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LAUNCH AND RECOVERY SYSTEM AND METHOD

TECHNOLOGICAL FIELD

The presently disclosed subject matter relates to systems and methods for launching and recovering underwater vehicles.

PRIOR ART

References considered to be relevant as background to the presently disclosed subject matter are listed below:

- US 3,807,335
- US 7,350,475
- US 7,028,627
- US 8,096,254
- US 5,995,882
- US 6,779,475
- US 7,156,036
- US 7,581,507
- US 7,712,429
- US 7,546,814
- US 2006/0254491
- US 2007/0137548
- US 2012/0192780
- US 2013/0025521

Acknowledgement of the above references herein is not to be inferred as meaning that these are in any way relevant to the patentability of the presently disclosed subject matter.

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BACKGROUND

Underwater vehicles have a variety of uses, including for example mine hunting. Some types of such underwater vehicles are launched and recovered by a host surface ship, and launch and recovery systems for such underwater vehicles are known. Conventionally, such systems can only be used safely in calm waters, often require skilled manpower for operating the system, and the systems can often represent a significant capital cost, and corresponding high operating costs.

GENERAL DESCRIPTION

According to at least a first aspect of the presently disclosed subject matter, there is provided an underwater launch and recovery system, comprising:

- a surface water vehicle;
- at least one underwater vehicle;
- a docking system for selectively docking and undocking each said underwater vehicle with respect to the surface vehicle at a selectively controllable water depth, the docking system comprising a docking port for enabling said underwater vehicle to be selectively engaged and disengaged with respect to the docking system (for example docking port is selectively engageable and disengageable with respect to a docking interface that is mounted in or otherwise comprised in the at least one underwater vehicle), wherein the docking port is connected to the surface water vehicle via a movable connector;
- wherein the movable connector is configured for:
 - providing a predetermined said water depth to said docking port for enabling said selectively docking and undocking, and
 - decoupling at least surface heave movement of surface water vehicle from underwater heave movement of the docking port at said predetermined water depth.

Optionally, said predetermined water depth is chosen to provide underwater heave of the underwater vehicle within a predetermined threshold; for example, said predetermined threshold is less than 10cm.

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For example, said predetermined water depth is greater than 5m, or greater than 6m, or greater than 7m, or greater than 8m, or greater than 9m, or greater than 10m.

Additionally or alternatively, said underwater vehicle is any one of an underwater remotely piloted vehicle, an underwater autonomous vehicle and an underwater unmanned towed vehicle.

Additionally or alternatively, said surface vehicle comprises any one of a single hull surface vehicle, a multi hull vehicle for example a twin hull surface vehicle, a hovercraft, a hydrofoil, a submersible vehicle.

Additionally or alternatively, said surface vehicle comprises catamaran type surface vehicle, comprising a pair of hulls laterally spaced via a raised deck.

Additionally or alternatively, said surface vehicle is connected to the underwater vehicle via a tether. For example, said tether provides at least one of power communication and data communication between said surface vehicle and said underwater vehicle.

Additionally or alternatively, said movable connector comprises a connector arm and a joint arrangement, said connector arm comprising a first arm end connected to the joint arrangement, and a second arm end connected to said docking port, and wherein said joint arrangement is configured for:

- enabling selectively providing said predetermined water depth to said docking port via said connector arm, and
- decoupling at least said underwater heave movement of the docking port from surface heave movement of surface water vehicle at said predetermined water depth via said connector arm.

For example, said connector arm and said joint arrangement comprise a lumen.

Additionally or alternatively, said joint arrangement connects said first arm end to said surface vehicle, and is configured for allowing pivoting movement between said first arm end and said surface vehicle in at least one degree of freedom in rotation. For example, said at least one degree of freedom in rotation includes pitch and/or roll and/or yaw.

Additionally or alternatively, in at least one example said joint arrangement comprises passive flexible joint allowing free said pivoting movement between said first arm end and said surface vehicle. For example said passive flexible joint comprises an

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articulated joint. Additionally or alternatively, for example, said connecting arm comprises a single arm segment joining said first arm end to said second arm end, and wherein said single arm segments operates as a rigid body; alternatively, for example, said connecting arm comprises a first arm segment comprising said first arm end, and a second arm segment comprising said second arm end, said first arm segment being connected to said second arm segment via a free joint, and wherein each one of said first arm segment and said second arm segment operates as a rigid body. Additionally or alternatively, in operation of the underwater launch and recovery system for launching or recovering the underwater vehicle, the surface vehicle is caused to move with a forward velocity while the connector arm is at least partially submerged to provide said predetermined water depth to said docking port via said connector arm, the position of the docking port with respect to the surface vehicle via the connector arm defining a pitch angle. For example, at said forward velocity, a tension and a drag are induced in the connector arm; for example, the tension balances the weight and drag of the arm, thereby maintaining the depth and spatial orientation of the docking port stable.

Additionally or alternatively in at least another example, said joint arrangement comprises an active flexible joint arrangement configured for selectively and actively controlling said pivoting movement between said first arm end and said surface vehicle. For example, the connector arm is at least partially submerged to provide said predetermined water depth to said docking port via said connector arm, the position of the docking port with respect to the surface vehicle via the connector arm defining a pitch angle, a roll angle and a yaw angle. For example, the underwater launch and recovery system comprises an inertial control system for providing control inputs regarding the spatial position and attitude of the docking port, and wherein said passive flexible joint comprises a motorized articulated joint arrangement for controllably varying at least one of said pitch angle, roll angle, and yaw angle, responsive to said control inputs. For example, said inertial control comprises inertial sensors for sensing pivoting movement of the docking port about respective pitch, yaw and roll axes, and for sensing accelerations of the docking port along said respective pitch, yaw and roll axes. Additionally or alternatively, for example, said connecting arm comprises a single arm segment joining said first arm end to said second arm end, and wherein said single arm segments operates as a rigid body; alternatively, for example, said connecting arm

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comprises a first arm segment comprising said first arm end, and a second arm segment comprising said second arm end, said first arm segment being connected to said second arm segment via a free joint, and wherein each one of said first arm segment and said second arm segment operates as a rigid body.

Additionally or alternatively, said connector arm is selectively movable between a stowed position and a deployed position, wherein in the stowed position the docking port is immovably engaged to the surface vehicle, and wherein in the deployed position the connector arm is at least partially submerged to:

- provide said predetermined water depth to said docking port via said connector arm, and
- to allow decoupling of at least said underwater heave movement of the docking port from surface heave movement of surface water vehicle at said predetermined water depth via said connector arm.

Additionally or alternatively, the movable connector is configured for decoupling surface pitch and/or roll and/or yaw movements of surface water vehicle from the docking port from at said predetermined water depth.

According to this aspect of the presently disclosed subject matter, there is also provided an underwater launch and recovery method, comprising:

- providing the underwater launch and recovery system as defined herein, in particular as defined above;
- operating the underwater launch and recovery system to launch or recover the at least one said underwater vehicle with respect to the surface vehicle.

According to at least a second aspect of the presently disclosed subject matter, there is provided a docking system for selectively docking and undocking an underwater vehicle with respect to a surface water vehicle at a selectively controllable water depth, the docking system comprising:

a docking port connected to a movable connector,
said docking port being configured for enabling said underwater vehicle to be selectively engaged and disengaged with respect to the docking system;
said movable connector being configured for being mounted to the surface water vehicle;

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the movable connector being further configured for:

providing a predetermined said water depth to said docking port for enabling said selectively docking and undocking, and
decoupling at least surface heave movement of surface water vehicle from underwater heave movement of the docking port at said predetermined water depth.

Optionally, said predetermined water depth is chosen to provide underwater heave of the underwater vehicle within a predetermined threshold; for example, said predetermined threshold is less than 10cm.

For example, said predetermined water depth is greater than 5m, or greater than 6m, or greater than 7m, or greater than 8m, or greater than 9m, or greater than 10m.

For example, said movable connector comprises a connector arm and a joint arrangement, said connector arm comprising a first arm end connected to the joint arrangement, and a second arm end connected to said docking port, and wherein said joint arrangement is configured for:

- enabling selectively providing said predetermined water depth to said docking port via said connector arm, and
- decoupling at least said underwater heave movement of the docking port from surface heave movement of the surface water vehicle at said predetermined water depth via said connector arm.

For example, said connector arm and said joint arrangement comprise a lumen.

For example, said joint arrangement is configured for connecting said first arm end to said surface vehicle, and is configured for allowing pivoting movement between said first arm end and the surface water vehicle in at least one degree of freedom in rotation. For example, said at least one degree of freedom in rotation includes pitch and/or roll and/or yaw.

Additionally or alternatively, for example, said joint arrangement comprises passive flexible joint allowing free said pivoting movement between said first arm end and said surface vehicle. For example, said passive flexible joint comprises an articulated joint. For example, said connecting arm comprises a single arm segment joining said first arm end to said second arm end, and wherein said single arm segments operates as a rigid body. Alternatively, for example, said connecting arm comprises a

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first arm segment comprising said first arm end, and a second arm segment comprising said second arm end, said first arm segment being connected to said second arm segment via a free joint, and wherein each one of said first arm segment and said second arm segment operates as a rigid body.

Additionally or alternatively, for example, in operation of an underwater launch and recovery system for launching or recovering the underwater vehicle using said docking system, the surface vehicle is caused to move with a forward velocity while the connector arm is at least partially submerged to provide said predetermined water depth to said docking port via said connector arm, the position of the docking port with respect to the surface vehicle via the connector arm defining a pitch angle. For example, at said forward velocity, a tension and a drag are induced in the connector arm. For example, the tension balances the weight and drag of the arm, thereby maintaining the depth and spatial orientation of the docking port stable.

Alternatively, for example, said joint arrangement comprises an active flexible joint arrangement configured for selectively and actively controlling said pivoting movement between said first arm end and said surface vehicle. For example, the connector arm is at least partially submerged to provide said predetermined water depth to said docking port via said connector arm, the position of the docking port with respect to the surface vehicle via the connector arm defining a pitch angle, a roll angle and a yaw angle. For example, the docking system comprises an inertial control system for providing control inputs regarding the spatial position and attitude of the docking port, and wherein said passive flexible joint comprises a motorized articulated joint arrangement for controllably varying at least one of said pitch angle, roll angle, and yaw angle, responsive to said control inputs. For example, said inertial control comprises inertial sensors for sensing pivoting movement of the docking port about respective pitch, yaw and roll axes, and for sensing accelerations of the docking port along said respective pitch, yaw and roll axes.

Additionally or alternatively, for example, said connecting arm comprises a single arm segment joining said first arm end to said second arm end, and wherein said single arm segments operates as a rigid body. Alternatively, for example, said connecting arm comprises a first arm segment comprising said first arm end, and a second arm segment comprising said second arm end, said first arm segment being

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connected to said second arm segment via a free joint, and wherein each one of said first arm segment and said second arm segment operates as a rigid body.

Additionally or alternatively, for example, said connector arm is selectively movable between a stowed position and a deployed position, wherein in the stowed position the docking port is immovably engaged to the surface vehicle, and wherein in the deployed position the connector arm is at least partially submerged to:

- provide said predetermined water depth to said docking port via said connector arm, and
- to allow decoupling of at least said underwater heave movement of the docking port from surface heave movement of the surface water vehicle at said predetermined water depth via said connector arm.

Additionally or alternatively, for example, the movable connector is configured for decoupling surface pitch, roll and yaw movements of surface water vehicle from the docking port from at said predetermined water depth.

According to at least the second aspect of the presently disclosed subject matter, there is provided a surface water vehicle comprising the docking system as defined herein, in particular above for the second aspect of the presently disclosed subject matter.

According to at least a third aspect of the presently disclosed subject matter, there is provided an underwater launch and recovery method, comprising:

- providing a surface water vehicle;
- providing at least one underwater vehicle;
- providing a docking system for selectively docking and undocking each said underwater vehicle with respect to the surface vehicle at a selectively controllable water depth, the docking system comprising a docking port selectively engageable and disengageable with respect to the at least one underwater vehicle (for example the docking port is selectively engageable and disengageable with respect to a docking interface mounted to or otherwise comprised in the at least one underwater vehicle), wherein the docking port is connected to the surface water vehicle via a movable connector;
- providing a predetermined said water depth to said docking port via said movable connector for enabling said selectively docking and undocking, and

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- decoupling at least surface heave movement of surface water vehicle from underwater heave movement of the docking port at said predetermined water depth via said movable connector.

For example, the underwater launch and recovery method comprises choosing said predetermined water depth to provide underwater heave of the underwater vehicle within a predetermined threshold; for example said predetermined threshold is less than 10cm.

Additionally or alternatively, said underwater vehicle is any one of an underwater remotely piloted vehicle, an underwater autonomous vehicle and an underwater unmanned towed vehicle, and wherein said surface vehicle comprises any one of a single hull surface vehicle, a twin hull surface vehicle, a hovercraft, a hydrofoil, a submersible vehicle.

Additionally or alternatively, at least during operation of said underwater vehicle, said surface vehicle is connected to said underwater vehicle via a tether. For example, the underwater launch and recovery method comprises providing at least one of power and data communication between said surface vehicle and said underwater vehicle at least during operation of the underwater vehicle.

Additionally or alternatively, said movable connector comprises a connector arm and a joint arrangement, said connector arm comprising a first arm end connected to the joint arrangement, and a second arm end connected to said docking port, and wherein said joint arrangement is configured for:

- enabling selectively providing said predetermined water depth to said docking port via said connector arm, and
- decoupling at least said underwater heave movement of the docking port from surface heave movement of surface water vehicle at said predetermined water depth via said connector arm.

For example, the underwater launch and recovery method comprises allowing pivoting movement between said first arm end and said surface vehicle in at least one degree of freedom in rotation at least during docking or undocking operation between the underwater vehicle and the docking port. For example said at least one degree of freedom in rotation includes pitch and/or roll and/or yaw.

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Additionally or alternatively, in at least one example, the underwater launch and recovery method comprises allowing free said pivoting movement between said first arm end and said surface vehicle. For example, said connecting arm comprises a single arm segment joining said first arm end to said second arm end, and wherein said single arm segments operates as a rigid body; or for example said connecting arm comprises a first arm segment comprising said first arm end, and a second arm segment comprising said second arm end, said first arm segment being connected to said second arm segment via a free joint, and wherein each one of said first arm segment and said second arm segment operates as a rigid body. Additionally or alternatively, for example, the underwater launch and recovery method comprises causing the surface vehicle to move with a forward velocity while the connector arm is at least partially submerged to provide said predetermined water depth to said docking port via said connector arm, the position of the docking port with respect to the surface vehicle via the connector arm defining a pitch angle. For example, at said forward velocity, a tension and a drag are induced in the connector arm. For example, the forward velocity is chosen such that the tension balances the weight and drag of the arm, thereby maintaining the depth of the docking port at said predetermined water depth stable, and the spatial orientation of the docking port stable.

Additionally or alternatively, in at least another example, the underwater launch and recovery method comprises selectively and actively controlling said pivoting movement between said first arm end and said surface vehicle. For example, the connector arm is at least partially submerged to provide said predetermined water depth to said docking port via said connector arm, the position of the docking port with respect to the surface vehicle via the connector arm defining a pitch angle, a roll angle and a yaw angle. For example, the underwater launch and recovery method comprises providing control inputs regarding the spatial position and attitude of the docking port, and controllably varying at least one of said pitch angle, roll angle, and yaw angle, responsive to said control inputs. For example, the underwater launch and recovery method comprises sensing pivoting movement of the docking port about respective pitch, yaw and roll axes, and sensing accelerations of the docking port along said respective pitch, yaw and roll axes, to provide said control inputs. For example, said connecting arm comprises a single arm segment joining said first arm end to said

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second arm end, and wherein said single arm segments operates as a rigid body; alternatively, for example, said connecting arm comprises a first arm segment comprising said first arm end, and a second arm segment comprising said second arm end, said first arm segment being connected to said second arm segment via a free joint, and wherein each one of said first arm segment and said second arm segment operates as a rigid body.

Additionally or alternatively, the underwater launch and recovery method comprises selectively moving the connector arm between a stowed position and a deployed position, wherein in the stowed position the docking port is immovably engaged to the surface vehicle, and wherein in the deployed position the connector arm is at least partially submerged to:

- provide said predetermined water depth to said docking port via said connector arm, and
- to allow decoupling of at least said underwater heave movement of the docking port from surface heave movement of surface water vehicle at said predetermined water depth via said connector arm.

Additionally or alternatively, the underwater launch and recovery method comprises decoupling surface pitch, roll and yaw movements of surface water vehicle from the docking port at said predetermined water depth.

A feature of at least some examples of the presently disclosed subject matter is that launching and recovery of the underwater vehicle by the surface vehicle is possible at WMO Sea States greater than 1, including 3, 4, and 5, and even higher, depending on the ruggedness and/or design of the underwater vehicle and the docking port of the surface vehicle, and/or on the depth at which the docking operation is performed.

Another feature of at least some examples of the presently disclosed subject matter is that launching and recovery of the underwater vehicle by the surface vehicle can be carried out in an autonomous or remotely piloted manner, enabling the operators to be far away from the launching and recovery site; at the same time, this also allows the surface vehicle to ferry the underwater vehicle to a launch and recovery site, safely and at high speed. Such a feature may be useful where the operational site can be dangerous, for example a mine field.

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Another feature of at least some examples of the presently disclosed subject matter is that the surface vehicle can transfer the underwater vehicle from one desired location to another in a time and cost effective manner.

Another feature of at least some examples of the presently disclosed subject matter is that the underwater vehicle can be configured for mine clearing operations, including follow up damage assessment after neutralization of the mine, in a safe and efficient manner.

