle may further be adapted for operation without using a tether cable.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] A preferred embodiment of the present invention will now be described, by way of example only and not in any limitative sense, with reference to the accompanying drawings, in which:

Figure 1 schematically illustrates a typical known ROV in use;

Figure 2 schematically illustrates the forces affecting the vehicle of Figure 1 with a top-side tether cable in high-flow conditions;

Figure 3 shows the vehicle of Figure 1 in low-flow conditions;

Figure 4 shows a perspective side-front view of an embodiment of the invention including part of the tether cable and a clump weight;

Figure 5 shows a perspective side-rear view of an embodiment of the invention including part of the tether cable;

Figure 6 schematically illustrates a mechanism of a

first mounting apparatus for the present invention;

Figure 7 schematically illustrates a mechanism of a second mounting apparatus for the present invention;

Figure 8 schematically illustrates a mechanism of a third mounting apparatus for the present invention;

Figure 9 schematically illustrates an embodiment of the invention in high-flow mode when in use; and

Figure 10 schematically illustrates an embodiment of the invention in low-flow mode when in use;

DETAILED DESCRIPTION OF EMBODIMENT

[0027] Referring to **Figures 4 and 5**, a remotely operated submersible vehicle **100** embodying the present invention comprises a hydrodynamic chassis **102** that houses the components making up the vehicle **100**. The components may also include a structural frame, motors, pumps, valve packs, control equipment, tooling packages, attachments for payloads etc. within the streamlined shape.

[0028] Furthermore, hydrofoils **104, 106, 108** are located at various positions around the vehicle **100** to control not only the gross position of the vehicle **100** in the water column but also its orientation.

[0029] In addition to the hydrofoils, high power steerable thrusters **110** may be orientated in such a way to enable control of the gross position of the vehicle **100** in the water column, or to provide lift capacity for payloads carried by the vehicle **100**. Also, in low-flow mode, which is used when operating the vehicle in water flow with flow speeds significantly less than about 2 knots (1 m/s), the high-power steerable thrusters **110** would primarily be used for manoeuvring the vehicle **100** in conjunction with the vertical **112** and vectored horizontal thrusters **114**.

[0030] Additional vertical thrusters **112** and vectored horizontal thrusters **114** are fitted to augment the vehicle's gross and fine position,

[0031] Two variable buoyancy tanks **122** maybe provided on the vehicle **100**, which are adapted to provide a variable weight to the vehicle **100** by either filling or emptying the tanks **122** using a suitable pump and valve system (not shown). The weight of the vehicle **100** may also be adjusted by other means such as adding/removing ballast.

[0032] Furthermore, a protection frame **124** is provided to minimise risk of damage to the hydrofoils **104, 106, 108** and high-power steerable thrusters **110**. Tooling and manipulators **126** may be fitted to the rear of the vehicle **100** in order to protect them, for example, from the full force of the water flow. The tooling or manipulators **126** may also be located at any of the other sides of the vehicle **100**.

[0033] The tether cable **118** may either be a simple

wire or fibre rope, providing the remotely operated submersible vehicle has onboard power, or an electrical lifting umbilical cable adapted to provide electrical power and allowing signal transfer or more complicated umbilical containing hoses as well as electrical cables. The umbilical cable **118** may be detachable so the vehicle can be disconnected for autonomous operations or in case of an emergency. The umbilical cable **118** can also be used to lift the vehicle **100** into and out of the water.

[0034] Since the location of the cable **118** on the housing **102** is crucial to the stability of the vehicle's position when operating in high-flow or low-flow conditions, the position where the cable **118** is coupled to the vehicle **100** is adjustable to suit the mode of operation.

[0035] **Figure 4** shows the present invention in high-flow mode, where the mounting apparatus **116** provides for the tether cable **118** to be positioned near the front of the vehicle **100** with regard to the flow direction of the vehicle **100**, i.e. the front of the vehicle **100** faces the flow direction of the vehicle when pulled behind a vessel **200** or the flow of a water column **210** that is directed towards the vehicle **100**. The tether cable or umbilical cable **118** is coupled to the mounting apparatus **116** and a suitable single or a plurality of clump weights **120**, or other means that are adapted to apply a downward force to the tether cable **118**, is/are coupled to the tether cable **118** in order to assist the gross positioning of the tether cable **118** and subsequently the vehicle **100** in the water column.

[0036] **Figure 5** shows the present invention in low-flow mode, where the mounting apparatus **116** provides for the tether cable or umbilical cable **118** to be located in a more conventional manner at the top-side of the vehicle **100**, with regards to the operating position of the vehicle **100**.

Tether mounting terminal mechanism

[0037] A detailed example of a first mechanism **117** for the mounting apparatus **116** is shown in **Figure 6**. The umbilical cable **118** is attached to a chain or conveyor belt **126** that is moved by one or two hydraulically or electrically driven sprockets **128**. The chain or conveyor belt **126** may be supported by supporting rollers **130** or edge guides **131**. This bridle mechanism may be locked in position by a lock **132** in order to fix the umbilical cable **118** in the desired position.

[0038] **Figure 7** shows a detailed example of a second mechanism **119** of the mounting apparatus **116**. The umbilical cable is coupled to rollers **136** that run within a rail system **134** allowing movement along the housing **102** of the vehicle **100**. The rollers **136** are moved by a remotely controlled hydraulic arm **138** that may also lock the umbilical cable **118** in the desired position.

