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(71) Applicant: **C-leanship A/S**
**2970 Hørsholm (DK)**

(72) Inventors:
- **DYRBYE, Tomas**
**2970 Hørsholm (DK)**
- **SCHIØLER, Peter**
**2970 Hørsholm (DK)**

(74) Representative: **Hoffmann Dragsted A/S**
**Rådhuspladsen 16**
**1550 Copenhagen V (DK)**

(54) **CLEANING SYSTEM**

(57) The present invention relates to a cleaning system, comprising a vessel to be cleaned, the vessel having a hull with a submerged hull face, the hull face comprising one or more predetermined marks, such as draught marks, and a submergible cleaning device configured to clean the submerged hull face, the cleaning device comprising a housing comprising a top face and side faces having edges and an open bottom face, the edges and bottom face being arranged opposite the hull face, and the housing further comprising a rotary disc having a plurality of nozzles arranged around a periphery of the rotary disc, the nozzles facing the hull face, rolling spacing devices for providing a predetermined first gap between the rotary disc and the hull face, a suction device fluidly connected to an outlet arranged in the housing for providing a negative pressure within the housing, a pressurising device fluidly connected with the nozzles for providing a high pressure fluid to the nozzles, whereby the nozzles are adapted to discharge fluid under high pressure against the hull face for cleaning, and a navigation unit configured to navigate the cleaning device in relation to the hull face and to provide positions of the cleaning device, wherein the system further comprises a logging unit which is connected with the navigation unit and/or the cleaning device for receiving data and/or measurements from the navigation unit and/or the cleaning device, the logging unit being configured to store a log of the data and/ measurements, and a control unit, the control unit being connected with the logging unit and configured to graphically provide an image of the log, so that the positions of the submergible cleaning device on the hull face are presented.

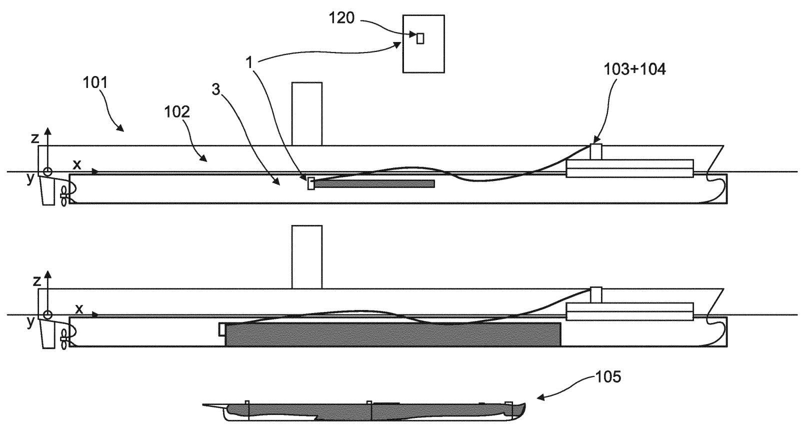


Fig. 1



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## Description

**[0001]** The present invention relates to a cleaning system, comprising a vessel to be cleaned, the vessel having a hull with a submerged hull face, the hull face comprising one or more predetermined marks, such as draught marks, and a submergible cleaning device configured to clean the submerged hull face.

**[0002]** Smooth underwater hull surfaces are essential for ensuring optimum performance of ships, and even a thin layer of slime, which develops rapidly, creates additional friction. Considering the high cost of fuel and the high utilisations of ships, even a marginal additional friction has a significant negative impact on the total fuel cost.

**[0003]** The current anti-fouling paint systems cannot prevent the formation of slime and other fouling within the usual docking intervals; thus, there is a need for underwater hull cleaning between dockings to minimise the formation of slime, fouling and other friction-enhancing objects on the underwater hull.

**[0004]** It is known to clean the underwater hull. However, several disadvantages have been observed with these known techniques, namely:

a) The anti-fouling layer, i.e. paint, on the underwater hull may be sporadically damaged, or even in some circumstances completely removed, whereby the underwater hull is exposed to the maritime environment, and thereby there is a huge risk of an increasing future growth rate of the slime on the underwater hull. This is most often the case when mechanical cleaning, that is the application of brushes and similar means, is used.

b) The cleaning of the underwater hull often contaminates the environment with the residues of the anti-fouling layer in the slime. The slime itself can furthermore be harmful to the environment as it may contain non-indigenous species.

c) The cleaning operation is time-consuming and may in many circumstances exceed the ships' usual turn-around time in the harbours, which may have severe consequences for the ship-owners due to the fact that they cannot then keep to their schedules.

d) The cleaning operations are often performed manually by divers, and the underwater environment provides unfavourable working conditions for the divers. Since the working conditions for the divers are unfavourable, the divers often have an urge to finish the cleaning operations rapidly, which in some circumstances may result in the quality of the cleaning being non-satisfactory.

**[0005]** There is thus a need for a submergible cleaning system wherein the quality of the cleaning may be checked.

**[0006]** From WO 2012/074408 A2 and WO 2014/090847 A1 submergible cleaning systems are known.

**[0007]** It is an object of the present invention to wholly or partly overcome the above disadvantages and drawbacks of the prior art. More specifically, it is an object to provide an improved submergible cleaning system wherein the quality of the cleaning may be checked and documented.