Another feature of at least some examples of the presently disclosed subject matter is that the underwater vehicle can operate in the desired manner while tethered to the surface vehicle close thereby, requiring a relatively short tether, minimizing risk of cable entanglement, and minimizing the forces applied by, and thus the effects of, underwater currents on the cable.

Another feature of at least some examples of the presently disclosed subject matter is that the surface vehicle can be maintained in a position close to the underwater vehicle, for example providing power thereto via a tether, and serving as a radio and/or satellite communication relay station or platform for the underwater vehicle.

Another feature of at least some examples of the presently disclosed subject matter is that the underwater vehicle can be brought into proximity with and locked with respect to the surface vehicle in a safe manner, even in non-calm sea surface conditions.

Another feature of at least some examples of the presently disclosed subject matter is that the underwater vehicle can be reeled into close proximity to the docking port via the tether, and relative vertical positions between the underwater vehicle and the docking port is maintained stable for a range of WMO Sea States, including WMO Sea States greater than 1.

Another feature of at least some examples of the presently disclosed subject matter is that the launch and recovery system can be used for a variety of applications, including for example one or more of the following: wherein the underwater vehicle is a towable sonar array; for the launch and recovery of ROV's and other underwater vehicles used for construction and/or maintenance of equipment in marine oil fields and marine gas fields, or used for underwater survey and/or underwater rescue and/or underwater archaeology and/or other underwater operations, even in high sea states.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to better understand the subject matter that is disclosed herein and to exemplify how it may be carried out in practice, examples will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 illustrates in bottom isometric view, a first example of the launch and recovery system in deployed mode.

Fig. 2 illustrates in side view the example of Fig. 1.

Fig. 3 illustrates in rear view the example of Fig. 1; **Fig. 3(a)** illustrates the example of Fig. 3 in retracted mode.

Fig. 4 illustrates in partial fragmented side view an alternative variation of the example of Fig. 1.

Fig. 5 illustrates in partial fragmented rear view the movable connector of the example of Fig. 3(a).

Fig. 6 illustrates in partial fragmented isometric view the portions of the flexible joint of the example of Fig. 4.

Fig. 7 schematically illustrates variation of particle excursions with depth and surface heave movements of the surface vehicle of the example of Fig. 1.

Fig. 8 schematically illustrates forces acting on the movable connector in operation of the example of Fig. 1.

Fig. 9(a) and **Fig. 9(b)** schematically illustrate decoupling of the surface movements of the surface vehicle with respect to the docking port for the example of Fig. 1.

Fig. 10 illustrates in side view an alternative variation of the example of Fig. 1.

Fig. 11 illustrates in isometric rear view another alternative variation of the example of Fig. 1 in retracted mode.

Fig. 12 illustrates in isometric rear view the example of Fig. 11 in deployed mode.

Fig. 13 illustrates in isometric side view the example of Fig. 12 with the underwater vehicle disengaged from the docking port.

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Fig. 14 schematically illustrates in rear view the example of Fig. 11 in deployed mode.

Fig. 15 illustrates in side view, a second example of the launch and recovery system in deployed mode.

Fig. 16 illustrates in side view an alternative variation of the example of Fig. 15.

DETAILED DESCRIPTION

Referring to Figs. 1 to 3, a system for launch and/or recovery of underwater vehicles (also referred to interchangeably herein as a launch and recovery system) according to a first example of the presently disclosed subject matter, generally designated **100**, comprises a surface vehicle **200**, an underwater vehicle **300**, and a docking system **400** including a movable connector **500** (also referred to interchangeably herein as a movable docking arm system **500**).

While in this example, the system **100** is used for launch and/or recovery of one underwater vehicle, the skilled practitioner appreciates that in alternative variations of this example and in other examples, the system **100** can be modified to include a plurality of underwater vehicles **300**, suitably disposed on correspondingly suitably sized surface vehicle **200**, and each of the underwater vehicles **300** can be launched and/or recovered from the surface vehicle **200**.

While in this example, the system **100** is used both for launch and recovery of an underwater vehicle, the skilled practitioner appreciates that the system **100** can be used only for launching the underwater vehicle **300**, for example when the underwater vehicle **300** is expendable or wherever it is intended for the underwater vehicle **300** not to be rejoined with its surface vehicle **200** but rather to be picked up elsewhere, for example in a conventional manner in calm seas, or by another surface vehicle similar to surface vehicle **200**. Similarly, the skilled practitioner also appreciates that the system **100** can be used only for recovery of the underwater vehicle **300**, for example when the underwater vehicle **300** has been launched via a different surface vehicle (e.g. similar to surface vehicle **200**) or in a conventional manner in calm seas, and for example the surface vehicle **200** is sent to pick up the underwater vehicle **300** at the end of its mission.

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The surface vehicle **200** (also referred to interchangeably herein as a water surface vehicle, or as a water surface vessel, or as a surface vessel) is configured for travelling over a water surface (such as the surface of the ocean, or the surface of the sea, or the surface of a lake, or the surface of a river, or the surface of a water reservoir or other artificial body of water, for example) and for floating on the water surface, at least during launching and/or recovery operations of launch and recovery system **100**.

In this example, the surface vehicle **200** is self propelled, and includes any suitable marine propulsion system. Such a marine propulsion system can include, for example any suitable internal combustion engine, for example diesel propulsion systems and hydraulic systems for reducing electromagnetic signature, or electric propulsion system, or a hybrid propulsion system.

The surface vehicle **200** in this example is in the form of a catamaran, comprising a port hull **202** and a starboard hull **204**, each being, for example, of multi-cell configuration.

The port hull **202** and the starboard hull **204** are connected and laterally spaced from one another via a deck in the form of a raised, partially open frame **210**, having a frame underside **215**.

In this example, the surface vehicle **200** is unmanned, and is operated remotely by an operator via a suitable radio or satellite link (not shown), or is operated autonomously, and can include a suitable control and navigation system, optionally including any suitable satellite based positioning system, for example GPS.

In alternative variations of this example and in other examples, the surface vehicle **200** can have other configurations. For example, the surface vehicle can be configured as a multi-hull or single-hull surface vessel or any other surface boat, or hydrofoil, or a hovercraft, or a submersible craft (that nevertheless operates on or near the surface of the water at least during launch and/or recovery operations of launch and recovery system **100**), and/or, the surface vehicle **200** can be manned. Nevertheless, the catamaran configuration for the surface vehicle **200** can provide a number of features including one or more of the following: greater stability during launch and/or recovery of the underwater vehicle; enables the launch and/or recovery of underwater vehicle to occur near to the center of gravity of the surface vehicle in a simple design; allows for launch and/or recovery of underwater vehicle without the need for the surface vehicle to be submerged

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thereby simplifying the design and minimizing the cost of the surface vehicle as compared with for example other configurations.

The underwater vehicle **300** (also referred to interchangeably herein as a submersible vehicle, or as a submersible vessel, or as an underwater vessel) is configured for operating when submerged, and can take many different forms. In this example, the underwater vehicle **300** is self propelled, comprising a suitable underwater propulsion system and a suitable underwater maneuvering system (not shown), and is tethered to the surface vehicle **200** via a tether **250**, for example in the form of a cable. In at least this example, the tether **250** is configured for providing power transmission and/or data communication between the surface vehicle **200** and the underwater vehicle **300**, at least in operation of the underwater vehicle.

In this example, the underwater vehicle **300** is also configured for mine hunting, including one or more of surveillance, hunting, location, detection, identification and neutralization of underwater mines, and other underwater operations. Thus, the underwater vehicle **300** comprises one or more of the following: suitable sensors, for example imaging equipment (optical imaging and/or sonar imaging (for example synthetic aperture sonar SAS)), guidance equipment, and also mine neutralization equipment (for example explosive charges that are controllably detonated when secured in place, by the underwater vehicle **300**, in proximity to a located mine); manipulators, for example in the form of articulated manipulator arms for performing mechanical tasks in a marine environment, including for example for cutting the anchoring cable of moored mines. In this example, the underwater vehicle **300** is unmanned, and is also remotely piloted, via an operator in a geographic location that is suitably spaced from the underwater vehicle **300**. Sensor feeds from the underwater vehicle **300** are transmitted to the operator via the radio or satellite link provided by the surface vehicle **200**, in communication with the underwater vehicle **300** via data/communication lines (not shown) parallel to or provided in the tether **250**, and operator commands to the underwater vehicle **300** are received by the radio or satellite link and channeled to the underwater vehicle **300** via the data/communications lines.

However, in alternative variations of the above or other examples, the underwater vehicle **300** can be configured for performing different tasks – for example underwater archaeology, and/or underwater exploration, and/or Oceanic floor surveying, and/or hunting/location/detection/identification of sunken ships or objects, and/or study of ocean

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ecology, and/or detection of smuggling operations, and/or undersea search and rescue, and/or underwater works (for example hunting/location/detection/identification gas fields, oil field, minerals, etc. and/or mining), and/or guarding/maintenance/managing fish farms, and/or underwater cable inspection and maintenance, and/or underwater pipe inspection and maintenance, and so on.

Additionally or alternatively, in alternative variations of the above or other examples, the underwater vehicle can have different configurations, including for example one of the following: the underwater vehicle is self propelled and is configured for operating unmanned in an autonomous manner, with or without a tether; the underwater vehicle is self propelled and is remotely operated without a tether, for example via acoustic communication; the underwater vehicle is optionally not self propelled, and is configured for operating unmanned, and operates while being towed by the surface vehicle – for example the underwater vehicle is configured as a towed sonar array.

The docking system **400** is configured for enabling the underwater vehicle **300** to be selectively engaged and secured with respect to the surface vehicle **200**, particularly during recovery mode of the launch and recovery system **100**, and for enabling the underwater vehicle **300** and the surface vehicle **200** to be selectively disengaged with respect to one another, particularly during launching mode of the launch and recovery system **100**. The docking system **400** comprises a docking port **410** selectively engageable and disengageable with respect to the underwater vehicle **300**, for example via a docking interface **420**. The docking interface **420** is mounted to or is otherwise comprised in the underwater vehicle **300**. The docking port **410** is connected to the surface vehicle **200** via the selectively movable interconnector **500**.

In this example, the docking port **410** comprises docking arms **415** that are movable from an open position **OP** to a closed position **CP**. In the open position, the docking interface **420** can be brought into proximity and engagement with the docking port **410**, after which the docking arms **415** close to the closed position **CP**, locking the docking interface **420** with respect to the docking port **410**, and thus locking the underwater vehicle **300** with respect to the surface vehicle **200**. Referring also to Fig. 4, the docking arms **415** optionally comprise fenders **418** for absorbing or damping impact loads that be applied between the docking interface **420** and the docking port **410** during recovery and engagement operations of the docking system **400**.

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In alternative variations of this example, the docking port can comprise a cage or hangar for accommodating therein the underwater vehicle **300**, and the docking interface can comprise, for example, any part of the underwater vehicle **300** that can engage with the inside of the cage or hangar. For example the underwater vehicle **300** comprises skis for enabling the underwater vehicle **300** to rest on a surface, and such skis can constitute or form part of the docking interface. In addition, clamps can be provided to secure the underwater vehicle **300** to the inside of the hangar or cage.

A docking head **450** is provided proximal to docking port **410**, and accommodates various equipment and services, for example floats and an instrument box including for example control mechanism for the docking port, data communication equipment, ballast tanks, gauges including at least depth gauges, magazines for replenishing expendable cargo of the underwater vehicle **300**, and power for the underwater vehicle **300**. Such cargo can include, for example, suitable explosives that can be used for detonating undersea mines. Thus, the underwater vehicle **300** can optionally be resupplied when docked, and/or its batteries recharged, and/or data (including new or updated operating instructions) can be uploaded or downloaded between the surface vehicle **200** and the underwater vehicle **300**.

Optionally, the cable or tether **250** can be configured for powering the underwater vehicle **300** while docked or while undocked, and/or for enabling the underwater vehicle **300** to have its batteries recharged, and/or for enabling data (including new or updated operating instructions) to be uploaded or downloaded between the surface vehicle **200** and the underwater vehicle **300**, either continuously or periodically.

Optionally, and particularly in alternative variations of the above example and in other examples, the launch and recovery system comprises an acoustic pinger mounted to the docking port **410** or docking head **450**. Additionally or alternatively, a set of approach and docking lights can be provided in the underwater vehicle **300** and an optical sensor or imaging camera in the docking head **450** or docking port **410** to facilitate homing and navigation of the underwater vehicle **300** and capture via the docking system **400**, particularly where there is no tether between the underwater vehicle and the surface vehicle **200**; additionally or alternatively, docking lights can be provided in docking head **450** or docking port **410**, and the an optical sensor or imaging camera in the underwater vehicle **300**.

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Additionally or alternatively, an acoustic homing system (for example comprising an acoustic pinger in one of the underwater vehicle **300** or the docking system **400**, and an acoustic receiver in the other one of the underwater vehicle **300** or the docking system **400**) can also be provided to facilitate homing and navigation of the underwater vehicle **300** and capture via the docking system **400**, particularly where there is no tether between the underwater vehicle and the surface vehicle **200**.

Referring also to Fig. 7, the movable interconnector **500** is configured for providing a predetermined submerged depth **H** to the docking port **410** while the surface vehicle **200** is on the water surface, to thereby enable selective docking and undocking between the surface vehicle **200** and the underwater vehicle **300** at the predetermined depth **H**. As will become clearer herein, this predetermined depth **H** is a minimum depth at which heave **q** of the underwater vehicle **300** (as a result of water surface conditions, such as wave amplitude) is within an acceptable range **R1**. The movable interconnector **500** is also configured for raising the docking port **410** with the underwater vehicle **300** engaged to the movable interconnector **500** while the surface vehicle **200** is on the water surface, to thereby enable the underwater vehicle **300** to be locked in position with the surface vehicle **200**, for example with the underwater vehicle **300** raised above the water surface.

The movable interconnector **500** is also configured for decoupling at least heave movement **q** of the underwater vehicle **300** at the predetermined depth **H** from surface heave movement **Q** of surface vehicle **200** while the underwater vehicle **300** is connected to or is in close proximity to the surface vehicle **200**, particularly during launch and/or recovery operations. In other words, at least when providing said depth **H** to the docking system **400**, the movable interconnector **500** operates to ensure that most or all of surface heave movements **Q** experienced by the surface vehicle **200** are not transmitted to the underwater vehicle **300** (again, while the underwater vehicle **300** is docking or undocking with respect to the surface vehicle **200**, particularly during launch and/or recovery operations), and thus the underwater vehicle **300** is thereby not compelled to mimic or follow these surface heave moments; rather, the underwater vehicle **300** only experiences the heave **q** appropriate for depth **H** at the prevalent sea state.

It is to be noted that at least in this example, the movable interconnector **500** is also configured for decoupling roll, pitch and yaw movements, in addition to heave movement **q**, of the underwater vehicle **300** at the predetermined depth **H** from surface roll, pitch and

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yaw movements as well as surface heave movement **Q** of surface vehicle **200** while the underwater vehicle **300** is connected to or is in close proximity to the surface vehicle **200**, particularly during launch and/or recovery operations. In other words, at least when providing said depth **H** to the docking system **400**, the movable interconnector **500** operates to ensure that most or all of surface roll, pitch and yaw movements as well as surface heave movements **Q** experienced by the surface vehicle **200** are not transmitted to the underwater vehicle **300** (again, while the underwater vehicle **300** is docking or undocking with respect to the surface vehicle **200**, particularly during launch and/or recovery operations), and thus the underwater vehicle **300** is thereby not compelled to mimic or follow these surface roll, pitch, yaw or heave moments; rather, the underwater vehicle **300** only experiences the roll, pitch and yaw movements and the heave **q** appropriate for depth **H** at the prevalent sea state.

Such surface heave movements **Q** are often caused by surface waves and are correlated to the amplitudes of the surface waves. The greater the sea state, the larger these heave movements **Q** can be. For example, Table I below lists average wave amplitudes (which correlate to surface heave movements **Q**) corresponding to several sea states, as classified by the World Meteorological Organization (WMO).

TABLE I
World Meteorological Organization (WMO) Sea State Codes and Corresponding
Average Wave Amplitudes

WMO Sea State Code	Average Wave Amplitude	Sea Characteristics
0	0	Very calm
1	0 to 0.1m	Calm, rippled
2	0.1m to 0.5m	Smooth, wavelets
3	0.5m to 1.25m	Slight
4	1.25m to 2.5m	Moderate
5	2.5 to 4.0m	Rough

In this example, the movable connector **500** is also configured for decoupling the docking port **410** at the predetermined depth **H** from one, two or all of roll, pitch and yaw surface movements of surface vehicle **200**, again while the underwater vehicle **300** is in

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proximity with the surface vehicle **200**, particularly during launch and/or recovery operations.

In this example, and referring in particular to Fig. 4, the movable connector **500** comprises launch and recovery arm **520** (also referred to interchangeably herein as an arm, or a connector arm, or a boom, or a launch and recovery boom), having a free distal arm end **525** onto which the docking port **410** is mounted via docking head **450**, and a proximal arm end **522** movably connected at to the frame **210** via a joint arrangement in the form of flexible joint **550**.

In particular, the flexible joint **550** is configured to allow the arm **520** to pivot with respect to the surface vehicle **200** in at least two degrees of freedom, i.e., in pitch and roll, and furthermore the flexible joint **550** is movably connected to the surface vehicle **200** to allow the arm **520** to pivot in yaw via the flexible joint **550**. However, in at least some alternative variations of this example the flexible joint **550** is configured to allow the arm **520** to pivot with respect to the surface vehicle **200** in one degree of freedom, i.e., in pitch only (and thus the respective flexible joint only needs to allow pivoting in pitch), or, the flexible joint **550** is configured to allow the arm **520** to pivot with respect to the surface vehicle **200** in only in two degrees of freedom, i.e., in pitch and in roll only (and thus the respective flexible joint is fixedly connected to the surface vehicle **200** and does not allow the arm **520** to pivot in yaw via the respective flexible joint).