[0039] **Figure 8** shows a detailed example of a third mechanism **121** of the mounting apparatus **116**. Similar to the second mechanism **119**, the umbilical cable is coupled to rollers **140** that run within a rail system **142** allowing movement along the housing **102** of the vehicle

100. The rollers **140** are coupled to a first remotely controlled hydraulic ram **144** via a first cable **148** on one side of the rail **142**, and to a second remotely controlled hydraulic ram **146** via a second cable **150** on the other side of the rail **142**. Through activation of either the first or second hydraulic ram **144**, **146**, the rollers **140** may be moved into various positions along the housing **102** of the vehicle **100**.

High-flow mode operation

[0040] During a typical operation in high-flow mode, the remotely operated submersible vehicle **100** uses a combination of the high-power steerable thrusters **110**, the vertical and vectored horizontal thrusters **112**, **114**, the tether cable's length and position, the hydrofoils **104**, **106**, **108** and the variable weight provided by the buoyancy tanks **122** and/or clump weight **120** to maintain the desired position in the water column.

[0041] For most operations the support vessel **200** is likely to maintain its position. However, the vehicle **100** may simply be towed behind the vessel **200** for, for example, survey operations. The support vessel **200** could be any suitable structure in the tidal flow onto which the associated deck equipment for the vehicle **100** is installed.

[0042] As shown in **Figure 9**, the vehicle **100** is connected to a suitable tether winch **220** on the surface support vessel **200** or any other structure (not shown). The clump weight's **120** position and its mass are adjusted to move the vehicle **100** in the desired position within the water column. Then, the mounting apparatus **116** moves the cable **118** towards the front of the vehicle **100** so that when the vehicle **100** is deployed into the water flow the drag force F_{drag} is minimised. Subsequently, the water flow has a tendency to align the vehicle **100** and tether cable **118** behind the surface support vessel **200**. The tether cable **118** is then paid out to the desired length and the vehicle operates its hydrofoils **104**, **106**, **108** to move the vehicle into the desired vertical and lateral position and orientation. Any of the thrusters **110**, **112**, **114** and variable buoyancy tanks **122** may also be used in conjunction / or on their own to help positioning the vehicle **100**.

[0043] When the vehicle **100** is in the desired position, the required task is completed. Typical tasks may include (i) reversing and connecting onto a structure to deliver services, e.g. electrical, hydraulic, air etc., (ii) deploying payloads to an accurate location on the seabed, e.g. ACDP, (iii) manipulation work such as connecting electrical connectors or cleaning, or (iv) inspection.

Low-flow mode operation

[0044] **Figure 10** shows an embodiment of the present invention during a typical operation in low-flow mode.

[0045] The remotely operated submersible vehicle **100** is connected to a suitable tether winch **220** on the surface

support vessel **200**. The mounting apparatus **116** moves the cable position towards the top of the vehicle **100** like in a more conventional work-class ROV. The tether cable **118** is then paid out to the desired length and the vehicle **100** operates its thrusters **104**, **106**, **108** and variable buoyancy tanks **122** to manoeuvre the vehicle into position.

[0046] When the vehicle **100** is in the desired position, the required task is completed. Typical tasks may include (i) reversing and connecting onto a structure to deliver services, e.g. electrical, hydraulic, air etc., (ii) deploying payloads to an accurate location on the seabed, e.g. ACDP, (iii) manipulation work such as connecting electrical connectors or cleaning, or (iv) inspection.

[0047] It will be appreciated by persons skilled in the art that the above embodiments have been described by way of example only, and not in any limitative sense, and that various alterations and modifications are possible without departure from the scope of the invention as defined by the appended claims.

Claims

1. A remotely operated submersible vehicle, comprising:
 - a housing;
 - positioning means adapted to control a position and/or orientation of said remotely operated submersible vehicle;
 - a mounting apparatus adapted to be connected to a tether cable to enable a position at which a towing force is applied from the cable to the apparatus to be adjusted.
2. A vehicle according to claim 1, wherein said position at which a towing force is applied by a cable to said apparatus includes at least one first position above the centre of gravity of said vehicle in use.
3. A vehicle according to claim 1 or 2, wherein said position at which a towing force is applied by a cable to said apparatus includes at least one second position upstream of the centre of gravity of said vehicle when in use in the direct flow of fluid in which said vehicle is submerged.
4. A vehicle according to any one of the preceding claims, further comprising detachment means for enabling remote detachment of a tether cable.
5. A vehicle according to any one of the preceding claims, wherein said positioning means comprises at least one thruster and/or at least one hydrofoil and/or at least one variable buoyancy chamber.
6. A vehicle according to claim 5, wherein at least one said hydrofoil is remotely controllable.
7. A vehicle according to claim 5 or 6, wherein at least one said thruster is positioned adjacent an edge region of said housing.
8. A vehicle according to claim 7, wherein the orientation of at least one said thruster is remotely adjustable.
9. A vehicle according to any one of the preceding claims, further comprising at least one tool.
10. A vehicle according to claim 9, wherein at least one said tool comprises at least one manipulator.
11. A vehicle according to claim 9 or 10, wherein at least one said tool is adapted to be located downstream of the centre of gravity of said vehicle in use in the direction of flow of fluid in which said vehicle is submerged.
12. A vehicle according to any one of the preceding claims, further comprising a protection frame adapted to provide protection to said at least one hydrofoil and/or at least one said thruster.
13. A vehicle according to any one of the preceding claims, wherein the vehicle is adapted for operation without using a tether cable.