**[0008]** The above objects, together with numerous other objects, advantages and features, which will become evident from the below description, are accomplished by a solution in accordance with the present invention by a cleaning system, comprising:

- a vessel to be cleaned, the vessel having a hull with a submerged hull face, the hull face comprising one or more predetermined marks, such as draught marks, and
- a submergible cleaning device configured to clean the submerged hull face, the cleaning device comprising:
    - a housing comprising a top face and side faces having edges and an open bottom face, the edges and bottom face being arranged opposite the hull face, and the housing further comprising:
        - a rotary disc having a plurality of nozzles arranged around a periphery of the rotary disc, the nozzles facing the hull face,
        - rolling spacing devices for providing a predetermined first gap between the rotary disc and the hull face,
        - a suction device fluidly connected to an outlet arranged in the housing for providing a negative pressure within the housing,
        - a pressurising device fluidly connected with the nozzles for providing a high pressure fluid to the nozzles, whereby the nozzles are adapted to discharge fluid under high pressure against the hull face for cleaning, and
        - a navigation unit configured to navigate the cleaning device in relation to the hull face and to provide positions of the cleaning device,

wherein the system further comprises:

- a logging unit which is connected with the navigation unit and/or the cleaning device for receiving data and/or measurements from the navigation unit and/or the cleaning device, the logging unit being configured to store a log of the data and/ measurements, and
- a control unit, the control unit being connected

with the logging unit and configured to graphically provide an image of the log, so that the positions of the submergible cleaning device on the hull face are presented.

**[0009]** The navigation unit may comprise sonar equipment, subsea transponder(s), compass(es), Inertia measurement unit/Gyro, global positioning system, pressure sensor(s) and/or double velocity log.

**[0010]** Moreover, the control unit may provide a coordinate system having an x-axis, a y-axis and a z-axis, the x-axis being in a length direction of the vessel, the y-axis being in a width direction of the vessel and the z-axis being in a depth direction of the vessel.

**[0011]** Also, the control unit may be configured to at least provide an image presenting the positions of the submergible cleaning device along the x-axis and the z-axis.

**[0012]** Further, data and/or measurements may be position, pictures, video, pressure, thickness, speed and/or orientation.

**[0013]** Additionally, pictures, video, pressure, speed, orientation and/or measurements may be logged together with the position of the the submergible cleaning device.

**[0014]** Furthermore, the logging unit may receive pump data from the suction device of the submergible cleaning device, indicating when the suction device has been active and inactive, the control unit being configured to compare the pump data to the data and/or positions from the navigation unit, so that an image of positions of the submergible cleaning device on the hull face is only presented when the suction device has been active.

**[0015]** The cleaning system according to the present invention may further comprise a remotely operated vehicle (ROV).

**[0016]** Said ROV may comprise propulsion means.

**[0017]** Also, the submergible cleaning device may comprise one or more cameras and/or light devices.

**[0018]** Moreover, a position of the submergible cleaning device may be calibrated in relation to the predetermined mark on the hull face.

**[0019]** In addition, the calibration of the position of the submergible cleaning device may be performed automatically or manually.

**[0020]** Further, the nozzles may be interlocked with a pressure switch in the housing, so that the cleaning is provided only when the housing has a negative pressure.

**[0021]** The logging unit may receive pressure measurements from the pressure switch of the submergible cleaning device, indicating when the housing has a negative pressure, the control unit being configured to compare the pressure measurements to the data and/or positions from the navigation unit, so that an image of positions of the submergible cleaning device on the hull face is only presented when a negative pressure of the housing has been present.

**[0022]** Furthermore, a residue and debris recovery arrangement may be arranged in relation to the outlet in the housing for collecting effluent water from the cleaning of the hull face.

**[0023]** Also, the recovery arrangement may comprise a filter unit adapted to filter the effluent water for residues and/or debris.

**[0024]** Moreover, the filter unit may be completely submerged so that the suction device does not have to lift the effluent water above a sea level.

**[0025]** Additionally, the filtered effluent water may be discharged into the seawater when filtered.

**[0026]** Further, the filter unit may comprise a long filter sock.

**[0027]** The rotation speed of the rotary discs may be adjusted in relation to a speed of the ROV so that when the speed of the ROV increases, the rotation speed of the discs will increase accordingly, and vice versa.

**[0028]** In addition, the ROV may comprise one or more thrusters.

**[0029]** Said thrusters may be electrically powered.

**[0030]** Furthermore, the control unit may be arranged on a work boat or the vessel, enabling an operator to control the submergible cleaning system and/or the ROV.

**[0031]** Moreover, the logging unit may be arranged on the work boat or the vessel for storing data regarding the cleaning of the submerged hull face.

**[0032]** Also, the control unit may comprise a display enabling the operator to follow a cleaning operation of the submergible cleaning device.

**[0033]** The submergible cleaning device may comprise first sensor means and second sensor means, the first sensor means and second sensor means may be configured to measure a fouling layer thickness on the hull face, the first sensor means may be configured to measure the fouling layer thickness in a movement direction of the submergible cleaning device and the second sensor means may be configured to measure the fouling layer thickness in the opposite direction of the movement direction.

**[0034]** Further, the logging unit may be configured to receive sensor measurements from the first sensor means and the second sensor means, respectively, the control unit being configured to compare the sensor measurements received from the first sensor means to the sensor measurements received from the second sensor means to provide sensor data presenting the thickness differences between the fouling layer thickness in the movement direction and the fouling layer thickness in the opposite direction of the movement direction.

**[0035]** Moreover, the control unit may be configured to compare the sensor data to the data and/or positions from the navigation unit, so that an image of positions of the submergible cleaning device on the hull face is only shown when the thickness differences between the fouling layer thickness in the movement direction and the fouling layer thickness in the opposite directions of the movement direction are below a predetermined level.