In this example, flexible joint **550** comprises an articulated joint construction, for example a universal joint or a Cardan joint, having a plurality (at least two) joint elements **560**. In Fig. 4, the flexible joint **550** is shown as having five joint elements **560**, but in alternative variations of this example a different number of joint elements can be provided. In any case, each pair of adjacent joint elements **560** are pivotably connected to one another with respect to a pivot axis **P**, and adjacent pivot axes **P** are orthogonal to one another and orthogonal to the longitudinal axis of the respective joint elements **560**. The most distal joint element **560D** is pivotably mounted to the proximal end **522** of the arm **520**. The most proximal joint element **560P** is pivotably mounted to a rotary stage **566** on the underside **215** by another pivot axis **P**. The rotary stage **566** is itself pivotably mounted to the underside **215** about the yaw axis **YA** of the surface vehicle **200**, allowing the arm **520**-flexible joint **550** assembly to yaw with respect to the surface vehicle **200**.

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independently of the pitch angle θ and independently of the roll angle ϕ of the arm **520** (see Fig. 2).

In alternative variations of the above example and in other examples, the flexible joint **550** can have any other suitable form, for example, a bellows arrangement or asemi-stiff tubing, in either case comprising a suitable guide for the tether **250** to pass therethrough.

In this example, the arm **520** is formed as a single element, in the sense that the arm **520** pivots with respect to the surface vehicle **200** as a rigid body. Furthermore, the arm **520** is tubular, elongate and rectilinear in this example.

As can be seen in Fig. 2, the arm **520** can be pivoted about a pitch axis **PA** of the surface vehicle **200** from a retracted or stowed position **RP** generally parallel to the underside **215** to a deployed position **DP** in which the arm **520** is at a pitch angle θ with respect to the longitudinal axis **LA** of the surface vehicle **200**. In this example, the flexible joint **550** provides a full range **R2** for pitch angle θ from at least 0° (parallel to the longitudinal axis **LA** of the surface vehicle **200**, and the arm facing aft) in a clockwise direction as viewed in Fig. 2 to at least -180° (again parallel to the longitudinal axis **LA** of the surface vehicle **200**, and the arm facing forward). Optionally, the pitch angle θ can reach a positive value of about $+10^\circ$ in the stowed position, i.e., counterclockwise from the 0° position. This can be useful in further raising the docking system **400** including the movable connector **500**, above the water line.

In the deployed mode this range for pitch angle θ is nominally from about -5° to about -175° , and in practice, in the deployed mode the pitch angle θ is between about -5° to about -90° , typically between about -30° to about -60° , for example any one of -35° or -40° or -45° or -50° or -55° .

Referring again to Fig. 4 in particular, a main cable **529** is connected at one end **528** thereof to the docking port **410** that is at the free distal end **525** of the arm **520**, and this main cable **529** is connected at the other end **527** thereof to a winch or windlass **528** mounted to an aft end of the frame **210**, the windlass **528** being configured for selectively winching the arm **250** from the deployed position **DP** to the retracted position **RP**.

The windlass **528** is optionally also configured for selectively allowing the arm **520** to deploy from the retracted position **RP** to any desired maximum deployed position **DP**,

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and for selectively changing the maximum deployed position **DP** to a different maximum deployed position **DP**. Thus, the length of main cable **529** that is reeled out from windlass **528** (with respect to the retracted position **RP**) determines the maximum pitch angle θ available for the arm **520** (corresponding to the maximum deployed position **DP**), and this enables the arm to adopt a smaller, desired pitch angle θ when the main cable **529** is thus reeled out, thereby enabling the arm **520** to naturally adopt the desired pitch angle θ (smaller than the maximum pitch angle θ) during launch or recovery operations of the system **100**, without interference from the main cable **529**.

A releasable locking mechanism **270** is also provided for locking the docking system **400** in the retracted portion **RP**, and comprises a hook element **272** at the end **528** of cable **529**, and a catch or bar element **274** near the windlass **528** for selectively engaging/disengaging with the hook element **272**. Additional clamping elements can optionally be provided to further secure the docking system **400** and the underwater vehicle **300** to the surface vehicle **200**.

Referring in particular to Figs. 1, 3 and 3(b), the underside **215** further optionally comprises wedge-shaped guides **280** for guiding the arm **520** into the retracted position **RP**. As can be seen in Fig. 5, the guides **280** can optionally comprise fenders **282** with shock absorbing elements **281** for absorbing or damping impact loads that be applied between the arm **520** and the surface vehicle **200** during deployment or retraction operations of the arm **520**.

In addition, the arm **520** can optionally also be pivoted about a yaw axis **YA** of the surface vehicle **200** while in the deployed position **DP** in which the arm **520** is at a yaw angle β with respect to the longitudinal axis **LA** of the surface vehicle **200** (see Fig. 1). Similarly, the arm **520** can optionally also be pivoted about a roll axis (typically the longitudinal axis **LA** or parallel thereto) of the surface vehicle **200** while in the deployed position **DP** in which the arm **520** is at a roll angle ϕ with respect to the yaw axis **YA** of the surface vehicle **200** (see Fig.3).

In this example, the flexible joint **550** provides a range for yaw angle β from about $+45^\circ$ to about -45° . It is to be noted that typically, while the surface vehicle **200** is in forward motion and the arm **520** is the deployed position **DP**, the yaw angle β is negligible, i.e. 0° or close thereto. The degree of freedom in yaw for the arm **520** is

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typically useful in situations wherein the surface vehicle **200** is stationary, and it may be useful for the arm to pivot in an unrestricted manner in pitch, roll and yaw. On the other hand, the surface vehicle **200** can be fitted with maneuvering thrusters to maintain position as well as orientation, in which case the flexible joint **550** can be fixedly mounted to the surface vehicle **200**, i.e., without allowing pivoting in yaw.

As can be seen in Fig. 3, two auxiliary cables **567** can optionally be provided to control sideways movement of the free distal end **525** of the arm **520**, and thus to control or limit the yaw angle β and the roll angle ϕ of the arm **520** at any desired pitch angle θ , in particular during launch or recovery operations where the arm is rising towards, or falling away from the locked position with respect to the surface vehicle **200**, when the arm **520** is out of the water. Each auxiliary cable **567** is connected to one or the other lateral side of the free distal end **525** and to a respective winch and windlass system **569** symmetrically mounted to an aft end of the frame **210** with respect to the retracted position **RP** of the arm **520**. The two winch and windlass systems **529** are interconnected and the length of auxiliary cable **528** that is reeled out from each windlass **529** limit sideways movement of the arm particular during launch and recovery operations by limiting the yaw angle β and the roll angle ϕ , minimizing risk of collision between the arm and the surface vehicle **200**.

Referring again to Fig. 4, the arm **520** and the flexible joint **550** are hollow, comprising a lumen, allowing the tether **250** to pass from a reel or drum **255**, mounted on the surface vehicle **200**, via cable guide **258** and rollers **253** through the flexible joint **550** and the arm **520** to the docking port **410** and thence to the underwater vehicle **300**. As best seen in Fig. 6, the individual joint elements **560** can each be provided with a pair of spaced rollers **563** to facilitate reeling in and reeling out of the tether **250** with respect to the drum **255** (driven by a suitable powered winch, not shown), as the underwater vehicle is brought into proximity with and distanced from, respectively, the surface vehicle **200**. The rollers **563** also minimize friction between the joint elements **560** and the tether **250** (or at least the part thereof that is inside the flexible joint **550**), protect the tether **250**, and allow efficient and smooth decoupling of heave movement of the underwater vehicle **300** from surface heave movement of surface vehicle **200** via movable interconnector **500**. The rollers **563** also allow efficient and smooth decoupling of pitch, roll and yaw movement of the underwater vehicle **300** from surface movements of surface vehicle **200** via movable interconnector **500**.

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The drum **255** can be mounted on the upper side **216** or on the lower side **215** of the frame **210**, for example on the rotary stage **566** to pivot in yaw together with the arm **520**, thereby minimizing or eliminating risk of twisting of the tether **250** during yawing movements.

Referring to Figs. 7 and 8, the launch and recovery system **100** can be used according to the following method for launch and/or recovery of underwater vehicles **300**, even at seas states greater than WMO sea states 0 and 1 that correspond to calm waters.

According to at least a first example of this method, the underwater vehicle **300** is in close proximity to the docking port **410** (both, when launching or recovering the underwater vehicle **300**), and relative movement between the two, caused by movement of the surrounding water environment, is minimized.

For the purpose of minimizing this relative movement, docking and undocking of the underwater vehicle **300** with respect to the surface vehicle **200** is carried out at a predetermined depth **H** for the underwater vehicle **300**, in which heave of the underwater vehicle **300** as a direct result of water surface conditions is within a range of, for example, about 0m to 0.1m, but can be greater according to the ruggedness of the underwater vehicle **300** and of the docking port **410**. In particular, docking and undocking of the underwater vehicle **300** with respect to the surface vehicle **200** is carried out at a predetermined depth **H** for the underwater vehicle **300**, in which relative heave displacements between the underwater vehicle **300** and the docking port **410**, as a direct result of water surface conditions, is within range **R**. For example, **R** can be the range 0m to 0.1m, and the relative speed between the underwater vehicle **300** and the docking port **410** can be a few cm/sec, allowing soft docking without damaging the underwater vehicle **300** or the arm **520** or the docking port **410**.

It is well known in the art that (water) particle motion amplitude reduces with depth away from the water surface. Thus, for example, given a WMO Sea State of **3**, with a particular surface wave having an amplitude of 1.10m and wavelength 14m, surface (water) particles will move vertically through an amplitude of 1.10m; however, at a sea bed depth of 10m or greater, (water) particles at a depth of about 7m will only exhibit heave with an amplitude of about 0.05m.

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According to some theoretical studies (for example the Airy Wave Theory or Linear Wave Theory), particle movement ζ (also referred to interchangeably herein as particle excursion or particle motion amplitude) of water particles in deep water (i.e., the water depth h to the sea bed being greater than half the surface wave lengths) reduces exponentially with depth. The term “sea bed” is used herein interchangeably with “sea bottom”, and also refers to the bottom of other bodies of water, for example rivers, lakes, reservoirs, etc., *mutatis mutandis*.

Thus, particle movement ζ at surface depth z (i.e., at an average depth z from the water surface) is related to surface wave amplitude A_0 , surface wave length λ , and depth z , by expression (1) below (for sea bottom water depths h greater than half of the wave length λ) :

$$\zeta = A_0 * e^{z(2\pi/\lambda)} \dots\dots\dots (1)$$

For sea bottom water depths h (i.e., depth of water from the surface to the sea bed less than 50% but greater than 5% of surface wave length λ , the vertical particle motion amplitude ζ_v , and the horizontal particle motion amplitude ζ_H can be derived from the following expressions (2) and (3), respectively, provided by the aforesaid the Airy Wave Theory or Linear Wave Theory:

$$\zeta_v = A_0 * (\sinh(2\pi/\lambda(z + h))) / (\sinh((2\pi/\lambda)*h)) \dots\dots\dots (2)$$

$$\zeta_H = A_0 * (\cosh(2\pi/\lambda(z + h))) / (\sinh((2\pi/\lambda)*h)) \dots\dots\dots (3)$$

Table II below provides examples vertical particle motion amplitude ζ_v , and the horizontal particle motion amplitude ζ_H vertical amplitude as well as horizontal amplitude) for a range of WMO sea states, wave amplitudes and wave lengths, obtained with expressions (1), (2) or (3) above.

TABLE II
Particle Excursion at a Variety of WMO Sea States and Conditions

					Particle Excursion		
WMO Sea State	Significant Wave Height (amplitude) [m]	Average Length of Wave [m]	Water depth [m]	Arm depth [m]	Vertical & Horizontal $h > \lambda / 2$ [m]	Vertical $\lambda/20 < h < \lambda/2$ [m]	Horizontal $\lambda/20 < h < \lambda/2$ [m]
	A_0	λ	h	z	$\zeta = A_0 * e^{z(2\pi/\lambda)}$	ζ_v	ζ_H
3	1.10	14.00	10.00	-7.00	0.05		
3	1.10	14.00	6.00	-4.00		0.15	0.21
3	1.20	16.00	10.00	-7.00	0.08		
3	1.20	16.00	7.00	-5.00		0.13	0.20
5	2.40	32.00	16.00	-7.00	0.61		
5	2.40	32.00	10.00	-7.00		0.43	0.81
5	3.70	48.00	24.00	-7.00	1.48		
5	3.70	48.00	10.00	-7.00		0.87	2.32

Thus, for example, the value for depth **z** corresponding to the predetermined depth **H** for undocking and docking of the underwater vehicle **300** with respect to the surface vehicle **200**, when respectively launching or recovering the underwater vehicle **300**, can be about 7m in WMO sea state 3, with average sea wave lengths of 14m to 16m. In sea depths **h** of 10m or greater, the respective particle motion amplitude ζ will be about 0.05m to 0.08m; even in sea depths **h** of about 6m or 7m, the respective vertical particle motion amplitude ζ_v will be between about 0.13m and 0.15m.

It is also to be noted that the relative motion between the underwater vehicle **300** and the arm **520**, at a mutual spacing between the two of about 1m, is a function of the wavelength λ of the sea waves, approximately $(2/\lambda)$ of the particle excursion ζ , i.e., only a few centimeters, even at a WMO Sea State 5.

The movable connector **500** can be deployed to a desired deployed position **DP** from the retracted position **RP** by unlocking the locking mechanism **270**, and reeling out the cable **529** from the drum **528**, to allow the arm to freely pivot downwardly and adopt any pitch angle θ within a desired range that will enable the docking port **410** to be submerged to the desired predetermined depth **H**.

In operation of the launch and recovery system **100**, the heave motion **Q** of the surface vehicle **200** is decoupled from the docking port **410**, and thus it follows that relative movement (in heave due to the surface wave motion) between the docking port **410** and the underwater vehicle **300** during the aforesaid undocking and docking of the underwater vehicle **300** with respect to the surface vehicle **200**, when respectively launching or recovering the underwater vehicle **300**, is actually very small. In at least some cases, such relative movement is significantly smaller than the heave **q** of the underwater vehicle **300**. In addition, in operation of the launch and recovery system **100**, one or more of, and typically all of, roll pitch and yaw motion of the surface vehicle **200** is decoupled from the docking port **410**, and thus it follows that relative movement (in roll pitch and/or yaw due to the surface wave motion) between the docking port **410** and the underwater vehicle **300** during the aforesaid undocking and docking of the underwater vehicle **300** with respect to the surface vehicle **200**, when respectively launching or recovering the underwater vehicle **300**, is zero or very small.

In operation of the underwater launch and recovery system **100** for launching or recovering the underwater vehicle **300**, the surface vehicle **200** is caused to move with a forward velocity while the connector arm **520** is at least partially submerged to provide a predetermined water depth **H** to the docking port **410** via said connector arm **410**, the position of the docking port with respect to the surface vehicle **200** via the connector arm defining a pitch angle θ . For example, at this forward velocity, a tension and a drag are induced in the connector arm; for example, the tension balances the weight and drag of the arm, thereby maintaining the depth and spatial orientation of the docking port stable.

According to this first example of the method, the heave motion **Q** of the surface vehicle **200** is decoupled from the docking port **410** as follows. Referring in particular to Fig. 8, with the movable connector **500** in the deployed position such that the docking port **410** is at said predetermined depth **H**, the surface vehicle **200** is provided with forward motion at a predetermined velocity **V**, which is maintained at a controlled velocity to ensure that the depth **H** is maintained constant. At velocity **V**, a number of forces are induced at the free end **525** (including the docking port **410** and docking head **450**), including: the weight **mg** of the free end **525** (including the docking port **410** and docking head **450**), acting vertically downwards, drag force **D** induced by the docking

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head **450** and docking port **410** acting in a generally horizontal direction away from the direction of motion of the surface vehicle **200**, and tension **T** in the arm **520**, in a direction along the longitudinal axis thereof towards the surface vehicle **200** and thus at the respective pitch angle θ with respect to the horizontal . Tension **T** thus has a horizontal component that balances the drag **D**, and a vertical component (lift force that balances the weight **mg**. The tension **T** and drag **D** intersect at a point **f** that acts as a fulcrum. Thus, as illustrated in Figs. 9(a) and 9(b), the balance of forces between the tension **T**, drag **D** and weight **mg** maintain the pitch angle θ_H of the arm **520** with respect to the horizontal constant even where the surface vehicle **200** is experiencing severe heave **H** (for example due to severe WMO Sea State conditions), in which surface movements of the surface vehicle **200** (in particular heave movements) are decoupled from the arm **520** via the flexible joint **550**. Thus, and as illustrated in Figs. 9(a) and 9(b), the pitch angle θ_H of the arm **520** with respect to the horizontal constant, while the pitch angle θ between the arm **520** and the longitudinal axis **LA** may be changing, and while the pitch angle θ' between the longitudinal axis **LA** and the horizontal may be changing .

The free end **525**, in particular the docking port **410** and/or the docking head **450**, is configured for providing a desired level of drag **D** when the surface vehicle **200** is travelling at a desired forward velocity **V** for launch and recovery operations.

It is to be noted that according to this first example of the method, the roll, pitch and yaw motions of the surface vehicle **200** are decoupled from the docking port **410** via the flexible joint **550** including the rotary stage **566**.

The drag **D** increases with velocity **V** (and in fact drag **D** is proportional to V^2), and the tension **T** increases correspondingly.