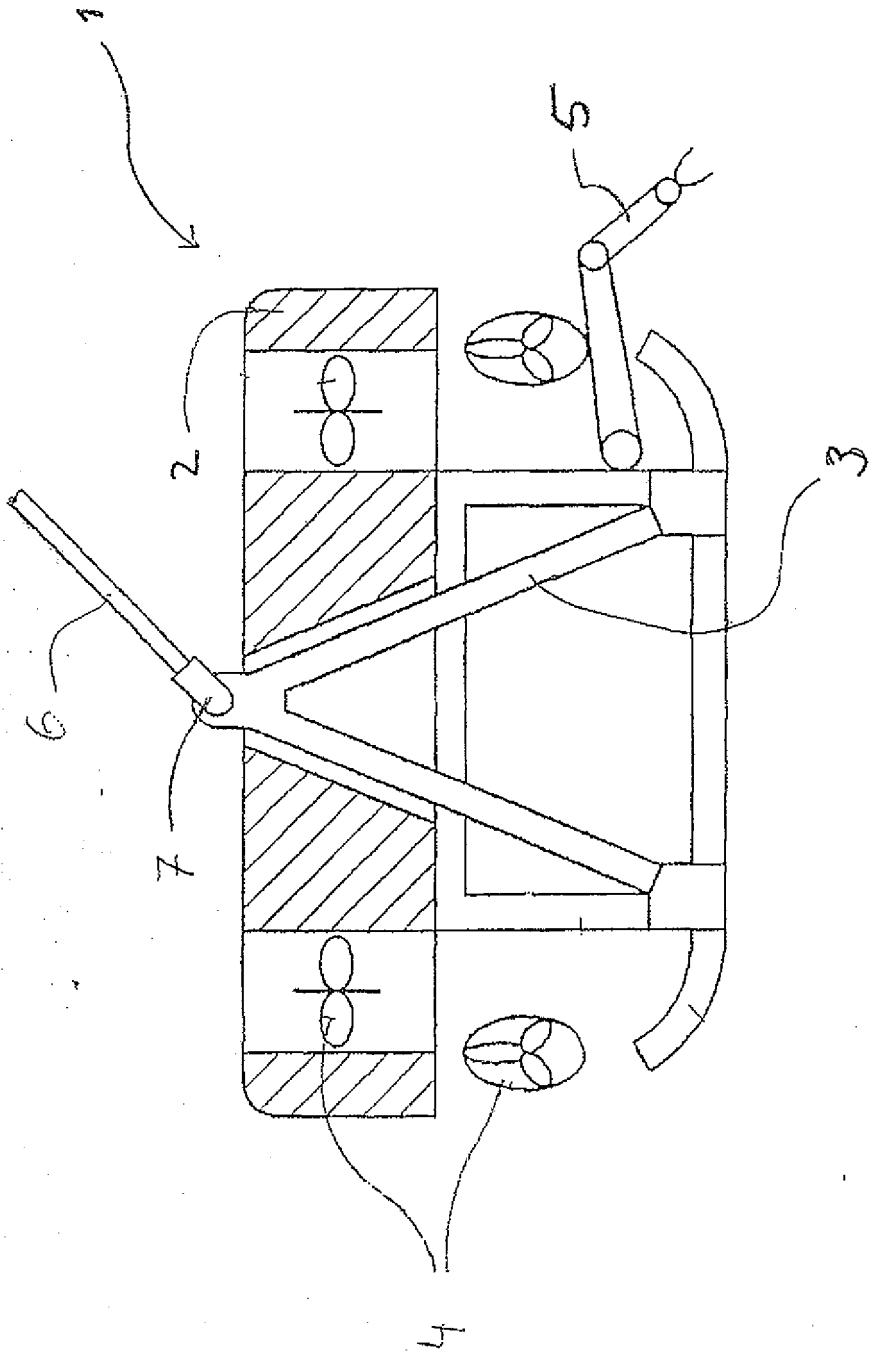


Fig. 1
(prior art)