**[0036]** Furthermore, the logging unit may receive fluid pressure measurements from the pressurising device of the submergible cleaning device, indicating when high pressure fluid to the nozzles has been provided, the control unit being configured to compare the fluid pressure measurements to the data and/or positions from the navigation unit, so that an image of positions of the submergible cleaning device on the hull face is only presented when high pressure fluid have been provided to the nozzles.

**[0037]** The present invention also relates to a submergible hull cleaning method comprising:

- providing a submergible cleaning device opposite a hull of a vessel, the hull having a submerged hull face, the hull face comprising one or more predetermined marks, such as draught marks,
- storing a log of data and/or measurements received from a navigation unit of the cleaning device and/or the cleaning device on a logging unit, and
- providing a graphical image of the log by means of a control unit so that the positions of the submergible cleaning device on the hull face are presented.

**[0038]** The submergible hull cleaning method as described above may further comprise:

- receiving pump data from a suction device of the submergible cleaning device, indicating when the suction device has been active and inactive, and
- comparing the pump data to the data and/or positions from the navigation unit so that an image of positions of the submergible cleaning device on the hull face is only presented when the suction device has been active.

**[0039]** Also said submergible hull cleaning method as described above may comprise:

- receiving pressure measurements from a pressure switch of the submergible cleaning device, indicating when a housing has a negative pressure, and
- comparing the pressure measurements to the data and/or positions from the navigation unit so that an image of positions of the submergible cleaning device on the hull face is only presented when a negative pressure of the housing has been present.

**[0040]** Moreover, submergible hull cleaning method as described above may comprise:

- providing the submergible cleaning device with first sensor means and second sensor means, the first sensor means and second sensor means being configured to measure a fouling layer thickness on the hull face, the first sensor means being configured to measure the fouling layer thickness in a movement direction of the submergible cleaning device and the second sensor means being configured to measure the fouling layer thickness in the opposite direction of the movement direction,
- receiving sensor measurements from the first sensor means and the second sensor means, respectively,
- comparing the sensor measurements received from the first sensor means to the sensor measurements received from the second sensor means to provide sensor data presenting the thickness differences between the fouling layer thickness in the movement direction and the fouling layer thickness in the opposite direction of the movement direction, and
- comparing the sensor data to the data and/or positions from the navigation unit so that an image of positions of the submergible cleaning device on the hull face is only shown when the thickness differences between the fouling layer thickness in the movement direction and the fouling layer thickness in the opposite direction of the movement direction are below a predetermined level.

**[0041]** In addition, submergible hull cleaning method may comprise:

- receiving fluid pressure measurements from a pressurising device of the submergible cleaning device, indicating when high pressure fluid to the nozzles has been provided, and
- comparing the fluid pressure measurements to the data and/or positions from the navigation unit so that an image of positions of the submergible cleaning device on the hull face is only presented when high pressure fluid has been provided to the nozzles.

**[0042]** The invention and its many advantages will be described in more detail below with reference to the accompanying schematic drawings, which for the purpose of illustration show some non-limiting embodiments and in which

Fig. 1 shows a cleaning system according to the invention,

Fig. 2 shows the submergible cleaning system in a schematic side view,

Fig. 3 shows the ROV of the cleaning system with a cover in a top view,

Fig. 4 shows the ROV of Fig. 3 in a bottom view,

Fig. 5 shows the ROV of Fig. 3 with the cover off,

Fig. 6 shows the ROV of Fig. 3 with the cover off in a bottom view,

Fig. 7 shows a workboat, and

Fig. 8 shows equipment arranged on the deck of the workboat.

**[0043]** All the figures are highly schematic and not necessarily to scale, and they show only those parts which are necessary in order to elucidate the invention, other parts being omitted or merely suggested.

**[0044]** Fig. 1 shows a cleaning system 100 according to the invention. The cleaning system 100 comprises a vessel 101 to be cleaned, the vessel 101 having a hull 102 with a submerged hull face 3, the hull face 3 comprising one or more predetermined marks, such as draught marks. The hull face 3 to be cleaned is indicated with the square.

**[0045]** The cleaning system 100 further comprises a submergible cleaning device 1 configured to clean the submerged hull face 3.

**[0046]** With reference to Fig. 2, the submergible cleaning device 1 comprises a housing 2 comprising a top face and side faces 4 having edges 5 and an open bottom face, the edges and bottom face being arranged opposite the hull face 3. The housing 2 further comprises a rotary disc 6 having a plurality of nozzles 7 arranged around a periphery of the rotary disc 6, the nozzles 7 facing the hull face 3. In addition, rolling spacing devices 8 are arranged for providing a predetermined first gap 9 between the rotary disc 6 and the hull face 3. The housing 2 also comprises a suction device 10, for instance a pump, which is fluidly connected to an outlet 11 arranged in the housing 2 for providing a negative pressure P within the housing 2.

**[0047]** The submergible cleaning device 1 further comprises a pressurising device 12 which is fluidly connected with the nozzles 7 in order to provide a high pressure fluid to the nozzles 7, whereby the nozzles 7 are adapted to discharge fluid under high pressure against the hull face 3 for cleaning. Furthermore, a navigation unit 120 is configured to navigate the cleaning device 1 in relation to the hull face 3 and to provide positions of the cleaning device in relation to the hull face 3.