It is to be noted that hydrostatic forces can optionally be used to adjust the buoyancy of the docking system **400** including the movable connector **500**, in particular one or more of the arm **520**, the docking head **450** and the docking port **410**, in order to provide a desired net weight **mg**. Furthermore, hydrodynamic forces can also be present, and act in all directions. Such hydrodynamic forces are a function of the orientation of the arm **520** (and thus of pitch angle θ and possible also of yaw angle β), of the hydrodynamic design of the docking head **450** and docking port **410**, of the

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forward speed **V**. It is also to be noted that such hydrodynamic forces can optionally be used to further control or supplement the lift force **L** by providing the movable connector **500** with suitable fins, which can be stationary (for example, fixed at a preset angle), or movable. In the case of movable fins, these can be controlled, for example, using suitable active control (e.g. a computer controller connected to suitable sensors) or via mechanically simple hydrostatic control systems to balance, thereby introducing a the lift force **L** and adjusting the pitch angle θ . It is also to be noted that such hydrodynamic forces can optionally be reduced or practically eliminated by providing a corresponding hydrodynamic design for the docking head **450** and docking port **410**.

In any case, as speed **V** of the surface vehicle is increased, the depth **z** of the docking port **410** is decreased, and vice versa. Thus, the speed **V** of the surface vehicle **200** can be used for controlling the pitch angle θ and the depth of the docking port **410**, and thus a stable depth **z** can be provided corresponding to the predetermined depth **H**.

Optionally, the predetermined depth **H** of the docking port **410** can be further controlled via one or more controllable small propulsion maneuvering units provided at fulcrum or close thereto.

Once this stable depth has been achieved, heave movements **Q** of the surface vehicle **200**, being decoupled from the arm **520** via the flexible joint **550**, do not affect at all, or to any significant degree, the vertical position of the docking port **410**, providing zero or little relative movement (at least vertically) between the underwater vehicle **300** and the docking port **410**.

The length of arm **520** and the drag **D**, together with the flexible structure of the flexible joint **525**, thus act to decouple the surface heave **Q** from the docking port **410**, which is close to the fulcrum point **f**. it is to be noted that the movable connector **500** also decouples yaw, roll or pitch of the surface vehicle **200** from the docking port **410**.

This decoupling in turn enables the underwater vehicle **300** to be reeled via the tether **250** into an engagement position in which the docking interface **420** engages and locks with the docking port **410**.

Thus, the stable predetermined depth **H** is achieved by the moveable connector **500** in an indirect manner, by controlling the surface vehicle speed **V**.

Once the underwater vehicle **300** is secured to the movable connector **500**, a number of options are open. For example, the underwater vehicle **300** can be resupplied

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via the docking head **450**, and/or the underwater vehicle can be stowed for the next operation. For the latter purpose, the arm **520** is raised by the winch **528** to the retracted position, and locked therein via the locking mechanism **270**. In this position, the underwater vehicle is fully above the water surface, and the surface vehicle **200** can then transport the underwater vehicle to any desired location.

Other variations of the above example of the movable connector are possible. For example, and referring to Fig. 10, such a movable connector can comprise, in addition to the flexible joint **550**, an arm **520** comprising two arm segments **520A**, **520B**, serially connected via a free joint **520C**, which can include a weight ballast. The first arm segment **520A** is connected to the flexible joint **550**, while the second arm segment **520B** includes the end **525** and thus carries the docking port **410** including the docking head **450**. For example, the second arm segment **520B** can be configured and operated to maintain the orientation of the docking port **510** constant (for example horizontal), irrespective of the movement of the first arm segment **520B**, possible via the free joint **520C**, and thus the first arm segment **520A** can be operated with a range of pitch angles θ . For example, the second arm segment **520B** can comprise fins or propulsion units for this purpose, while the first arm segment can pivot to compensate further for heave movements of the surface vehicle **200**. Alternatively, the first arm segment **520A** comprises fins **520D** for maintaining a fixed pitch angle for the first arm segment, **520A**, and the second arm segment **520B** pivots to a desired pitch angle θ according to the balance of forces between the tension **T**, drag **D** and weight **mg** of the arm **520** constant even where the surface vehicle **200** is experiencing severe heave **H** (for example due to severe WMO Sea State conditions, in which surface heave movements of the surface vehicle **200** (and also pitch/roll/yaw movements) are decoupled from the arm **520** via the flexible joint **550** and free joint **520C**).

In operation of the system **100** for launching an underwater vehicle **300**, the surface vehicle **200** propels the system **100** to a predetermined deployment zone, while the movable connector **500** is in the retracted position, above the water line. In this configuration, the system **100** minimizes drag and can travel to its destination efficiently and fast. Once the system **100** arrives at the deployment zone, the movable connector **500** is lowered into the water to the deployed position, at least partially submerged to

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provide via the connector arm **520** the predetermined water depth **H** to the underwater vehicle **300**, which is engaged to the docking port **410**. The surface vehicle **200** then moves with a forward velocity **V**, such that a tension and a drag are induced in the connector arm **520**, in particular such that the tension balances the weight and drag of the arm, thereby maintaining the depth and spatial orientation of the docking port stable. At this point, the movements of the surface vehicle **200** are essentially decoupled from the docking port **410**, and thus the underwater vehicle **300** can undock from the docking port **410** and carry out its mission.

Operation of the system **100** for recovering an underwater vehicle **300** is essentially the reverse of the launching operation. In examples where the surface vehicle **200** is connected to the underwater vehicle **300** via the tether **250**, the surface vehicle first reels in the tether **250** until the two vehicles are in close proximity, for example a few meters, depending on the wave height. The movable connector **500** is in the deployed position, with the docking port **410** submerged. . The surface vehicle **200** then moves with a forward velocity **V**, such that a tension and a drag are induced in the connector arm **520**, in particular such that the tension balances the weight and drag of the arm, thereby maintaining the depth at the predetermined water depth **H** for the docking port **410**, by providing a constant pitch angle θ_H with respect to the horizontal, and thereby maintaining spatial orientation of the docking port stable. At this point, the movements of the surface vehicle **200** are essentially decoupled from the docking port **410**, and thus the underwater vehicle **300** can be further reeled in via the tether **250** until it engages and docks with the docking port **410**. Once the underwater vehicle **300** is secured to the movable connector **500**, this is raised to the retracted position, above the water line. Thereafter, the system **100** can be deployed to a different location or operational site.

It is to be noted that other alternative variations of the above example of the docking system **400** or parts thereof are also possible. For example, in some such alternative variations, the winch and windlass system **569** illustrated in Fig. 3 can be omitted, and the auxiliary cables **567** are secured directly to the frame **210**, as illustrated in Figs. 11 to 13 for example. Furthermore, the lower ends of the auxiliary cables **567** are not secured to the docking system **400**, but rather to opposite sides of a ring member **576**, through which the main cable **529** is threaded. As can be seen in Figs. 12 and 13,

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for example, the lengths of the auxiliary cables **567** is relatively small, so that when the main cable **529** is extended to allow the arm **520** to adopt a large pitch angle θ , the ring member **576** is suspended high above the docking port **410**. On the other hand, when the movable connector **500** is in the retracted configuration illustrated in Fig. 11, the ring member **567** is displaced upwards by the docking port **410**. Referring also to Fig. 14, each of the auxiliary cables **567** is attached at one end **567a** thereof to a respective one of hulls **202** and **204** at a respective anchor point **289**. The other end **567b** of each auxiliary cable **567** is attached to the ring member **576**. Theoretically, the ends **567b** (if not attached to the ring member **576**) can be positioned anywhere within a respective circle **C1** of radius **R1**, wherein radius **R1** is the length of the respective auxiliary cable **567**, this being less than the lateral spacing **S** between the two anchor points **289**. However, since the ends **567b** are indeed connected to the ring member **576**, the ends **567b** are constrained to move only within the area **W** of overlap between the two circles **C1**, which thus avoids the hulls **202**, **204**. This arrangement reduces risk of cable entanglement on the one hand (for example as compared with the example of Fig. 1), while minimizing risk of collision between the docking port **410** (together with the underwater vehicle **300**) and the surface vehicle **200** (in particular the hulls **202**, **204**) while the docking system **400** is being raised to the retracted configuration.

Referring to Fig. 15, a second example of the launch and recovery system, generally designated **100'**, comprises the elements and features of the first example of the launch and recovery system **100** or alternative variations thereof, as disclosed herein but with some differences, *mutatis mutandis*. Thus, the launch and recovery system **100'** comprises surface vehicle **200**, and underwater vehicle **300**, as disclosed for the first example or alternative variations thereof, *mutatis mutandis*. The launch and recovery system **100'** also comprises docking system **400'** which includes a movable connector **500'**, similar to the docking system **400** and movable connector **500** of the first example, but with some differences *mutatis mutandis*, as will become clear herein.

In particular, the movable connector **500'** of the second example is also configured for providing a predetermined submerged depth **H** to the docking system **400** while the surface vehicle **200** is on the water surface, to thereby enable selective docking and undocking between the surface vehicle **200** and the underwater vehicle **300** at the predetermined depth **H**. As for the first example, this predetermined depth **H** is a

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minimum depth at which heave q of the underwater vehicle **300** (as a result of water surface conditions, such as wave amplitude) is within an acceptable range **R1**. The movable interconnector **500'** is also configured for actively raising the docking system **400** with the underwater vehicle **300** engaged to the movable interconnector **500'** while the surface vehicle **200** is on the water surface, to thereby enable the underwater vehicle **300** to be locked in position with the surface vehicle **200**, for example with the underwater vehicle **300** raised above the water surface.

The movable interconnector **500'** is also configured for actively decoupling at least heave movement q of the underwater vehicle **300** at the predetermined depth **H** from surface heave movement Q of surface vehicle **200** while the underwater vehicle **300** is connected to or is in close proximity to the surface vehicle **200**, particularly during launch and/or recovery operations. In other words, at least when providing said depth **H** to the respective docking port **410** of docking system **400'**, the movable interconnector **500'** operates to ensure that most or all of surface heave movements Q experienced by the surface vehicle **200** are not transmitted to the underwater vehicle **300** (again, while the underwater vehicle **300** is docking or undocking with respect to the surface vehicle **200**, particularly during launch and/or recovery operations), and thus the underwater vehicle **300** is thereby not compelled to mimic or follow these surface heave moments; rather, the underwater vehicle **300** only experiences the heave q appropriate for depth **H** at the prevalent sea state.

The docking port **410** of docking system **400'** is as disclosed for the first example or alternative variations thereof, *mutatis mutandis*.

It is to be noted that at least in this example, the movable interconnector **500'** is also configured for decoupling roll, pitch and yaw movements, in addition to heave movement q , of the underwater vehicle **300** at the predetermined depth **H** from surface roll, pitch and yaw movements as well as surface heave movement Q of surface vehicle **200** while the underwater vehicle **300** is connected to or is in close proximity to the surface vehicle **200**, particularly during launch and/or recovery operations. In other words, at least when providing said depth **H** to the docking port **410**, the movable interconnector **500'** operates to ensure that most or all of surface roll, pitch and yaw movements as well as surface heave movements Q experienced by the surface vehicle **200** are not transmitted to the underwater vehicle **300** (again, while the underwater vehicle **300** is docking or

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undocking with respect to the surface vehicle **200**, particularly during launch and/or recovery operations), and thus the underwater vehicle **300** is thereby not compelled to mimic or follow these surface roll, pitch, yaw or heave moments; rather, the underwater vehicle **300** only experiences the roll, pitch and yaw movements and the heave **q** appropriate for depth **H** at the prevalent WMO Sea State.

In this example, the movable interconnector **500'** is in the form of a robotic connector arm **520'**, and a joint arrangement in the form of an active flexible joint arrangement **540'** configured for selectively and actively controlling the movement between the respective free arm end **525** and the surface vehicle **200**.

The active flexible joint arrangement **540'** comprises a base **501'** attached to the surface vehicle **200**, for example the underside **215** thereof.

The active flexible joint arrangement **540'** further comprises a first arm platform **502'** is pivotably mounted to the base **501'** via a first motorized joint **503'** to allow selective active relative pivoting movements between the first arm platform **502'** and the base **501'** about a yaw axis **YA**.

The active flexible joint arrangement **540'** further comprises a second arm platform **504'** is pivotably mounted to the first arm platform **502'** via a second motorized joint **505'** to allow selective active relative pivoting movements between the second arm platform **504'** and the first arm platform **502'** about a roll axis **RA**.

The active flexible joint arrangement **540'** further comprises a third motorized joint **507'**. The arm **520'** is pivotably mounted to the second arm platform **504'** via the third motorized joint **507'** to allow selective active relative pivoting movements between the arm **520'** and the second arm platform **504'** about a pitch axis **PA**. The arm **520'** is similar to the arm **520** of the first example, *mutatis mutandis*, and includes arm end **525**, including the docking port **410** and docking head **450**, *mutatis mutandis*.

An inertial control unit **530'** is provided, for example at end **525**. The inertial control unit **530'** is configured for actively controlling the spatial position (in particular depth) and spatial attitude of the docking port **410** with respect to the Earth, and in particular for maintaining this spatial position and attitude of the docking port **410** stable during docking and undocking of the underwater vehicle **300** with respect to the surface vehicle **200**, in particular with respect to the docking port **410**, even at WMO Sea States greater than 1, for example at WMO Sea States of 2, 3, 4, 5 or higher than 5. In this

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example, the inertial control unit **530'** comprises inertial sensors and water depth sensors. The inertial sensors are configured for sensing the angular disposition of the docking head **450** or docking port **410** with respect to the pitch axis **PA**, the roll axis **RA** and the yaw axis **YA**, as well as accelerations along each of these three axes, in particular along the heave direction. A controller (for example a computer system or an electronic controller) in the inertial system **530'** or elsewhere in the system **100** provides control commands, based on sensor information provided by the inertial sensors, to the first motorized joint **503'**, and/or to the second motorized joint **505'**, and/or to the third motorized joint **507'**, to thereby control respective pivoting angles of the arm **520'** in pitch, roll (via second arm platform **504'**) and yaw (via first arm platform **502'**) to thereby maintain stable the spatial attitude of the docking port **410** with respect to the Earth. The water depth sensors can comprise a depth gauge, for example, and sensor information regarding depth from the water depth sensors can be provided to the controller, which provides control commands, based on this sensor information, to the first motorized joint **503'** and/or the second motorized joint **505'**, and/or the third motorized joint **507'** to thereby control respective pivoting angles of the arm **520'** in pitch, roll (via second arm platform **504'**) and yaw (via first arm platform **502'**) to thereby maintain the spatial depth of the docking port **410** with respect to the Earth stable.

For example, the inertial system **530'** can comprise an inertial navigation system (INS) plus a depth gauge, operatively connected to the controller.

Thus, in the second example, the movable interconnector **500'** is configured for selectively controlling and maintaining stable the spatial position and attitude of the docking port **410** during docking and undocking of the underwater vehicle **300** with respect to the surface vehicle **200**, in particular with respect to the docking port **410**, even where the surface vehicle **200** is stationary, i.e., where the surface vehicle **200** is not moving with respect to the water.

In the example of Fig. 15, the arm **520'** comprises a single arm segment which moves as a rigid body about pitch axis **PA**.

In a variation of the second example, and referring to Fig. 16, the arm **520'** comprises two arm segments **520A'**, **520B'**, each configured to move as a rigid body, and serially connected to one another via a motorized joint **520C'**. The first arm segment **520A'** is connected to the second arm platform **504'** via third motorized joint **507'**, while

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the second arm segment **520B'** includes the end **525** and thus carries the docking port **410** including the docking head **450**. For example, the second arm segment **520B** can be configured and operated to maintain the orientation of the docking port **510** constant (for example horizontal), irrespective of the movement of the first arm segment **520B**, possible via the motorized joint **520C'**, and thus the first arm segment **520A'** can be operated with a range of pitch angles $\theta 1$, while the second arm segment **520B'** can be operated with a different range of pitch angles $\theta 2$ relative to the first arm segment **520A'**. In yet other alternative variations of the second example, the arm **520'** comprises a more than two arm segments, each arm segment configured to move as a rigid body, and serially connected to one another via a respective motorized joint.

Operation of the system **100'** is similar to that the system **100**, *mutatis mutandis*, with the main differences being that the surface vehicle **200** in the system **100'** does not require (but can have) forward motion during docking/undocking procedures, and that the spatial position (i.e. depth) and attitude of the docking port **410** during docking and undocking of the underwater vehicle **300** with respect to the surface vehicle **200**, in particular with respect to the docking port **410**, is actively controlled.

In the method claims that follow, alphanumeric characters and Roman numerals used to designate claim steps are provided for convenience only and do not imply any particular order of performing the steps.

Finally, it should be noted that the word “comprising” as used throughout the appended claims is to be interpreted to mean “including but not limited to”.

While there has been shown and disclosed examples in accordance with the presently disclosed subject matter, it will be appreciated that many changes may be made therein without departing from the spirit of the presently disclosed subject matter.

CLAIMS:

1. An underwater launch and recovery system, comprising:
 - a surface water vehicle;
 - at least one underwater vehicle;
 - a docking system for selectively docking and undocking each said underwater vehicle with respect to the surface vehicle at a selectively controllable water depth, the docking system comprising a docking port for enabling said underwater vehicle to be selectively engaged and disengaged with respect to the docking system, wherein the docking port is connected to the surface water vehicle via a movable connector;
 - wherein the movable connector is configured for:
 - providing a predetermined said water depth to said docking port for enabling said selectively docking and undocking, and
 - decoupling at least surface heave movement of surface water vehicle from underwater heave movement of the docking port at said predetermined water depth.
2. The underwater launch and recovery system according to claim 1, where said predetermined water depth is chosen to provide underwater heave of the underwater vehicle within a predetermined threshold.
3. The underwater launch and recovery system according to any one of claims 1 to 2, wherein said underwater vehicle is any one of an underwater remotely piloted vehicle, an underwater autonomous vehicle and an underwater unmanned towed vehicle.
4. The underwater launch and recovery system according to any one of claims 1 to 3, wherein said surface vehicle comprises any one of a single hull surface vehicle, a multi hull surface vehicle, a hovercraft, a hydrofoil, a submersible vehicle, or a catamaran type surface vehicle, comprising a pair of hulls laterally spaced via a raised deck.
5. The underwater launch and recovery system according to any one of claims 1 to 4, wherein said surface vehicle is connected to the underwater vehicle via a tether, and

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wherein said tether provides at least one of power transmission and data communication between said surface vehicle and said underwater vehicle.