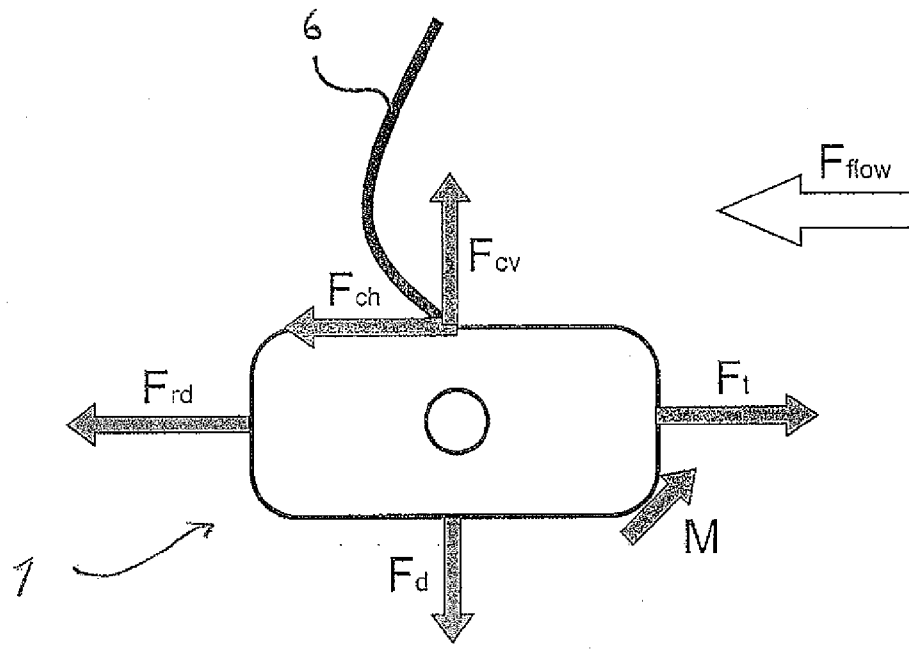


Fig. 2

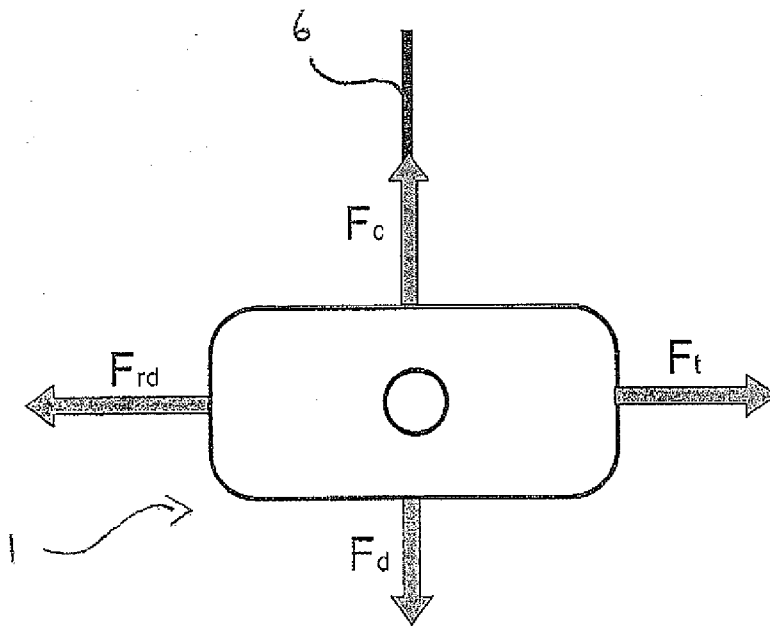