**[0048]** As seen in Fig. 1, the cleaning system 100 further comprises a logging unit 103 which is connected with the navigation unit 120 and/or the cleaning device 1 for receiving data and/or measurements from the navigation unit 120 and/or the cleaning device 1, the logging unit 103 is configured to store a log of the data and/or measurements, and a control unit 104, the control unit 104 is connected with the logging unit 103 and is configured to graphically provide an image 105 of the log so that the positions of the submergible cleaning device 1 on the hull face 3 may be presented.

**[0049]** By the present invention a log of the positions of the submergible cleaning device 1 in relation to the hull face 3 is created which in an expedient manner may be used as documentation for the cleaning operation performed by the submergible cleaning device 1. The graphical image may be a 2D or 3D model of the vessel. The image 105 shown in Fig. 1 is a 2D model. By incorporating the logging unit and the control unit in the cleaning system 100, it is possible to track the motions, i.e. positions, of the cleaning device 1 by means of the navigation unit under water whilst doing a cleaning operation on a vessel.

**[0050]** The control unit may be configured to mark, for instance by colouring, the 2D or 3D model of the vessel in relation to the real time positions of the cleaning device 1 in relation to the hull face of the vessel.

**[0051]** For instance, when a cleaning operation is commenced, the hull is for instance coloured grey. When the cleaning starts and the cleaning device moves along and opposite the hull face, the control unit may colour a track provided by the positions of the cleaning device, behind the cleaning device when it moves along the hull face.

**[0052]** The navigation unit 120 may comprise sonar equipment, subsea transponder(s), compass(es), Inertia measurement unit/Gyro, global positioning system, pressure sensor(s) and/or double velocity log. The input of the log is inter alia the navigation unit 120. In one embodiment, the navigation unit 120 may for instance comprise a double velocity log and an inertia measurement unit.

**[0053]** In addition, the navigation may be performed by the double velocity log and the inertia measurement unit alone plus for instance a pressure sensor measuring the hydrostatic pressure. The measurement of the hydrostatic pressure is used for the position of the cleaning device in the depth direction and the headings and speed over hull are determined by the double velocity log and the inertia measurement unit.

**[0054]** The image 105 may be created for both star board and port side of the vessel but also for the flat bottom, for instance as 2D models, but may also be a 3D representation.

**[0055]** Furthermore, the control unit 104 may provide a coordinate system having an x-axis, a y-axis and a z-axis, the x-axis being in a length direction of the vessel, the y-axis being in a width direction of the vessel and the z-axis being in a depth direction of the vessel. In Fig. 1, the x-axis and the z-axis are shown. The control unit 104 is configured to at least provide an image presenting the positions of the submergible cleaning device 1 along the x-axis and z-axis.

**[0056]** The data and/or measurements may be position, pictures, video, pressure, thickness, speed and/or orientation. All documentation, for instance pictures, video, pressure, speed, orientation and/or measurements may be logged together with the position of the the submergible cleaning device 1. All cleaning parameters (pressure, speed etc.) may be recorded and stored in the logging unit 103 to be accessed by the control unit 104. Hereby, the shipowner may receive a Digital Cleaning Log (DCL) of their vessel after it has been cleaned, documenting the cleaning operation.

**[0057]** Furthermore, the logging unit 103 may receive pump data from the suction device of the submergible cleaning device 1, indicating when the suction device has been active and inactive, the control unit 104 being configured to compare the pump data to the data and/or positions from the navigation unit 120 so that an image of positions of the submergible cleaning device 1 on the hull face is only presented when the suction device has been active. This may for instance be shown by colouring the track behind the cleaning device 1 when it moves along the hull face in another colour than the original. Hereby it is documented that cleaning has been performed where the suction device, i.e. the pump, has been active.

**[0058]** The logging unit may also receive fluid pressure measurements from the pressurising device 12 of the submergible cleaning device 1, indicating when high pressure fluid to the nozzles 7 has been provided, the control unit 104 being configured to compare the fluid pressure measurements to the data and/or positions from the navigation unit 120 so that an image of positions of the submergible cleaning device 1 on the hull face is only presented when high pressure fluid has been provided to the nozzles 7.

**[0059]** The submergible cleaning device 1 may also comprise one or more cameras and/or light devices.

**[0060]** Furthermore, a position of the submergible cleaning device may be calibrated in relation to the predetermined mark on the hull face. The vessel has predetermined marks and points such as the draught marks fore, mid and aft. These marks may be used to calibrate the navigation unit. Thus when the cleaning device passes one of these marks, the operator may calibrate the position. This is required in practice as the position is drifting to some extent.

**[0061]** The calibration may be performed by means of a video. When the cleaning device is positioned above a draught mark or another mark, which position is known, e.g. the x-axis, this position is set. This may then be performed again at the next known draught mark and so on.

**[0062]** Hence the calibration of the position of the submergible cleaning device may be performed automatically or manually. When it is performed automatically, it may be done by a video and recognition software.

**[0063]** As mentioned above, in Fig. 2, a part of the submergible cleaning system 1 for cleaning an underwater hull face 3 of a vessel while the vessel is afloat is shown. The cleaning system 1 comprises the housing 2 comprising a top face 3 and side faces 4 having edges 5 and an open bottom face, the edges and bottom face being arranged opposite the hull surface 3 in the cleaning position. The housing 2 further comprises the rotary disc 6 having a plurality of nozzles 7 arranged around a periphery of the rotary disc 6, the nozzles 7 facing the hull surface 3. The housing 2 also comprises rolling spacing devices 8 for providing a predetermined first gap 9 between the rotary disc 6 and the hull surface 3. A suction device 10, for instance a pump, is fluidly connected to an outlet 11 arranged in the housing 2 for providing a negative pressure P within the housing 2.