6. The underwater launch and recovery system according to any one of claims 1 to 5, wherein said movable connector comprises a connector arm and a joint arrangement, said connector arm comprising a first arm end connected to the joint arrangement, and a second arm end connected to said docking port, and wherein said joint arrangement is configured for:

- enabling selectively providing said predetermined water depth to said docking port via said connector arm, and
- decoupling at least said underwater heave movement of the docking port from surface heave movement of surface water vehicle at said predetermined water depth via said connector arm.

7. The underwater launch and recovery system according to claim 6, wherein said joint arrangement connects said first arm end to said surface vehicle, and is configured for allowing pivoting movement between said first arm end and said surface vehicle in at least one degree of freedom in rotation, wherein said at least one degree of freedom in rotation includes at least one of pitch, roll and yaw.

8. The underwater launch and recovery system according to any one of claims 6 to 7, wherein said joint arrangement comprises a passive flexible joint allowing free said pivoting movement between said first arm end and said surface vehicle.

9. The underwater launch and recovery system according to claim 8, wherein said connecting arm comprises a single arm segment joining said first arm end to said second arm end, and wherein said single arm segments operates as a rigid body, or wherein said connecting arm comprises a first arm segment comprising said first arm end, and a second arm segment comprising said second arm end, said first arm segment being connected to said second arm segment via a free joint, and wherein each one of said first arm segment and said second arm segment operates as a rigid body.

10. The underwater launch and recovery system according to any one of claims 8 to 9, wherein in operation of the underwater launch and recovery system for launching or recovering the underwater vehicle, the surface vehicle is caused to move with a forward velocity while the connector arm is at least partially submerged to provide said predetermined water depth to said docking port via said connector arm, the position of

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the docking port with respect to the surface vehicle via the connector arm defining a pitch angle, wherein at said forward velocity, a tension and a drag are induced in the connector arm.

11. The underwater launch and recovery system according to any one of claims 6 to 7, wherein said joint arrangement comprises an active flexible joint arrangement configured for selectively and actively controlling said pivoting movement between said first arm end and said surface vehicle, wherein the connector arm is at least partially submerged to provide said predetermined water depth to said docking port via said connector arm, the position of the docking port with respect to the surface vehicle via the connector arm defining a pitch angle, a roll angle and a yaw angle.

12. The underwater launch and recovery system according to claim 11, comprising an inertial control system for providing control inputs regarding the spatial position and attitude of the docking port, and wherein said passive flexible joint comprises a motorized articulated joint arrangement for controllably varying at least one of said pitch angle, roll angle, and yaw angle, responsive to said control inputs, wherein said inertial control comprises inertial sensors for sensing pivoting movement of the docking port about respective pitch, yaw and roll axes, and for sensing accelerations of the docking port along said respective pitch, yaw and roll axes.

13. The underwater launch and recovery system according to any one of claims 11 to 12, wherein said connecting arm comprises a single arm segment joining said first arm end to said second arm end, and wherein said single arm segments operates as a rigid body, or, wherein said connecting arm comprises a first arm segment comprising said first arm end, and a second arm segment comprising said second arm end, said first arm segment being connected to said second arm segment via a free joint, and wherein each one of said first arm segment and said second arm segment operates as a rigid body.

14. The underwater launch and recovery system according to any one of claims 6 to 13, wherein said connector arm is selectively movable between a stowed position and a deployed position, wherein in the stowed position the docking port is immovably engaged to the surface vehicle, and wherein in the deployed position the connector arm is at least partially submerged to:

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- provide said predetermined water depth to said docking port via said connector arm, and
- to allow decoupling of at least said underwater heave movement of the docking port from surface heave movement of surface water vehicle at said predetermined water depth via said connector arm.

15. The underwater launch and recovery system according to any one of claims 1 to 14, wherein the movable connector is configured for decoupling surface pitch, roll and yaw movements of surface water vehicle from the docking port from at said predetermined water depth.

16. A docking system for selectively docking and undocking an underwater vehicle with respect to a surface water vehicle at a selectively controllable water depth, the docking system comprising:

- a docking port connected to a movable connector,
- said docking port being configured for enabling said underwater vehicle to be selectively engaged and disengaged with respect to the docking system;
- said movable connector being configured for being mounted to the surface water vehicle;
- the movable connector being further configured for:
 - providing a predetermined said water depth to said docking port for enabling said selectively docking and undocking, and
 - decoupling at least surface heave movement of surface water vehicle from underwater heave movement of the docking port at said predetermined water depth.

17. The docking system according to claim 16, wherein said movable connector comprises a connector arm and a joint arrangement, said connector arm comprising a first arm end connected to the joint arrangement, and a second arm end connected to said docking port, and wherein said joint arrangement is configured for:

- enabling selectively providing said predetermined water depth to said docking port via said connector arm, and
- decoupling at least said underwater heave movement of the docking port from surface heave movement of the surface water vehicle at said predetermined water depth via said connector arm.

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18. The docking system according to any one of claims 16 to 17, wherein said joint arrangement is configured for connecting said first arm end to said surface vehicle, and is configured for allowing pivoting movement between said first arm end and the surface water vehicle in at least one degree of freedom in rotation.

19. The docking system according to claim 18, wherein said at least one degree of freedom in rotation includes at least one of pitch, yaw and roll.

20. The docking system according to any one of claims 17 to 19, wherein said joint arrangement comprises passive flexible joint allowing free said pivoting movement between said first arm end and said surface vehicle.

21. The docking system according to claim 20, wherein said connecting arm comprises a single arm segment joining said first arm end to said second arm end, and wherein said single arm segments operates as a rigid body, or, wherein said connecting arm comprises a first arm segment comprising said first arm end, and a second arm segment comprising said second arm end, said first arm segment being connected to said second arm segment via a free joint, and wherein each one of said first arm segment and said second arm segment operates as a rigid body.

22. The docking system according to any one of claims 20 to 21, wherein in operation of the underwater launch and recovery system for launching or recovering the underwater vehicle, the surface vehicle is caused to move with a forward velocity while the connector arm is at least partially submerged to provide said predetermined water depth to said docking port via said connector arm, the position of the docking port with respect to the surface vehicle via the connector arm defining a pitch angle.

23. The docking system according to claim 22, wherein at said forward velocity, a tension and a drag are induced in the connector arm, and wherein, the tension balances the weight and drag of the arm, thereby maintaining the depth and spatial orientation of the docking port stable.

24. The docking system according to any one of claims 17 to 19, wherein said joint arrangement comprises an active flexible joint arrangement configured for selectively and actively controlling said pivoting movement between said first arm end and said surface vehicle.

25. The docking system according to claim 24, wherein the connector arm is at least partially submerged to provide said predetermined water depth to said docking port via

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said connector arm, the position of the docking port with respect to the surface vehicle via the connector arm defining a pitch angle, a roll angle and a yaw angle.

26. The docking system according to claim 25, comprising an inertial control system for providing control inputs regarding the spatial position and attitude of the docking port, and wherein said passive flexible joint comprises a motorized articulated joint arrangement for controllably varying at least one of said pitch angle, roll angle, and yaw angle, responsive to said control inputs, and wherein said inertial control comprises inertial sensors for sensing pivoting movement of the docking port about respective pitch, yaw and roll axes, and for sensing accelerations of the docking port along said respective pitch, yaw and roll axes.

27. The docking system according to any one of claims 24 to 26, wherein said connecting arm comprises a single arm segment joining said first arm end to said second arm end, and wherein said single arm segments operates as a rigid body, or, wherein said connecting arm comprises a first arm segment comprising said first arm end, and a second arm segment comprising said second arm end, said first arm segment being connected to said second arm segment via a free joint, and wherein each one of said first arm segment and said second arm segment operates as a rigid body.

28. The docking system according to any one of claims 17 to 27, wherein said connector arm is selectively movable between a stowed position and a deployed position, wherein in the stowed position the docking port is immovably engaged to the surface vehicle, and wherein in the deployed position the connector arm is at least partially submerged to:

- provide said predetermined water depth to said docking port via said connector arm, and
- to allow decoupling of at least said underwater heave movement of the docking port from surface heave movement of the surface water vehicle at said predetermined water depth via said connector arm.

29. The docking system according to any one of claims 16 to 28, wherein the movable connector is configured for decoupling surface pitch, roll and yaw movements of surface water vehicle from the docking port from at said predetermined water depth.

30. A surface water vehicle comprising the docking system as defined in any one of claims 16 to 29.

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- 31.** An underwater launch and recovery method, comprising:
- providing the underwater launch and recovery system as defined in any one of claims 1 to 15;
 - operating the underwater launch and recovery system to launch or recover the at least one said underwater vehicle with respect to the surface vehicle.
- 32.** An underwater launch and recovery method, comprising:
- providing a surface water vehicle;
 - providing at least one underwater vehicle;
 - providing a docking system for selectively docking and undocking each said underwater vehicle with respect to the surface vehicle at a selectively controllable water depth, the docking system comprising a docking port selectively engageable and disengageable with respect to the underwater vehicle, wherein the docking port is connected to the surface water vehicle via a movable connector;
 - providing a predetermined said water depth to said docking port via said movable connector for enabling said selectively docking and undocking, and
 - decoupling at least surface heave movement of surface water vehicle from underwater heave movement of the docking port at said predetermined water depth via said movable connector.
- 33.** The underwater launch and recovery method according to claim 31 or claim 32, comprising choosing said predetermined water depth to provide underwater heave of the underwater vehicle within a predetermined threshold.
- 34.** The underwater launch and recovery method according to any one of claims 31 to 33, wherein said underwater vehicle is any one of an underwater remotely piloted vehicle, an underwater autonomous vehicle and an underwater unmanned towed vehicle, and wherein said surface vehicle comprises any one of a single hull surface vehicle, a multi hull surface vehicle, a hovercraft, a hydrofoil, a submersible vehicle and catamaran type surface vehicle.
- 35.** The underwater launch and recovery method according to any one of claims 31 to 34, wherein at least during operation of said underwater vehicle, said surface vehicle is connected to said underwater vehicle via a tether.

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36. The underwater launch and recovery method according to claim 35, comprising providing at least one of power and data communication between said surface vehicle and said underwater vehicle at least during operation of the underwater vehicle..

37. The underwater launch and recovery method according to any one of claims 31 to 36, wherein said movable connector comprises a connector arm and a joint arrangement, said connector arm comprising a first arm end connected to the joint arrangement, and a second arm end connected to said docking port, and wherein said joint arrangement is configured for:

- enabling selectively providing said predetermined water depth to said docking port via said connector arm, and
- decoupling at least said underwater heave movement of the docking port from surface heave movement of surface water vehicle at said predetermined water depth via said connector arm.

38. The underwater launch and recovery method according to claim 37, comprising allowing pivoting movement between said first arm end and said surface vehicle in at least one degree of freedom in rotation at least during docking or undocking operation between the underwater vehicle and the docking port.

39. The underwater launch and recovery method according to claim 38, wherein said at least one degree of freedom in rotation includes pitch.

40. The underwater launch and recovery method according to any one of claims 37 to 39, comprising allowing free said pivoting movement between said first arm end and said surface vehicle.

41. The underwater launch and recovery method according to claim 40, wherein said connecting arm comprises a single arm segment joining said first arm end to said second arm end, and wherein said single arm segments operates as a rigid body.

42. The underwater launch and recovery method according to claim 40, wherein said connecting arm comprises a first arm segment comprising said first arm end, and a second arm segment comprising said second arm end, said first arm segment being connected to said second arm segment via a free joint, and wherein each one of said first arm segment and said second arm segment operates as a rigid body.

43. The underwater launch and recovery method according to any one of claims 40 to 42, comprising causing the surface vehicle to move with a forward velocity while the

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connector arm is at least partially submerged to provide said predetermined water depth to said docking port via said connector arm, the position of the docking port with respect to the surface vehicle via the connector arm defining a pitch angle.

44. The underwater launch and recovery method according to claim 43, wherein at said forward velocity, a tension and a drag are induced in the connector arm.

45. The underwater launch and recovery method according to claim 44, wherein the forward velocity is chosen such that the tension balances the weight and drag of the arm, thereby maintaining the depth of the docking port at said predetermined water depth stable, and the spatial orientation of the docking port stable.

46. The underwater launch and recovery method according to any one of claims 37 to 39, comprising selectively and actively controlling said pivoting movement between said first arm end and said surface vehicle.

47. The underwater launch and recovery method according to claim 46, wherein the connector arm is at least partially submerged to provide said predetermined water depth to said docking port via said connector arm, the position of the docking port with respect to the surface vehicle via the connector arm defining a pitch angle, a roll angle and a yaw angle.

48. The underwater launch and recovery method according to claim 47, comprising providing control inputs regarding the spatial position and attitude of the docking port, and controllably varying at least one of said pitch angle, roll angle, and yaw angle, responsive to said control inputs.

49. The underwater launch and recovery method according to claim 48, comprising sensing pivoting movement of the docking port about respective pitch, yaw and roll axes, and sensing accelerations of the docking port along said respective pitch, yaw and roll axes, to provide said control inputs.

50. The underwater launch and recovery method according to any one of claims 31 to 49, comprising decoupling surface pitch, roll and yaw movements of surface water vehicle from the docking port at said predetermined water depth.