Fig. 3

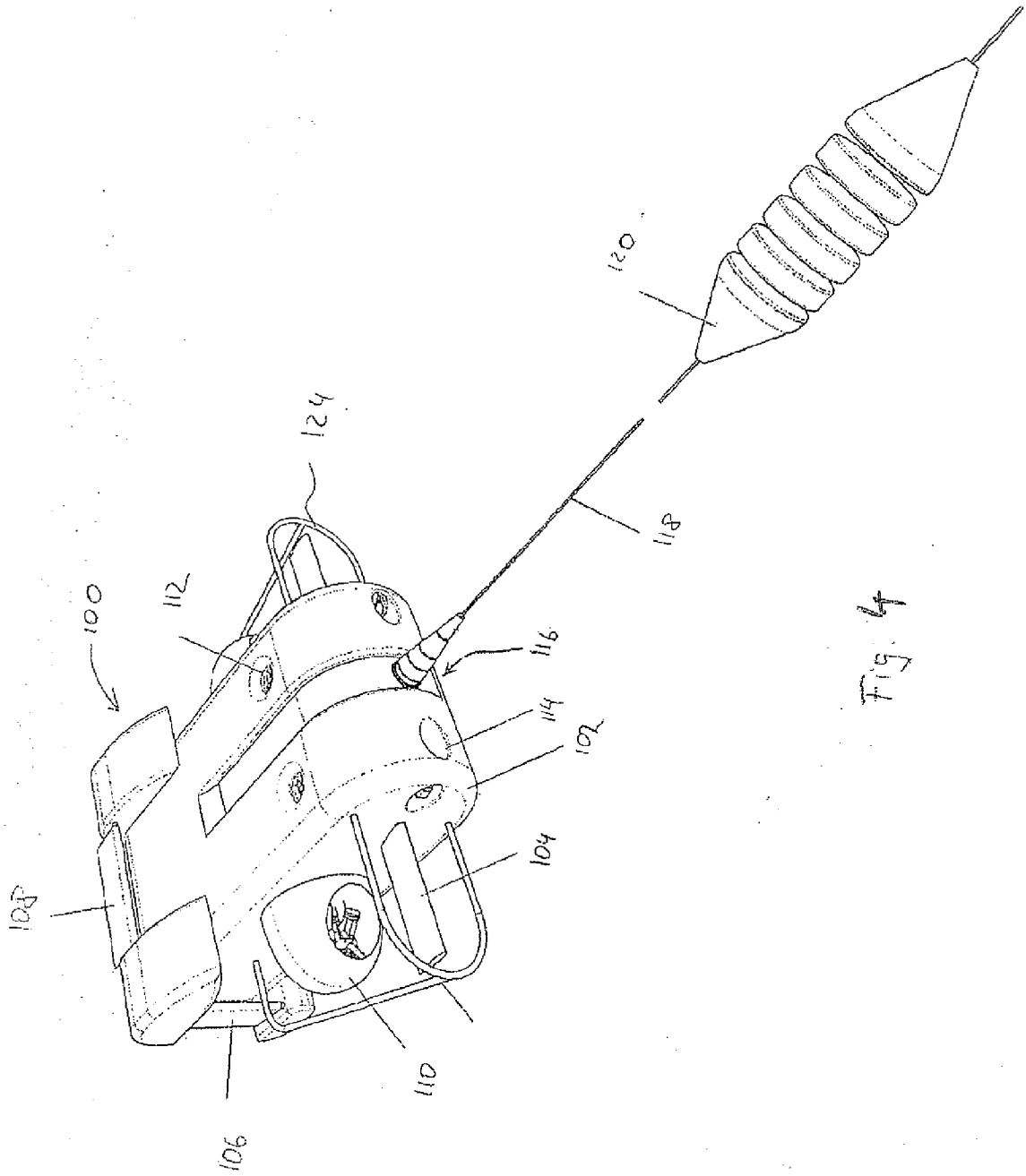
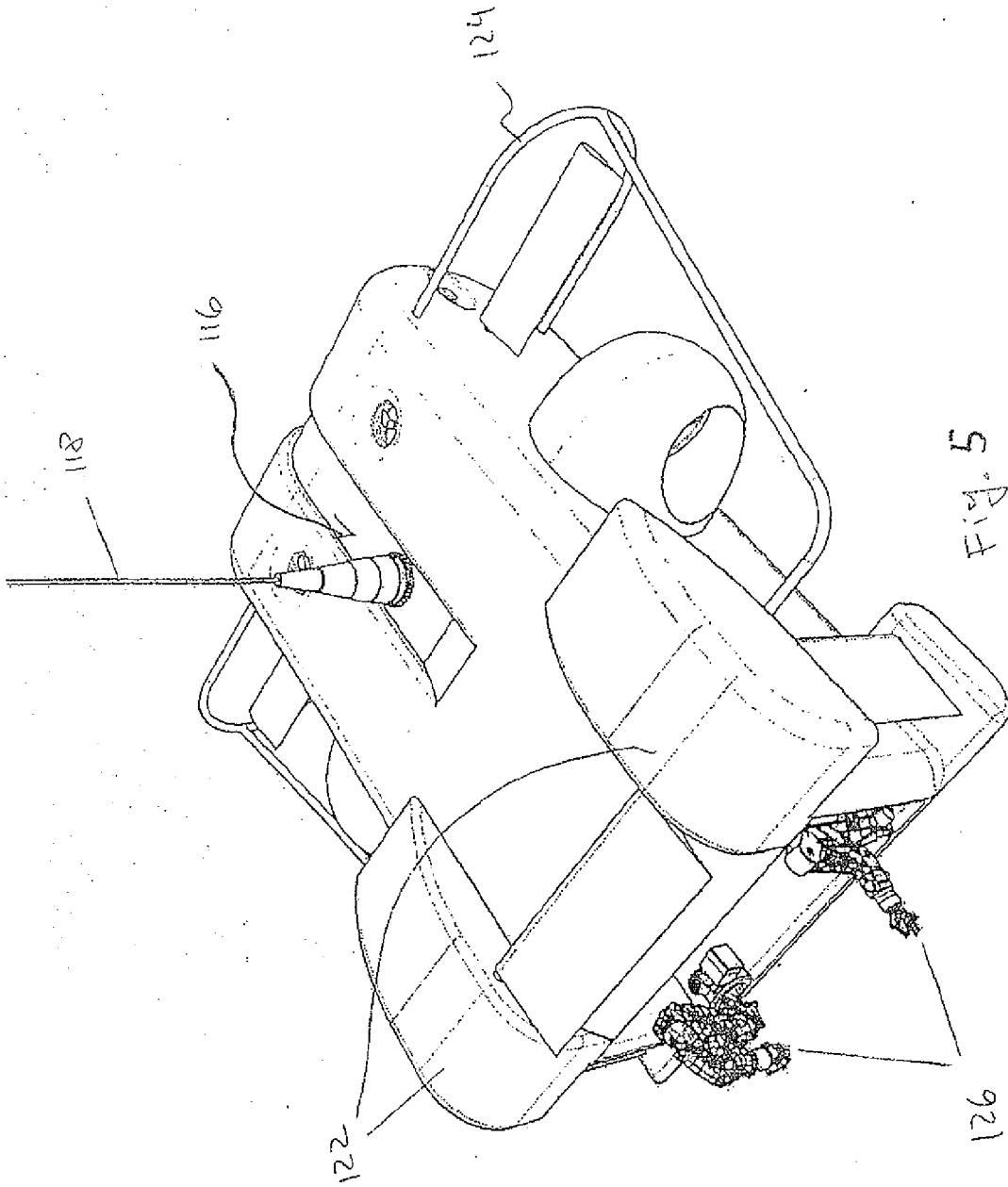