**[0064]** Furthermore, the cleaning system 1 comprises a pressurising device 12 fluidly connected with the nozzles 7 for providing a high pressure fluid to the nozzles 7, whereby the nozzles 7 are adapted to discharge fluid under high pressure against the hull surface 3 for cleaning.

**[0065]** The housing 2 may further comprise a shroud 13 at least partly arranged between the rotary disc 6 and the housing 2. The shroud 13 is arranged at a distance to the housing so that a chamber 14 is provided between the shroud 13 and the housing, the chamber 14 being in fluid communication with the suction device 10. Hereby it is obtained that the suction is applied in the chamber 14 only, causing the down force on the system to be significantly reduced. Also, by providing the negative pressure in the chamber, it is ensured that a constant inflow of water from outside the housing prevents anything from escaping from the cleaning system to contaminate the environments. Furthermore, since the cleaning device 1 has the shroud 13 arranged inside the housing, the necessary water intake velocity is reduced. A further advantage is that the chamber 14 provides a passage through which the debris resulting from the cleaning operation may be sucked by the suction device.

**[0066]** The rotary disc 6 comprises nozzles 7. The nozzles 7 are adapted to impinge a high pressure water spray through the open face onto the hull surface 3 and thereby clean and/or remove the slime, fouling and/or alga from the hull surface 3.

**[0067]** The rotary disc 6 comprises a rotational axis 70, and the nozzles 7 are supplied with the high pressure fluid through a hollow spindle 71 arranged concentrically to the rotational axis 70.

**[0068]** Furthermore, the nozzles 7 may be interlocked with a pressure switch 15, so that the cleaning of the hull surface cannot take place unless the housing 2 has the negative pressure P.

**[0069]** The negative pressure P in the housing 2, and thus the velocity of the inlet water flow F, may be controlled by adjusting the size of the gap between the housing 2 and the hull surface 3. The size of the gap may, in one embodiment, be adjusted automatically during the cleaning by adjustable wheels by means of a pressure controller 16.

**[0070]** The logging unit 103 may receive pressure measurements from the pressure switch 15 of the submergible cleaning device 1, indicating when the housing 2 has a negative pressure, the control unit 104 being configured to compare the pressure measurements to the data and/or positions from the navigation unit 120 so that an image of positions of the submergible cleaning device 1 on the hull face is only presented when a negative pressure of the housing 2 has been present.

**[0071]** Furthermore, the housing 2 may be provided with a skirt or curtain (not shown) made of a flexible material which allows the cleaning device 1 to operate on curved as well as double-curved surfaces of the hull surface 3 without jeopardising the recovery of debris. Furthermore, the skirt may be water-permeable.

**[0072]** Furthermore, the shroud 13 may comprises a top shroud face 17 and side shroud faces 18 having shroud edges 19 and an open bottom shroud face, the shroud edges 19 and bottom shroud face being arranged opposite the hull face 3. As mentioned above, the shroud 13 may be arranged within the housing 2 with a predetermined second gap 20 between the side shroud faces 18 and the side faces 4 of the housing 2. The predetermined second gap 20 may be smaller than 0.03 m, preferably smaller than 0.025 m, and more preferably smaller than 0.015 m.

**[0073]** Furthermore, the edges 5 of the side faces 4 of the housing 2 are arranged at a first distance 21 from the hull surface 3. The first distance 21 is smaller than a second distance 22 between the shroud edges and the hull face 3.

**[0074]** In addition, the cleaning device comprises a navigation unit 120.

**[0075]** Fig. 2 shows one embodiment of the cleaning device 1. However, several other designs may be used.

**[0076]** For instance, the cleaning device may comprise four rotary discs arranged in succession of each other within the shroud. As a result, the cleaning device may clean a larger area of the hull face. Other (not shown) embodiments may comprise a different number of rotary discs. Furthermore, the discs may be arranged in a row. In other embodiments, the rotary discs may be arranged in two or more rows, each row having a plurality of rotary discs.

**[0077]** The shroud may be arranged between the rotary discs and the housing. The rotary discs are preferably driven by a motor, or a plurality of motors, one for each rotary disc. Furthermore, a gearing unit may be arranged with each rotary disc.

**[0078]** In an embodiment, two adjacent rotary discs may have opposite directions of rotation for decreasing a friction between them, so that the energy consumption may be decreased for the cleaning device.

**[0079]** The rotary discs may comprise a rotational axis (not shown), and the nozzles are supplied with the high pressure fluid through a hollow spindle (not shown) arranged concentrically to the rotational axis. The pressure of the fluid leaving the nozzles is between 30 and 150 bar, preferably between 50 and 125 bar.

**[0080]** Additionally, the rotation speed of the rotary discs may be adjustable. The rotation of the rotary discs may be in the range of 250 to 550 rpm, preferably in the range of 350 to 400 rpm.

**[0081]** Furthermore, the pressure provided to the nozzles may be adjusted in relation to the rotation speed of the rotary discs so that when the rotation speed of the discs decreases, the pressure provided to the nozzles are decreased accordingly and vice versa. Hereby it is obtained that the cleaning of the surface to be cleaned may be performed more smoothly, since the power to the nozzles is adjusted in view of the rotation speed of the rotary discs.