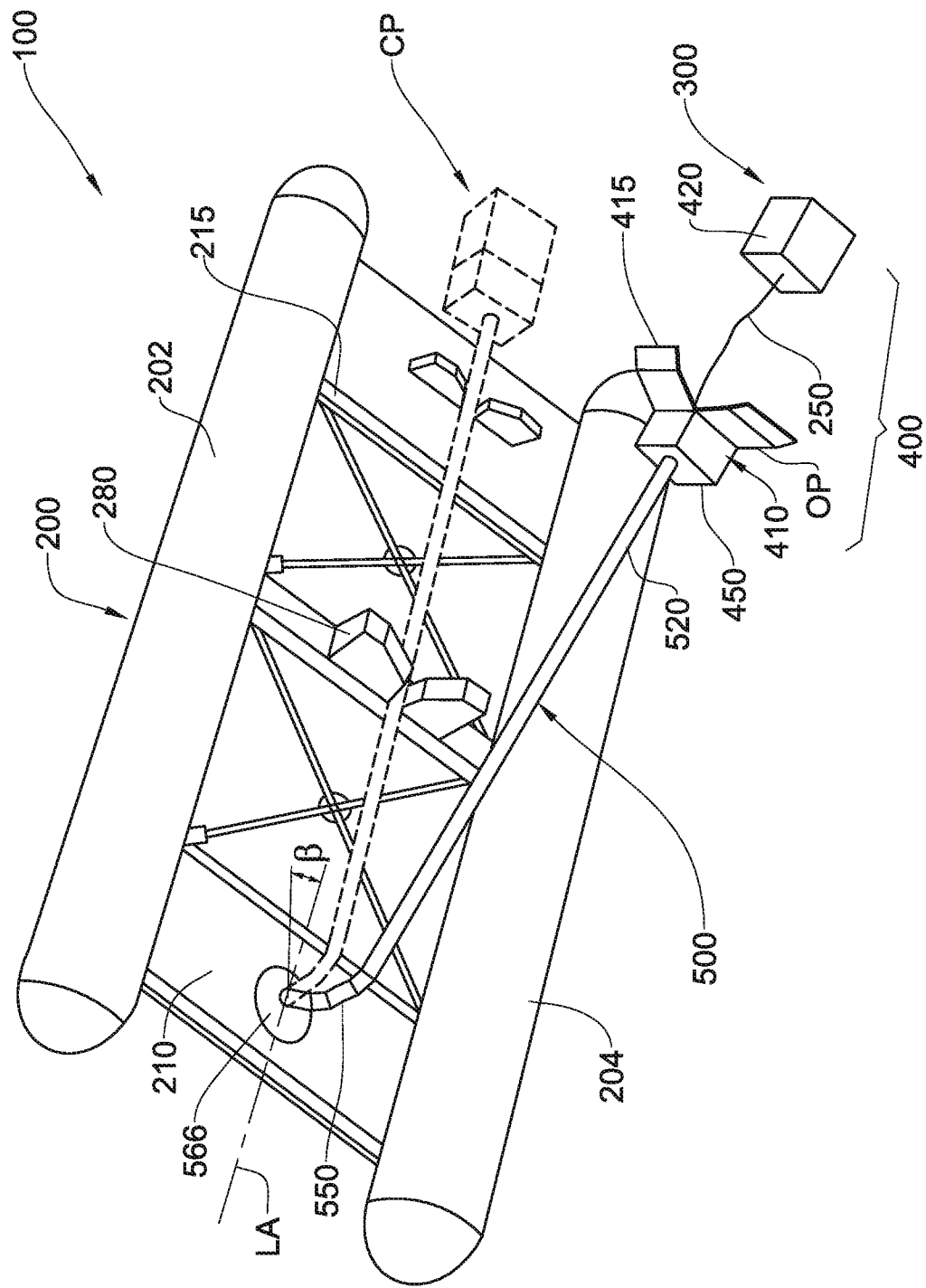


FIG. 1

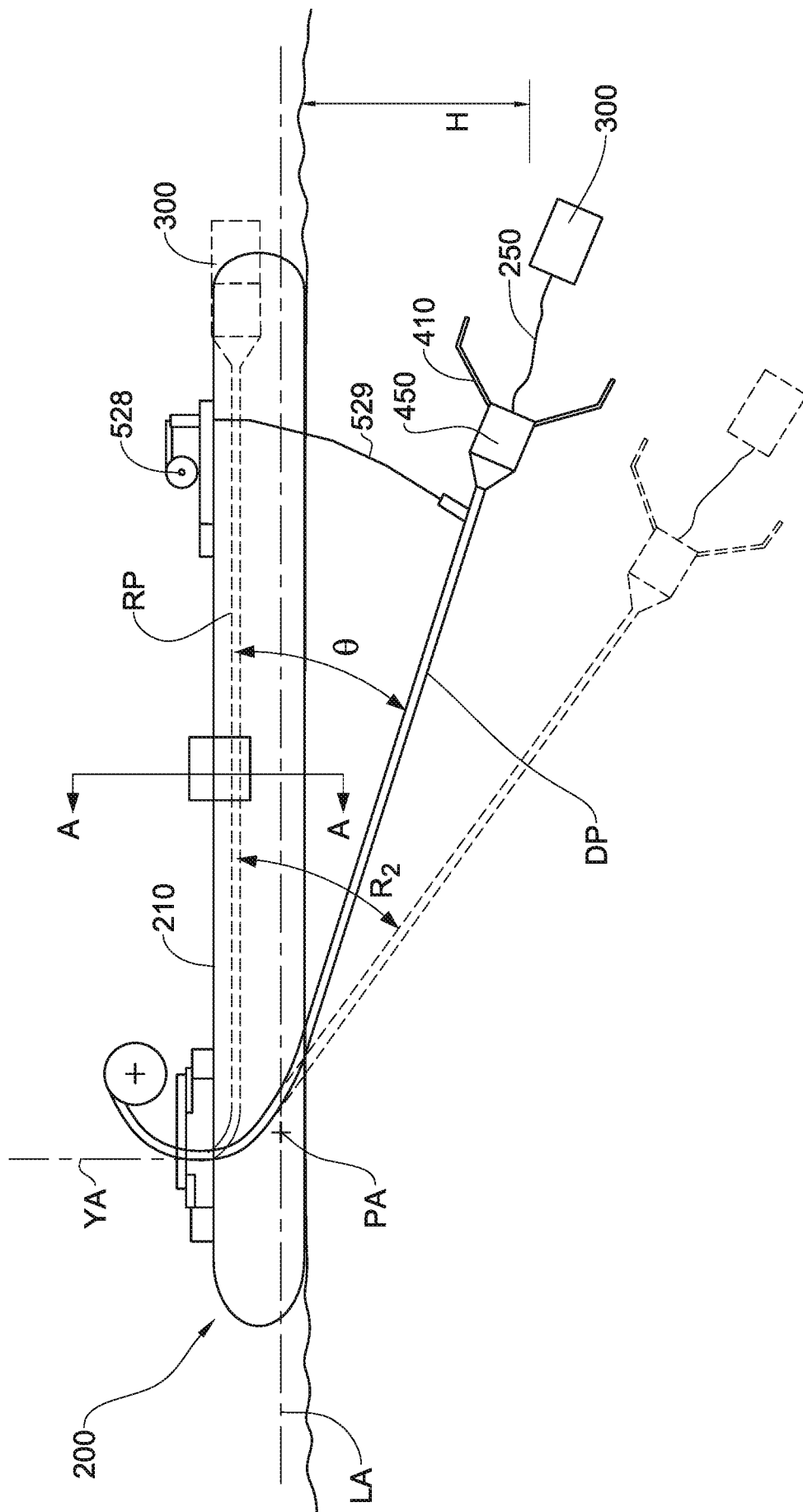


Fig. 2

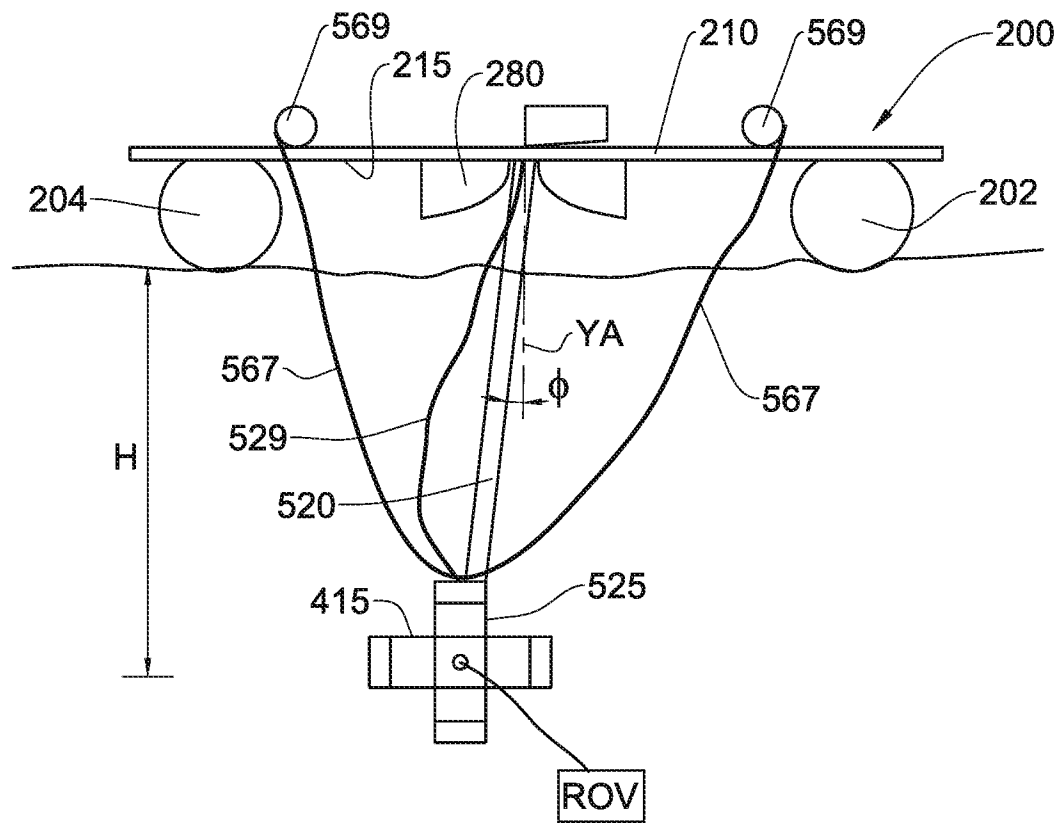


FIG. 3

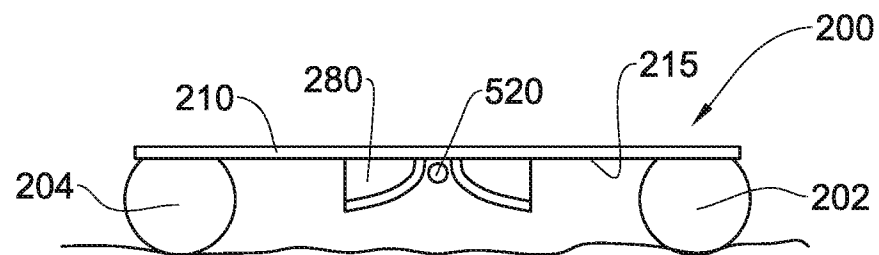


FIG. 3(a)

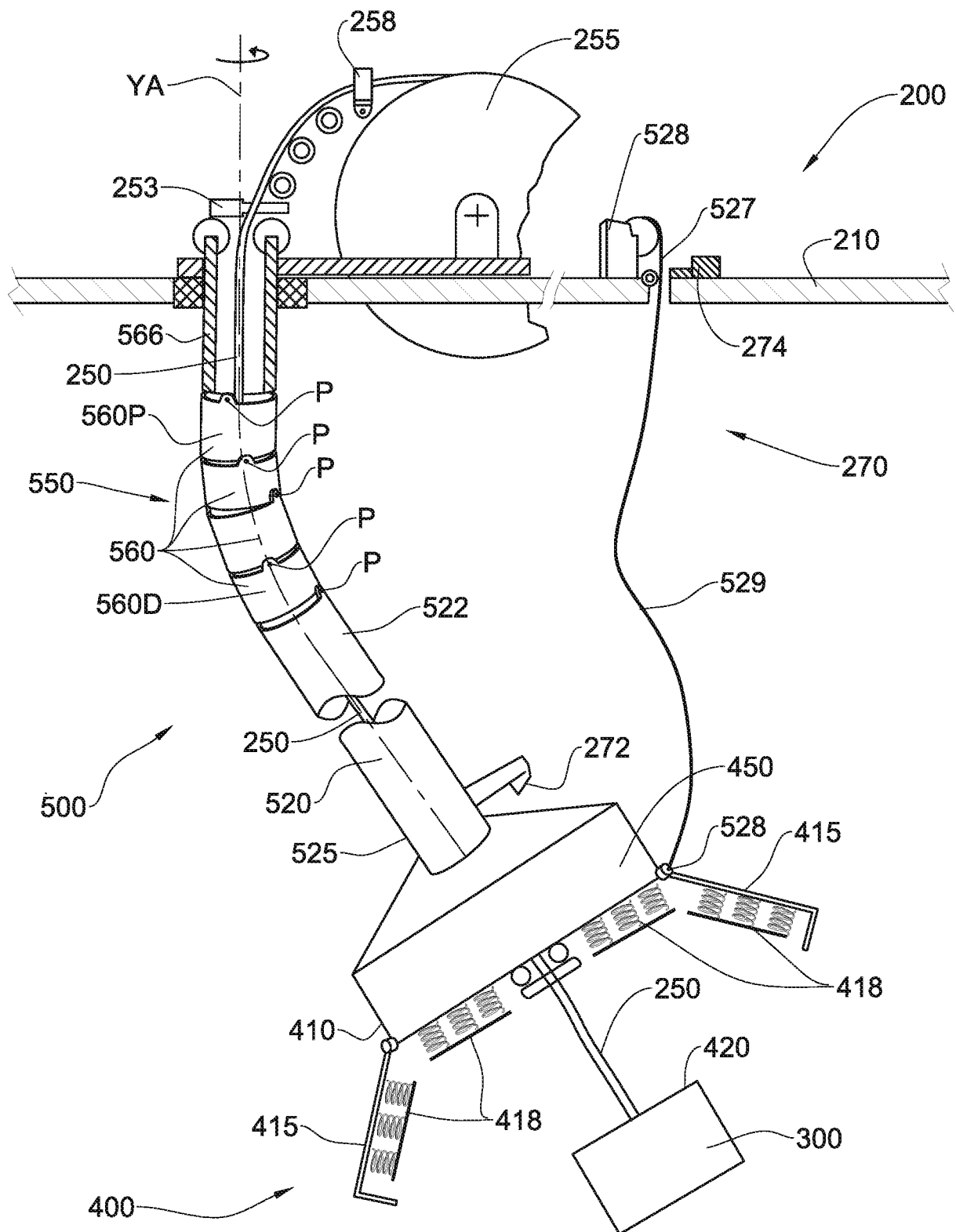


FIG. 4

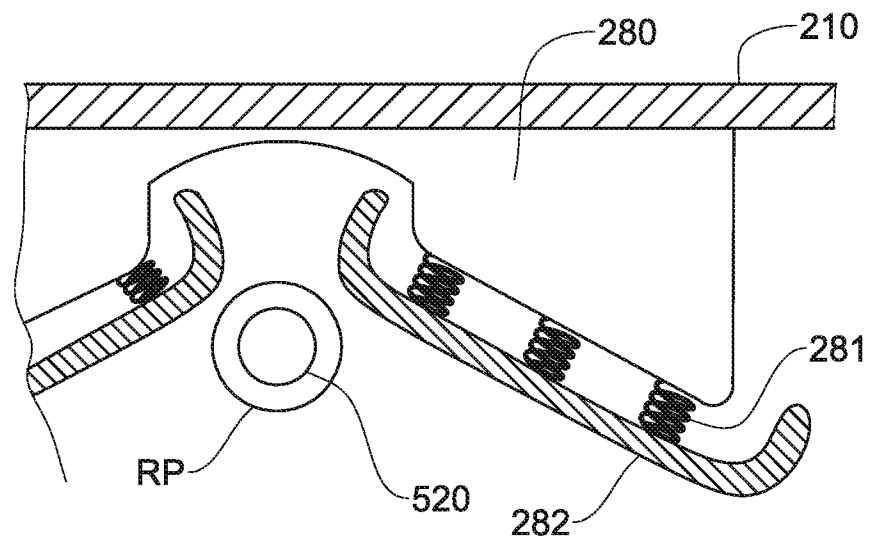


FIG. 5

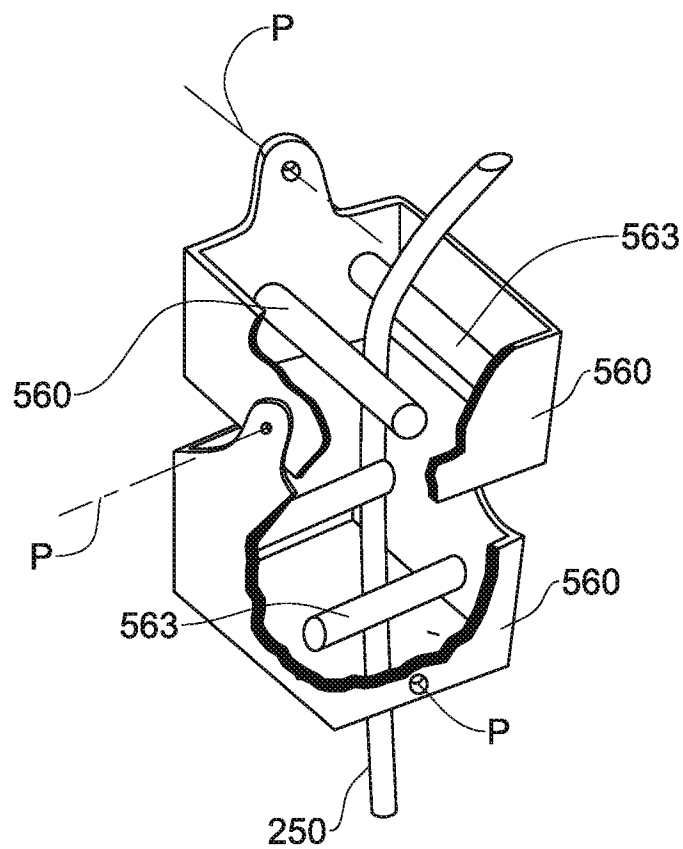
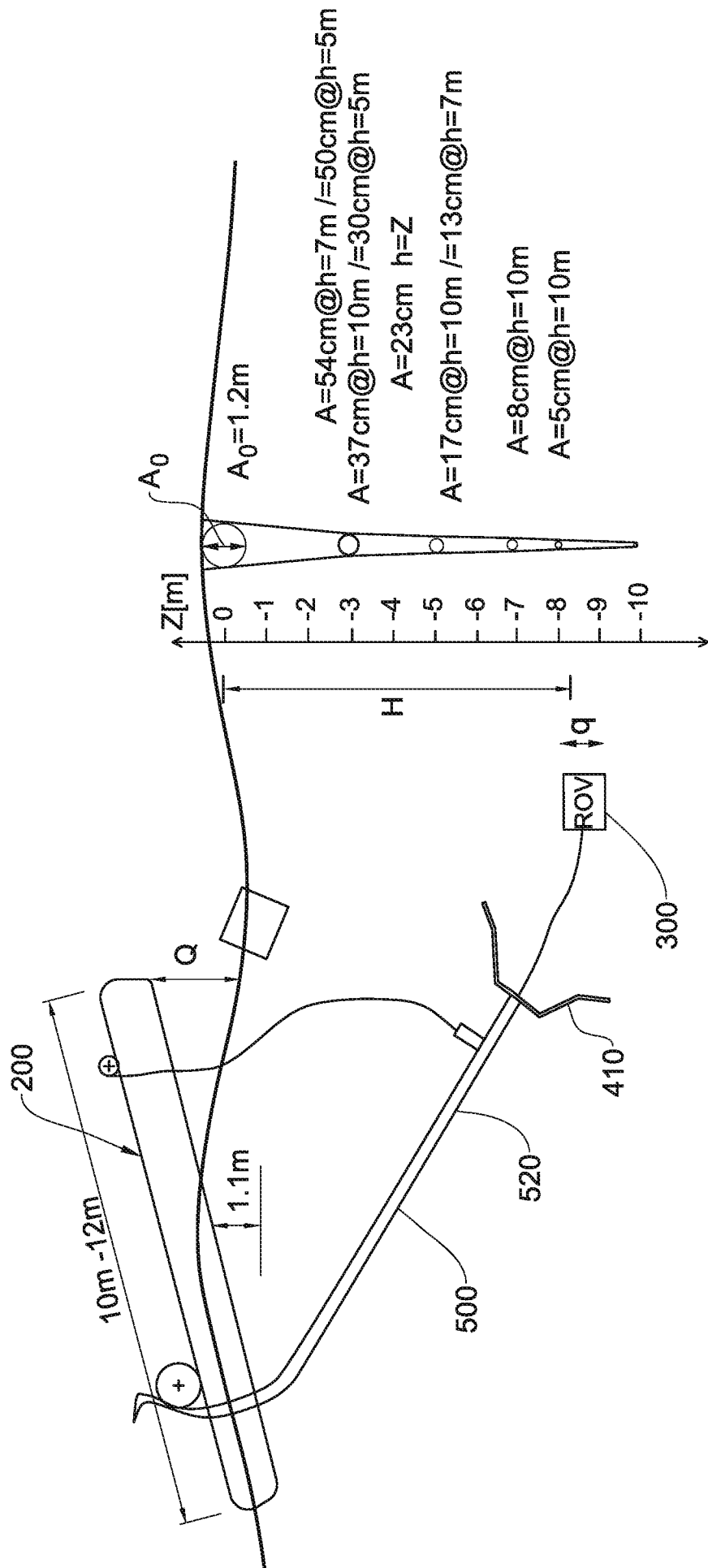