Fig. 4



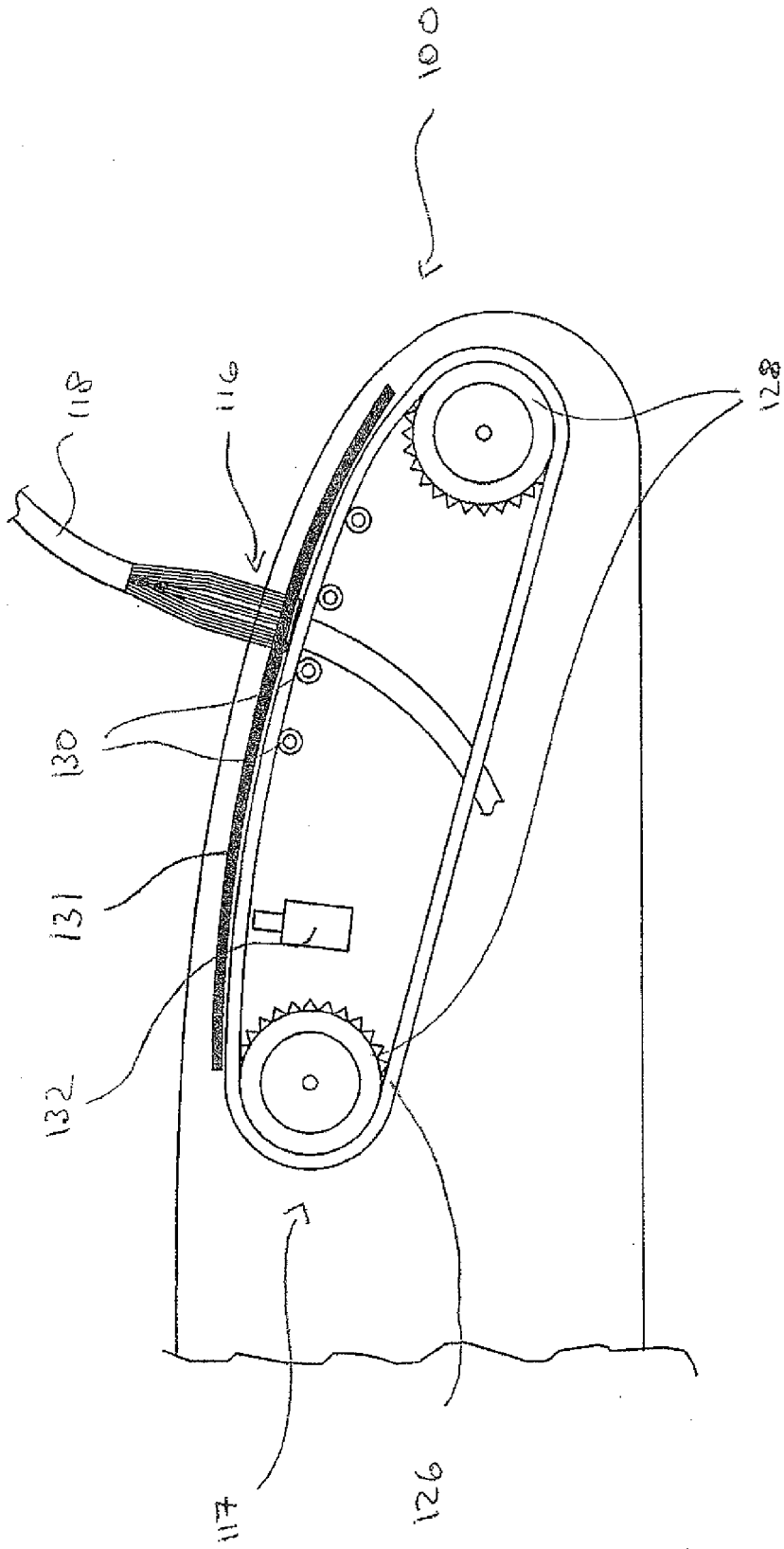


Figure 6

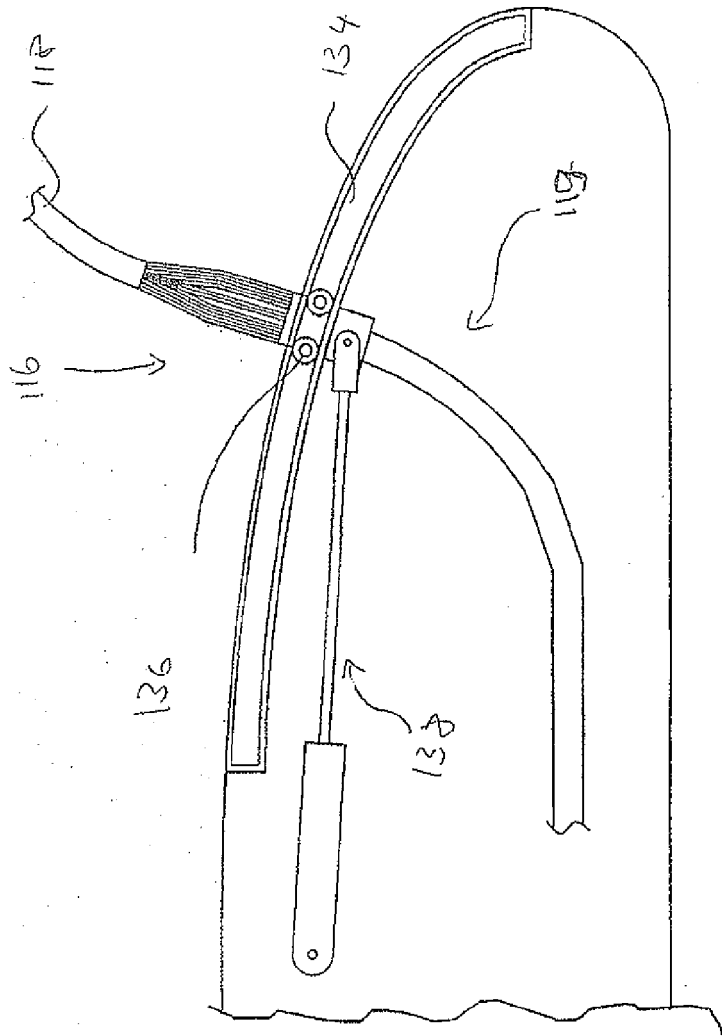


Figure 7

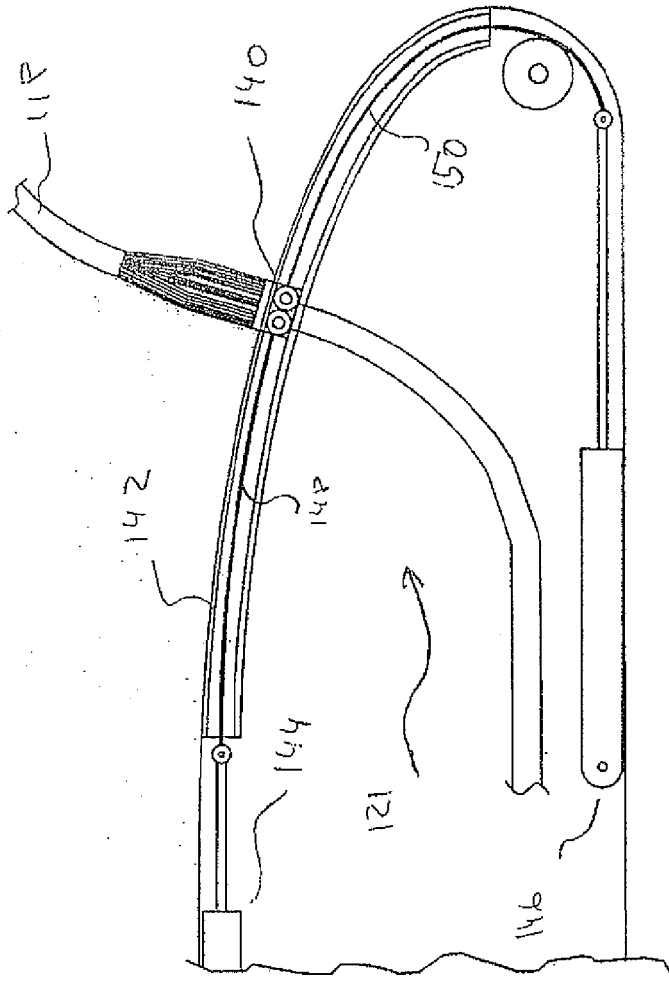


Figure 8

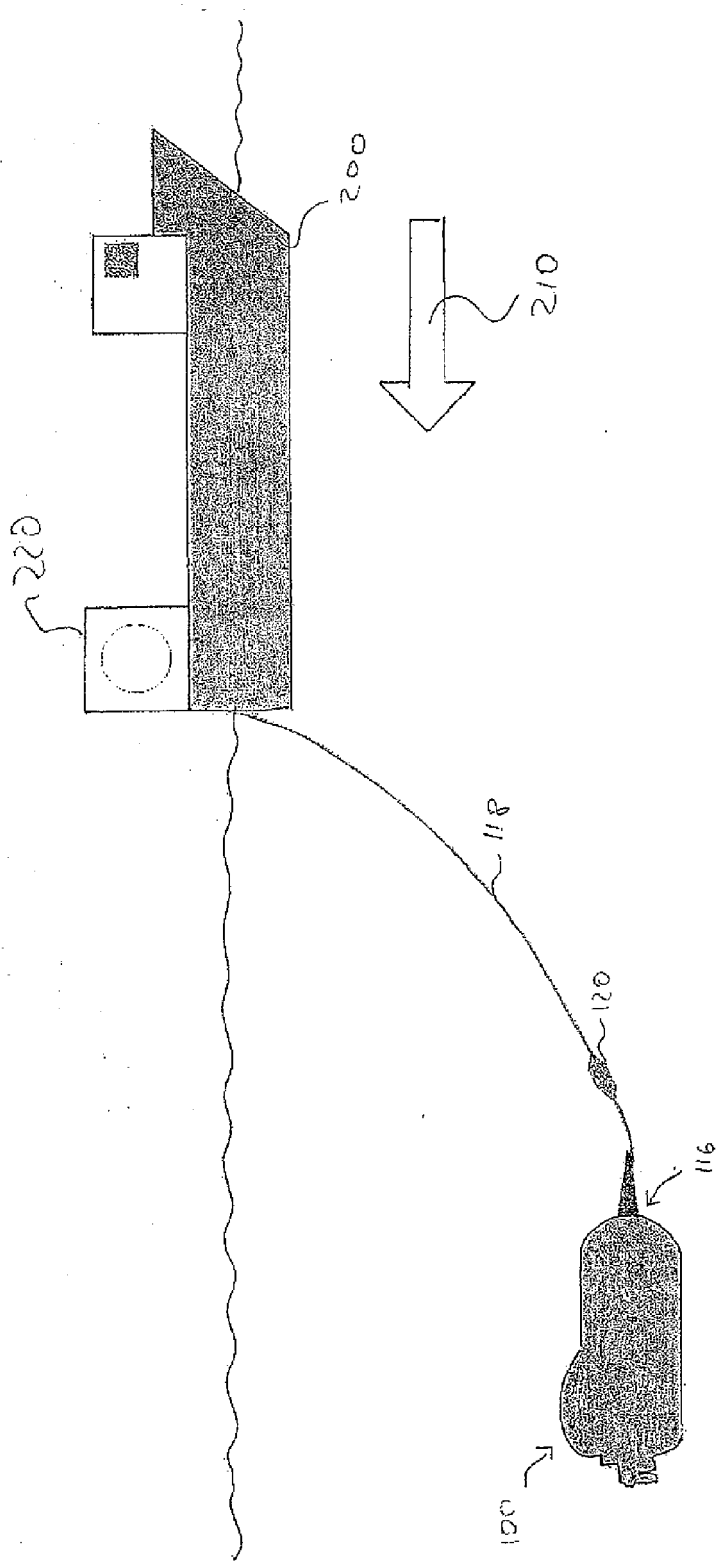


Fig. 9

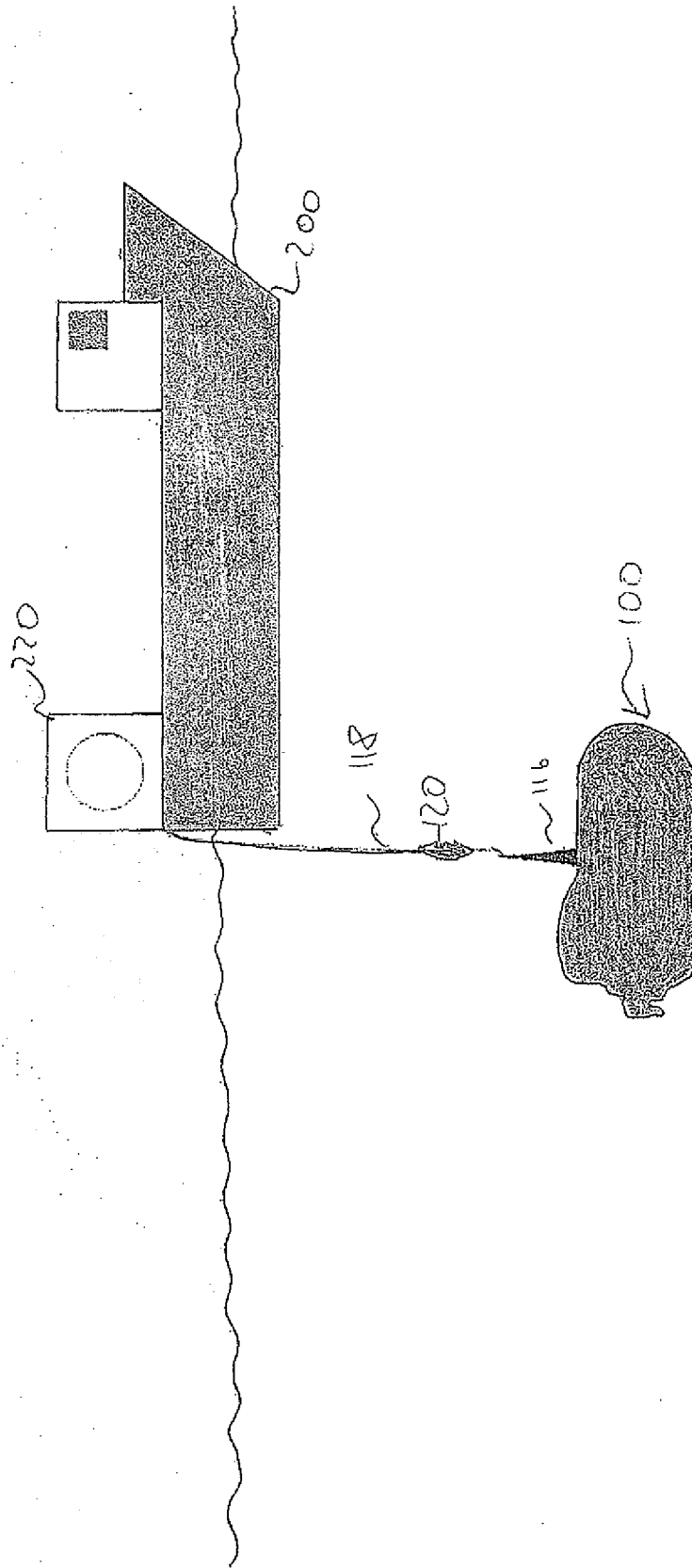


Fig. 10



EUROPEAN SEARCH REPORT

Application Number
EP 09 17 8230

| DOCUMENTS CONSIDERED TO BE RELEVANT | | | |
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| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC) |
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| CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document | | T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document | |

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