**[0082]** Furthermore, a residue and debris recovery arrangement is arranged in relation to the outlet in the housing for collecting effluent water from the cleaning of the hull face. The recovery arrangement may comprise a filter unit adapted to filter the effluent water for residues and/or debris. The filtered effluent water may be discharged into the seawater when filtered. Furthermore, the pump is adapted to provide suction inside the housing.

**[0083]** The nozzles may be cavitation type nozzles adapted to induce cavitation in front of the nozzle to provide high and localised stresses on the hull face due to bubble cavity collapse. Hereby an enhanced erosive power for the cleaning of the hull face is obtained, and at the same time the pumping power requirement is reduced. Thus, by using cavitation type nozzles, efficient cleaning may be obtained at lower fluid pressure than in the prior art. Also, the rotary disc may comprise a disc surface arranged opposite the hull face, the nozzles being arranged below the disc surface. Additionally, the nozzles may be adapted to be adjusted so that an angle of attack of the high pressure fluid can be altered in view of a rotation direction of the rotary disc.

**[0084]** The cleaning device 1 may also comprise a remotely operated vehicle (ROV) 35, as shown in Fig. 3. The ROV 35 is shown with a cover 36. The ROV may, in general, be equipped as a work-class ROV but be fully adapted to clean ship hulls in terms of thruster orientation, physical design, payload and sensors so that the ROV may be adapted to 4- to 6-dimensional movement while being submerged, preferably to 6-dimensional movement. The ROV may be powered electrically from surface through a neutrally-buoyant tether also including optical telemetry for communication.

**[0085]** In Fig. 4, the ROV 35 is shown in a bottom view disclosing the rotary discs 6. The different elements of the ROV will be described further below.

**[0086]** The cleaning device 1 with the ROV 35 also comprise first sensor means 125 and second sensor means 126, the first sensor means 125 and second sensor means 126 are configured to measure a fouling layer thickness on the hull face, the first sensor means 125 is configured to measure the fouling layer thickness in a movement direction M of the submergible cleaning device 1 (ROV 35), and the second sensor means 126 is configured to measure the fouling layer thickness in the opposite direction of the movement direction M. Hence, the first sensor means 125 is configured to measure the fouling layer before the cleaning, and the second sensor means 126 is configured to measure the fouling layer after the cleaning.

**[0087]** The logging unit (not shown) is configured to receive sensor measurements from the first sensor means 125 and the second sensor means 126, respectively, and the control unit (not shown) is configured to compare the sensor measurements received from the first sensor means 125 to the sensor measurements received from the second sensor means 126 to provide sensor data presenting the thickness differences between the fouling layer thickness in the movement direction M and the fouling layer thickness in the opposite direction of the movement direction M. The control unit may then be configured to compare the sensor data to the data and/or positions from the navigation unit so that an image of positions of the submergible cleaning device 1 on the hull face is only shown when the thickness differences between the fouling layer thickness in the movement direction and the fouling layer thickness in the opposite direction of the movement direction are below a predetermined level.

**[0088]** In Figs. 5 and 6, the ROV 35 is shown without the cover and comprises a frame 37 which may be built by welded stainless steel profiles. The frame 37 will serve as the foundation for all heavy equipment like pumps, motors and thrusters 38. This frame 37 is also connected to the lifting point, making it safe to handle during launch and recovery operations.

**[0089]** The ROV 35 is, in this embodiment, propelled by six thrusters 38 of 4.5 kW each. Three thrusters will press the ROV and thereby the cleaning system 1 against the target hull face, and the other three thrusters will control the ROV movement forwards/backwards and sideways, and control ROV heading. Depending on the thrusters' relative position, the thruster and buoyancy material configuration together with the ROV control system make the ROV controllable in all six degrees of freedom (i.e. 6-dimensional movement), i.e. forwards/backwards, sideways, up/down, heading, pitch and roll. The reason to use six equal and quite powerful motors is to get a stable ROV that can hold its position and follow its track in turbulent and high current waters. The ROV will also be big in volume and weight so powerful thrusters are required to get a vehicle with good response. It is also advantageous to have only one type of motor seen from a spare parts perspective.

**[0090]** The thrusters are preferably electrically powered for obtaining accurate and vibration-less operation.

**[0091]** The high pressure pump 12 may comprise self-cleaning filter for the inlet water to the high pressure pump. The self-cleaning mechanism is driven by a motor driven by water pressure.

**[0092]** The high pressure is provided by two fixed displacement axial piston pump units 12 that are driven by a double shaft 3000V/60Hz motor. These pumps 12 together provide a fixed flow of 340 l/min. 20 l/min from these pumps will be used for self-cleaning, and 1 l/min is used for the water motor drive of the filter. Each pump unit is connected to two rotary discs 6. This means that it is possible to run just two rotary discs if desirable.

**[0093]** In order to be able to reduce the flow to the nozzles when required, a proportional control valve 39 may be arranged after two of the high pressure pumps. These valves 39 are also used to turn the flow to the nozzles on and off, together with the relief valve described below.

**[0094]** A relief valve may be arranged after the other two pumps to be able to turn the flow to the nozzles on and off. To reduce the back pressure (pump/motor load) when starting up the pumps, the flow will also be turned off (pressure relief valve dumping to ambient sea).

**[0095]** The suction pump 10 is positioned on the ROV, since the pump must be close to the source. The pump is a particle and environmentally friendly centrifugal pump with approximately 620 L/min capacity at rated pressure drop. The pressure drop has been calculated by considering the diameter and length of the waste hoses plus other factors such as different junctions and external filter. The power needed to operate the suction pump is in the 10kW range.