FIG. 6



7. **FIG. 7**

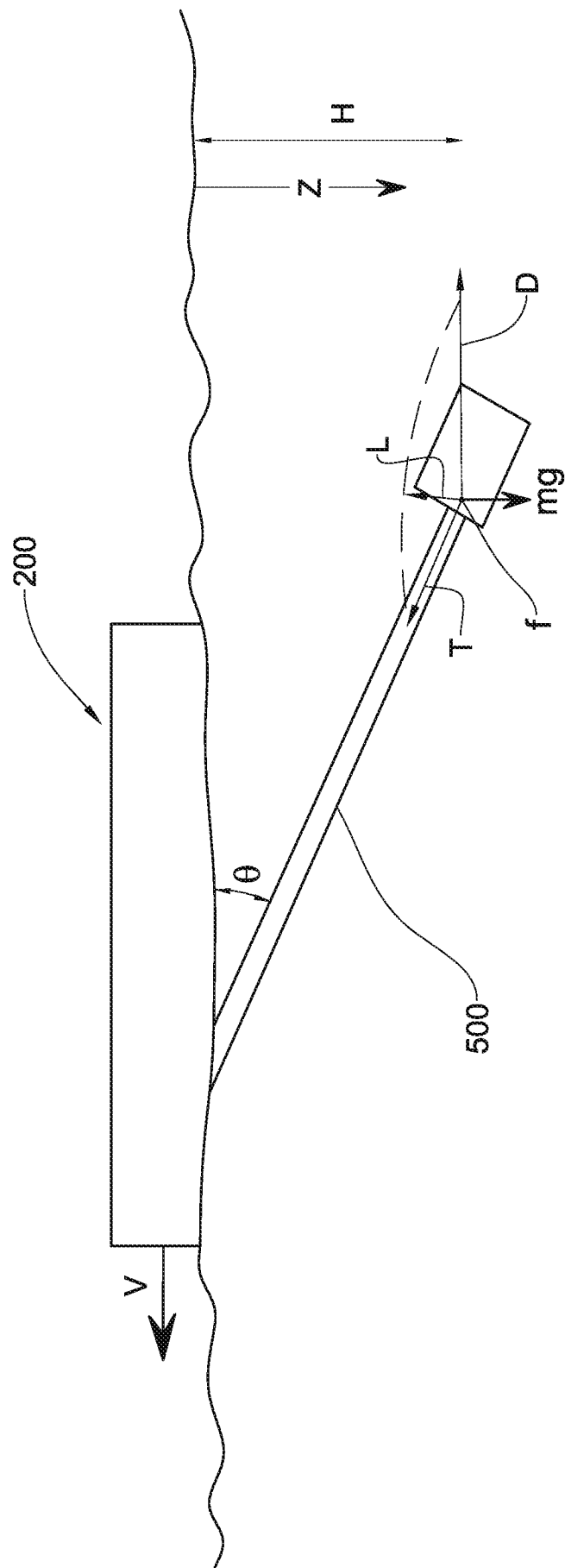


FIG. 8

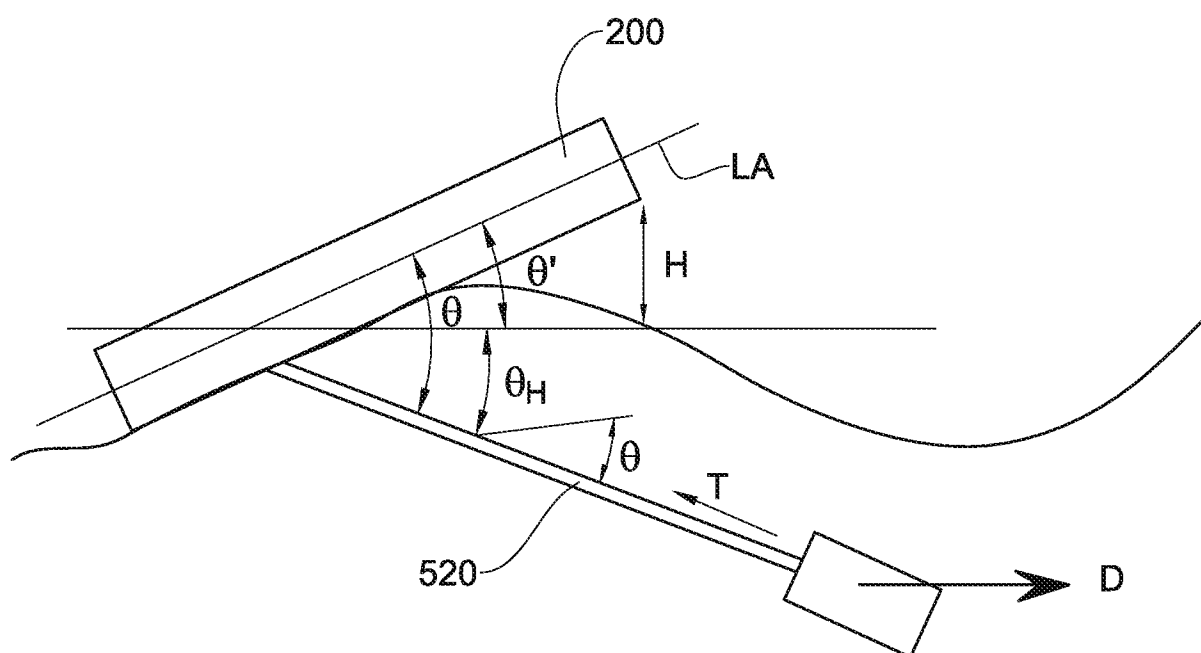


FIG. 9(a)

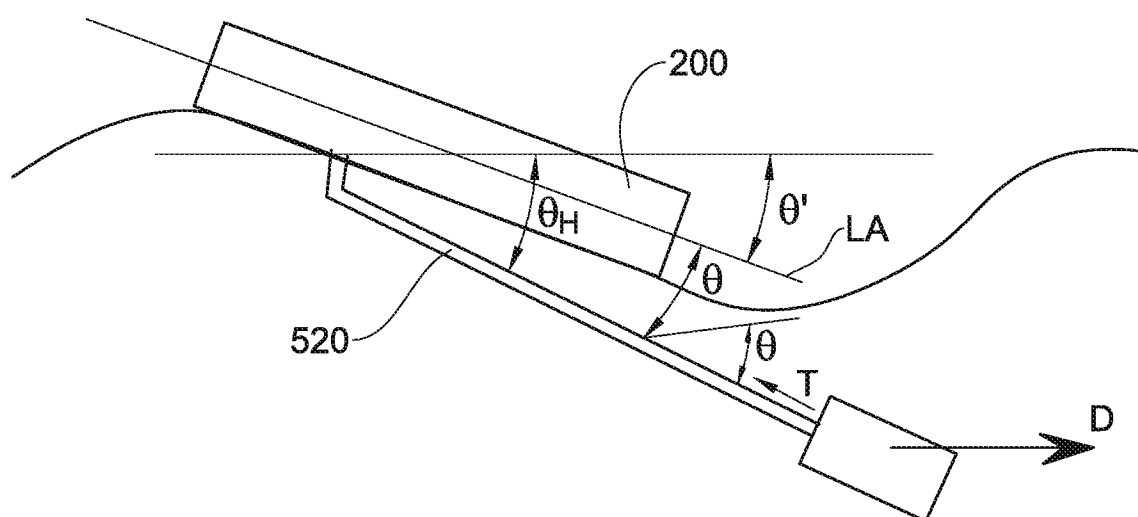


FIG. 9(b)

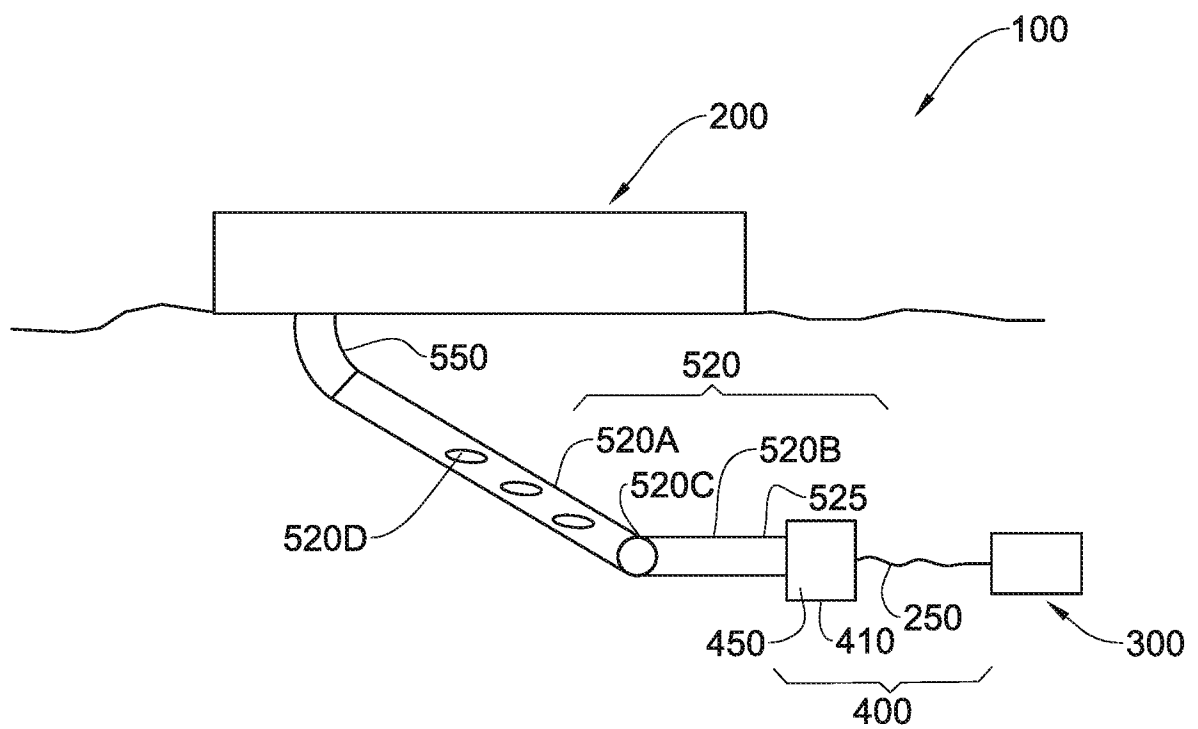


FIG. 10

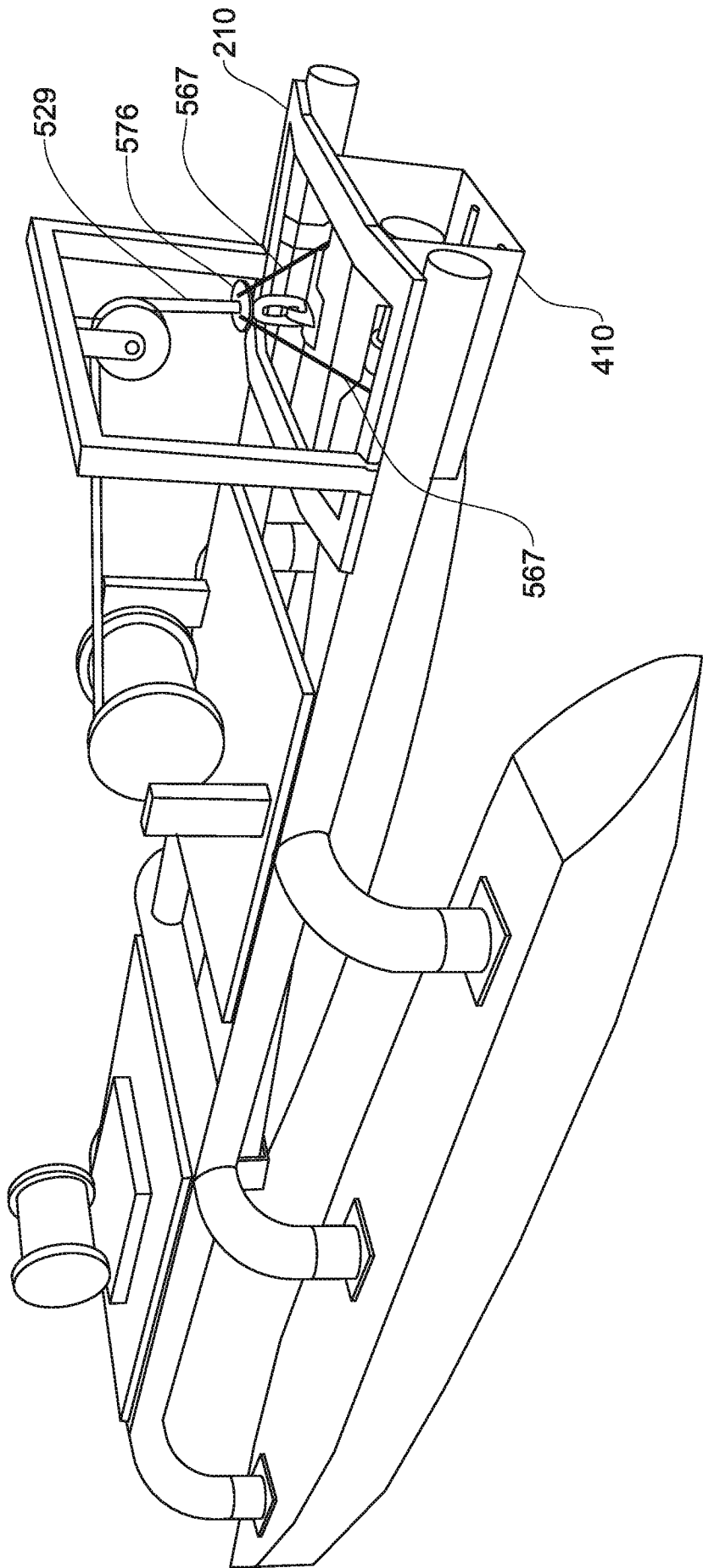
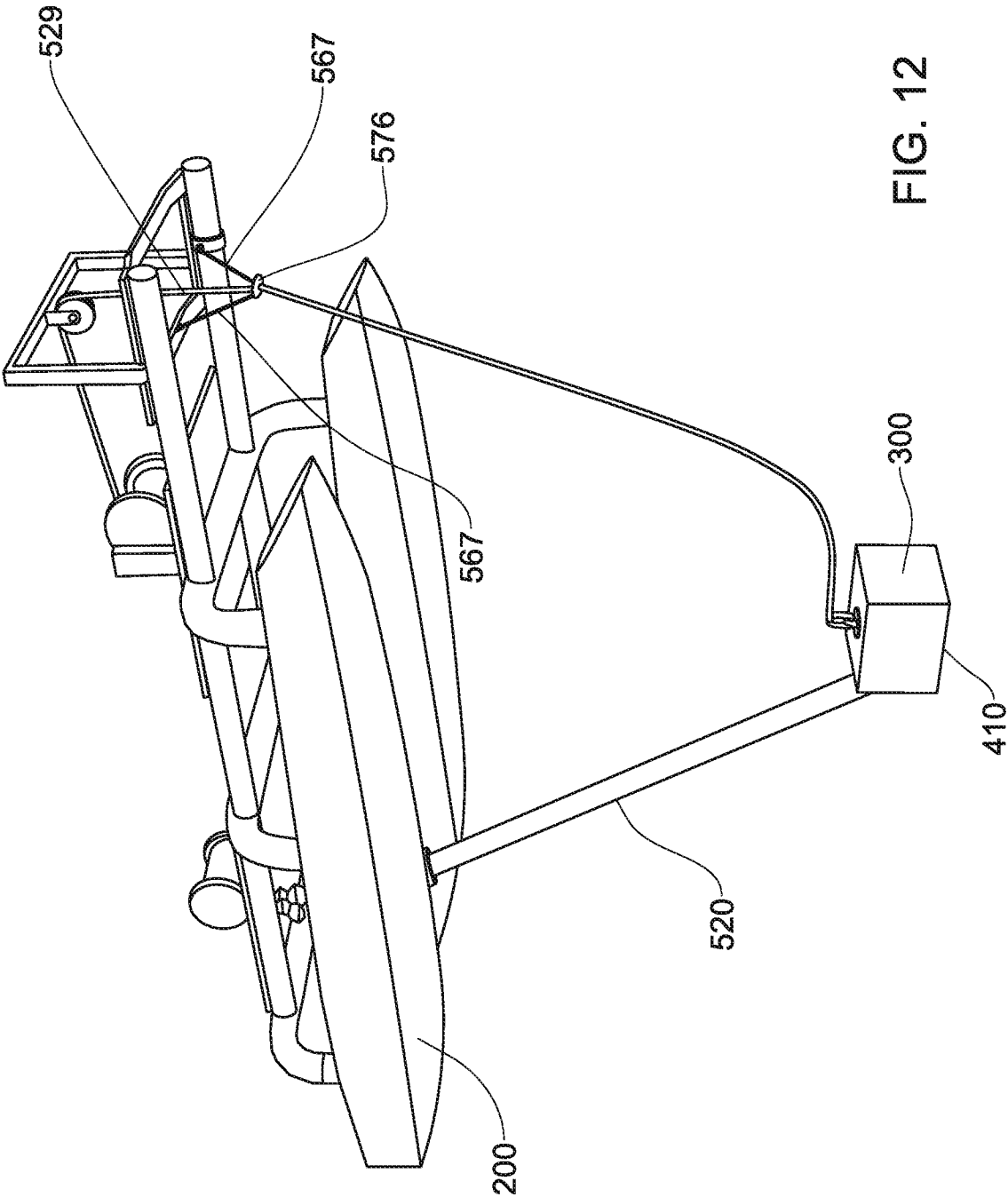
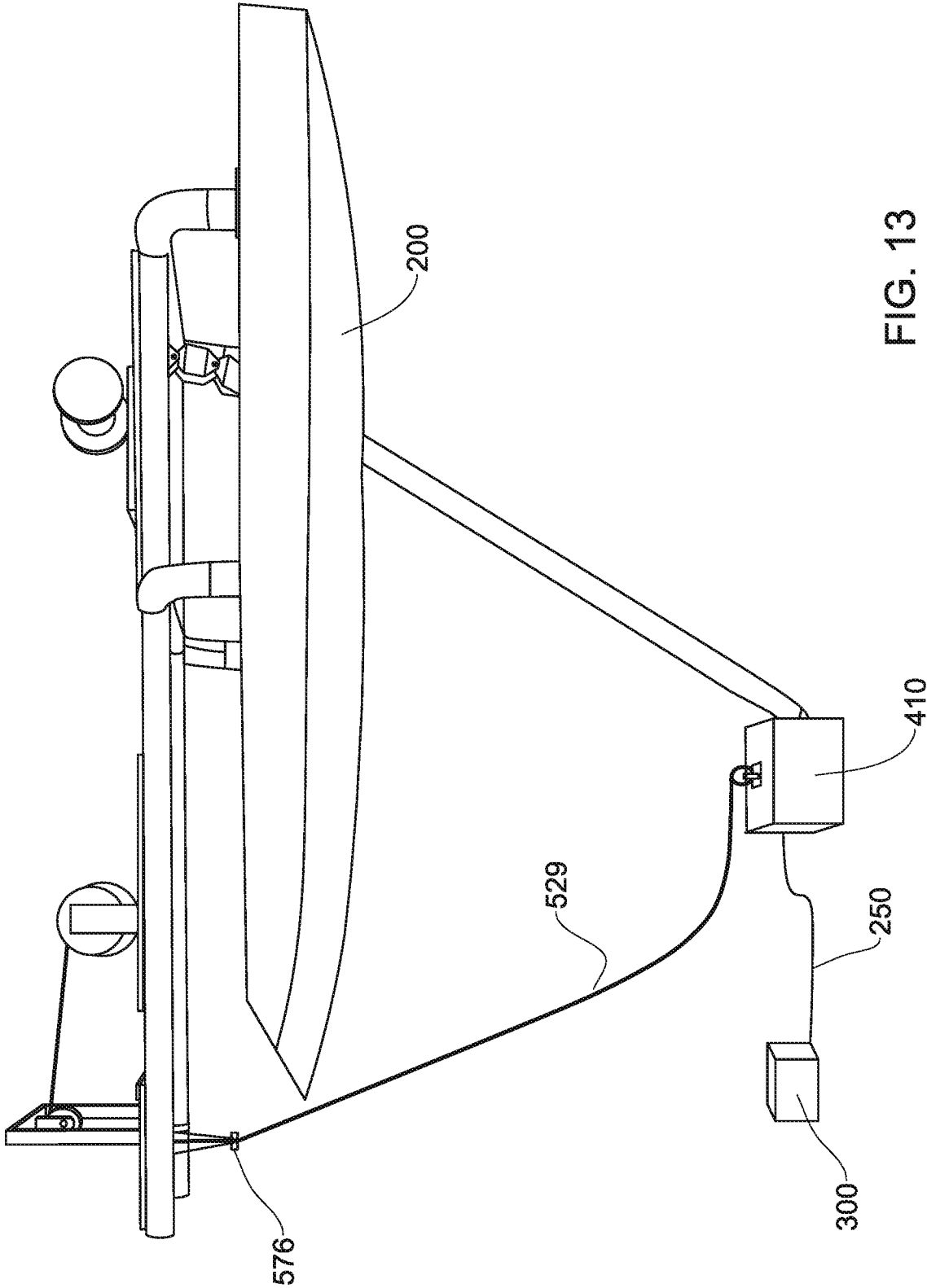


FIG. 11





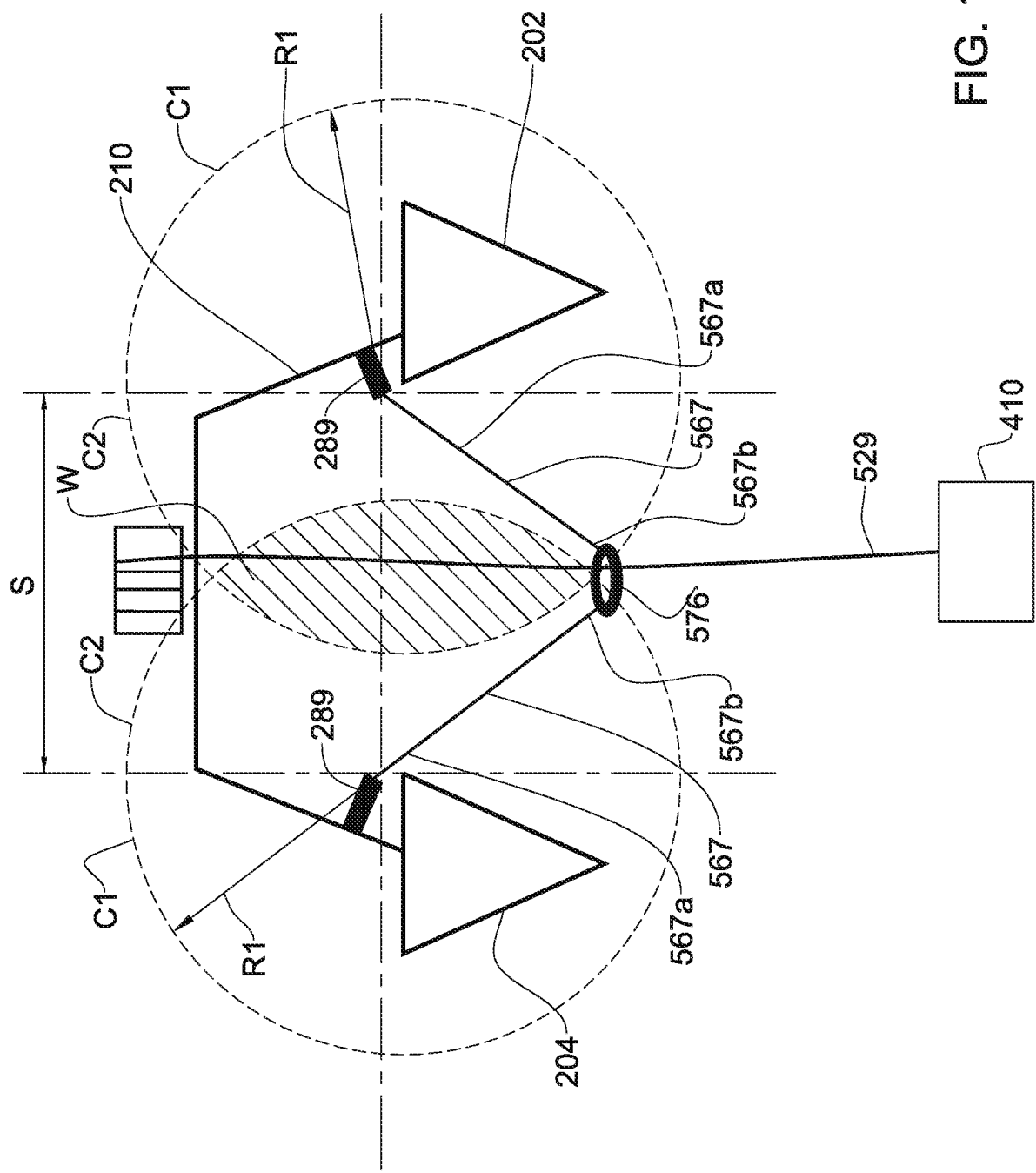


FIG. 14

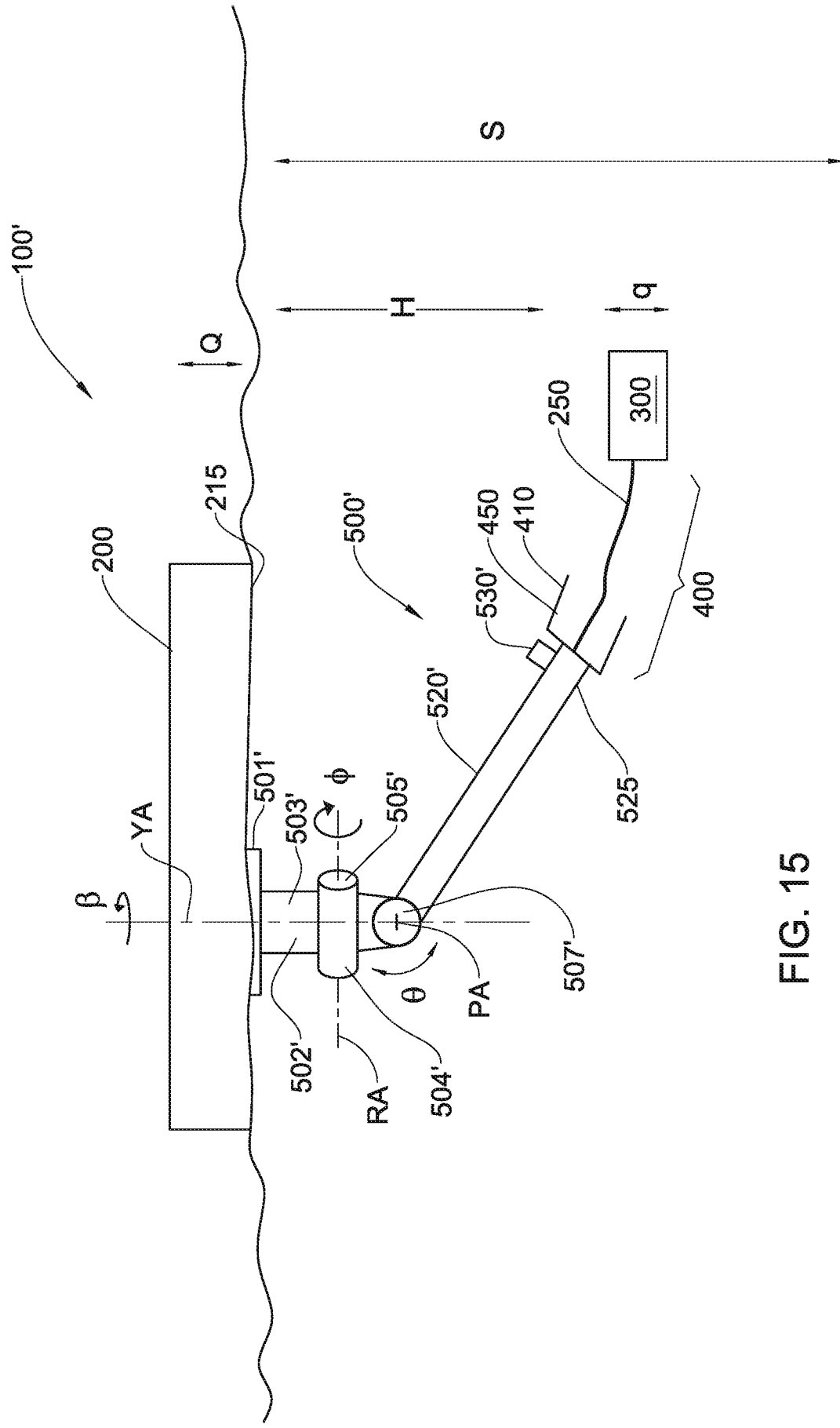


FIG. 15

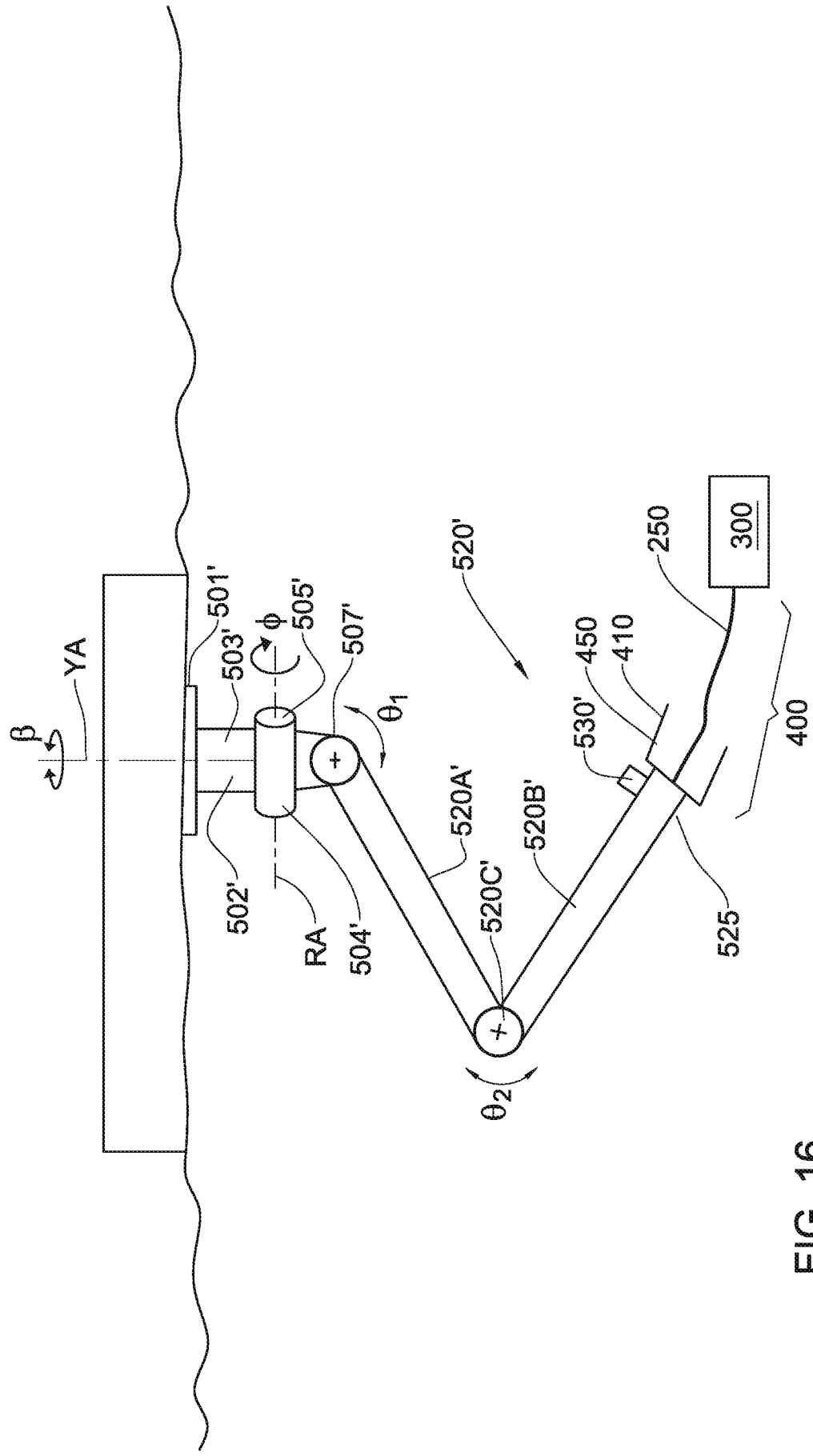


FIG. 16

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IL2014/050856

A. CLASSIFICATION OF SUBJECT MATTER IPC (2014.01) B60B 23/00, B60B 21/00, B63B 27/36 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 (2014.01) B60B 23/00, B60B 21/00, B63B 27/36 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 practicable, search terms used) Databases consulted: USPTO, THOMSON INNOVATION, Esp@cenet, Google Patents, PatBase		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3943875 B RAYMOND 16 Mar 1976 (1976/03/16) whole	1-3,16,31,32
Y	whole	4-15,17-30,33-50
Y	EP 2452869 A ALMDAL 16 May 2012 (2012/05/16) whole	4-15,17-30,33-50
Y	US 20100192831 A JEAN 05 Aug 2010 (2010/08/05) whole	4-15,17-30,33-50
Y	US 4072123 B BYERS 07 Feb 1978 (1978/02/07) whole	4-15,17-30,33-50
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
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Date of the actual completion of the international search 01 Jan 2015		Date of mailing of the international search report 18 Jan 2015
Name and mailing address of the ISA: Israel Patent Office Technology Park, Bldg.5, Malcha, Jerusalem, 9695101, Israel Facsimile No. 972-2-5651616		Authorized officer GUTKIN Solomon Telephone No. 972-2-5651763

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IL2014/050856

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 20120227654 A JOSEPH 13 Sep 2012 (2012/09/13) whole	1-50
A	US 7699015 B BRIAN 20 Apr 2010 (2010/04/20) whole	1-50
A	US 4304189 B HERBERT 08 Dec 1981 (1981/12/08) whole	1-50
A	US 4516517 B RAY 14 May 1985 (1985/05/14) whole	1-50
A	WO 2013017414 A KALWA 07 Feb 2013 (2013/02/07) whole	1-50

INTERNATIONAL SEARCH REPORT

Information on patent family members

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PCT/IL2014/050856

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US	7699015	B	20 Apr 2010	NONE	
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US	4516517	B	14 May 1985	NONE	
WO	2013017414	A	07 Feb 2013	NONE	