**[0096]** The concept for the external filter is a big "filter bag" that floats just below the surface. The filter is connected to a buoy at the surface to make it possible to see where it is and to make it more easily retrievable. A weight is arranged in the bottom of the filter to hold it in position. The debris inlet is also arranged in the bottom part of the filter bag. During cleaning operations, the external filter is positioned alongside the target ship. The filter follows the ROV as it moves along the target ship, since the debris hose is of a fixed length and connected to both the bag and the ROV. The position of the filter can, if necessary, be adjusted using support ropes that can be attached alongside the target ship and controlled from the platform/cleaning support vessel. The small RIB boat is also used to monitor the position and the status of the filter.

**[0097]** When the filter bag is lifted out of the water with a crane, the remaining water will drain, leaving only the debris. The basic concept is to use a disposable filter.

**[0098]** As seen from Fig. 7, the tether 40 running from the workboat 50 consists internally of cables for 3000VAC, 500VDC, and optically they will be spliced up in an oil-filled junction box on the ROV end. The first part is the 3000VAC going to the pumps in two different cables, the second part is the 500VDC going to the ROV main pressure housing. The third part is the optical fibre going to the ROV main pressure housing. To remove the tether 40 from the ROV, the connectors for 3000VAC, 500VDC and optical fibre need to be disconnected. The location of the tether inlet to the ROV is on the same side as the hose connection 41 and the guide wire 42.

**[0099]** The waste hose 41 connection to the external filter needs to be easily handled from the RIB boat 52 when replacing the filter bag.

**[0100]** The guide wire 42 is attached on the ROV on the same side as the waste hose and the tether. The idea is to have it easily accessible from the RIB boat 52 in order to be able to disconnect when cleaning parts close to the ship propeller.

**[0101]** As mentioned above, the navigation unit may comprise sonars 43. One profiling sonar may be used to monitor the environment, the distance to the bottom and the quay etc. The other sonar may be a forward-looking high resolution sonar that is used to avoid obstacles etc.

**[0102]** A preliminary test shows that it may be possible to detect the border between a cleaned and a not-cleaned surface on the target hull, so that the sonars may assist in navigation control.

**[0103]** A light and camera may be mounted on each of the two pan and tilt units 44. The angular observation range of these units 44 will be limited by the surrounding ROV components and the cabling for light and camera. The pan and tilt units 44 will be positioned for maximum viewing angle in all directions, which is particularly useful for identifying obstacles in conjunction with data from the obstacle avoidance sonar.

**[0104]** The pan and tilt unit 44 angular positions are programmable: it is possible to define multiple set-points and by the press of a button resume previously-programmed camera viewing headings. This feature may be used for quickly reconfiguring the ROV during operations, e.g. to ensure that the cameras are pointed in the direction of ROV travel.

**[0105]** Six colour video cameras 45 may be mounted on the ROV. Two of them are movable via pan and tilt units, and four are arranged in a fixed position. The cameras 45 act both as observation and navigation cameras.

**[0106]** The housing 2 with a soft skirt or curtain reducing the first distance to the hull surface combined with the flow of the suction pump will prevent any debris from leaking out during cleaning.

**[0107]** It is possible to control the rotation speed of the rotary discs 6 independently of water flow to the rotary discs. The rotation speed needs to be changed depending on the forward speed of the ROV. The reference point is 400 rpm at a forward speed of 0.5 m/s. The control system will provide functionality to ensure that if the ROV slows down, the rotary discs slow down proportionally.

**[0108]** The motors 25 for the rotary discs may be 3 phase delta coupled 400VAC motors with a maximum of 1.5kW per motor. The motors will be powered from the main 500VDC through individual motor drivers.

**[0109]** The main surface platform for the cleaning system 100 is a vessel or workboat 50 as seen in Fig. 7, which during operation is placed at and moored to the quay and in front of or behind the target ship. A filter bag for the debris will follow the ROV alongside the target ship. A small RIB boat 52 may also assist and handle the filter bag and may be used for other support issues.

**[0110]** The cleaning devices navigation unit may comprise inter alia depth sensor, gyroscope, accelerometers and Doppler Velocity Log (DVL).

**[0111]** Other sensors like fixed length data from guide wire winch, wheel data, DVL may be used together with the navigation unit to determine the position of the cleaning device/ROV. An accurate GPS will be installed on the workboat to have a point of origin in case of aborted missions and to be able relocate and continue the mission later on.

**[0112]** A typical cleaning scenario is that the ROV works its way forward in steps of 1.6 m, making an orthogonal trajectory seen from the ship direction. The trajectory is determined by the guide wire length. The ROV control system will always have the guide wire elongated by using two horizontal thrusters. It also commands three vertical thrusters to push the vehicle against the hull of the ship.

**[0113]** Several help functions can be introduced depending on the rotational speed of the drives, and the water pressure is regulated by the vessel's steering system. The water pressure and the rotation speed can for instance automatically change depending on the forward speed of the ROV.

**[0114]** All the trajectories including sensor data from the ROV, like heading, pitch, roll, depth, wire length, wheel data and DVL (optional) are used to determine if the hull has been fully cleaned and are presented in real time to the pilot during the operation.

**[0115]** All position data and camera pictures are logged and could be viewed after the operation on a playback HMI in the software. That playback function can also be installed on a standard computer. This logged data is stored on a separate hard drive for quality control.

**[0116]** The workboat 50 may have a lifting crane 54 to handle the load.

**[0117]** The tether 40 will be positively buoyant, and if needed mark-up buoys could be attached to make it more visible at surface. The tether 40 will be attached to the external filter buoy and strain relieved attached to the waste hose down to the ROV.

**[0118]** In order to be able to navigate the ROV, a guide wire is attached to the ROV. The guide wire may be a 3 mm Dyneema line that goes through a Tether Protection System 57 (TPS) to a one layer winch that controls the length of the line. The tension from the winch 56 is fixed and not adjustable up to a point where it will start to feed out in order to avoid that the line breaks. A sensor on the winch will measure the tension in the guide wire to be able to calculate the position of the TPS weight and maintain the track for the ROV.

**[0119]** The concept for the TPS 57 is dependent on the appearance of the platform for the equipment. The existing TPS consists of the TPS with winch and a TPS Launcher.

**[0120]** The workboat 50 as shown in Fig. 8 may be equipped with a lifting crane 54 with load, lift height and extension capacity to handle all the parts to be launched and recovered like the ROV 35 and filter bag 55.

**[0121]** The boat 50 needs to have available space on the deck 51 for the system winches, TPS with framework, the ROV 35 in a cradle as well as space for handling the filter bag. The operator needs an area which is easily accessible inside the workboat 50 in which to run the system.

**[0122]** The preferred option is to have a workboat with hover capability to obviate anchoring or lashing to the quay or ship to be cleaned. This would also minimise movements that will negatively affect the cleaning result.

**[0123]** The control unit 104 may be arranged on a work boat 50 or the vessel, enabling an operator to control the submergible cleaning device 1 and/or the ROV. The control unit 104 may comprise a display 108 enabling the operator to follow a cleaning operation of the submergible cleaning device 1.

**[0124]** Although the invention has been described in the above in connection with preferred embodiments of the invention, it will be evident for a person skilled in the art that several modifications are conceivable without departing from the invention as defined by the following claims.

## Claims

**1.** A cleaning system (100), comprising:

- a vessel (101) to be cleaned, the vessel having a hull (102) with a submerged hull face (3), the hull face comprising one or more predetermined marks, such as draught marks, and
- a submergible cleaning device (1) configured to clean the submerged hull face, the cleaning device comprising:

  - a housing (2) comprising a top face and side faces (4) having edges (5) and an open bottom face, the edges and bottom face being arranged opposite the hull face, and the housing further comprising:

    - a rotary disc (6) having a plurality of nozzles (7) arranged around a periphery of the rotary disc, the nozzles facing the hull face,
    - rolling spacing devices (8) for providing a predetermined first gap (9) between the rotary disc and the hull face,
    - a suction device (10) fluidly connected to an outlet (11) arranged in the housing for providing a negative pressure (P) within the housing,
    - a pressurising device (12) fluidly connected with the nozzles for providing a high pressure fluid to the nozzles, whereby the nozzles are adapted to discharge fluid under high pressure against the hull face for cleaning, and
    - a navigation unit (120) configured to navigate the cleaning device in relation to the hull face and to provide positions of the cleaning device,

wherein the system further comprises:

- a logging unit (103) which is connected with the navigation unit and/or the cleaning device for receiving data and/or measurements from the navigation unit and/or the cleaning device, the logging unit being configured to store a log of the data and/ measurements, and
- a control unit (104), the control unit being connected with the logging unit and configured to graphically provide an image of the log, so that the positions of the submergible cleaning device on the hull face are presented.

**2.** A cleaning system according to claim 1, wherein the navigation unit comprises sonar equipment, subsea transponder(s), compass(es), Inertia measurement unit/Gyro, global positioning system, pressure sensor(s) and/or double velocity log.

**3.** A cleaning system according to claim 1 and/or 2, wherein the control unit provides a co-ordinate system having an x-axis, a y-axis and a z-axis, the x-axis being in a length direction of the vessel, the y-axis being in a width direction of the vessel and the z-axis being in a depth direction of the vessel.

**4.** A cleaning system according to any of the preceding claims, wherein the control unit is configured to at least provide an image presenting the positions of the submergible cleaning device along the x-axis and the z-axis.

**5.** A cleaning system according to any of the preceding claims, wherein data and/or measurements is/are position, pictures, video, pressure, thickness, speed and/or orientation.

**6.** A cleaning system according to claim 5, wherein pictures, video, pressure, speed, orientation and/or measurements is/are logged together with the position of the the submergible cleaning device.

**7.** A cleaning system according to any of the preceding claims, wherein the logging unit receives pump data from the suction device of the submergible cleaning device, indicating when the suction device has been active and inactive, the control unit being configured to compare the pump data to the data and/or positions from the navigation unit, so that an image of positions of the submergible cleaning device on the hull face is only presented when the suction device has been active.

**8.** A cleaning system according to any of the preceding claims, further comprising a remotely operated vehicle (ROV).

**9.** A cleaning system according to any of the preceding claims, wherein the submergible cleaning device comprise one or more cameras and/or light devices.

**10.** A cleaning system according to any of the preceding claims, wherein a position of the submergible cleaning device is calibrated in relation to the predetermined mark on the hull face.

**11.** A cleaning system according to claim 10, wherein the calibration of the position of the submergible cleaning device is performed automatically or manually.

**12.** A cleaning system according to any of the preceding claims, wherein the nozzles are interlocked with a pressure switch in the housing, so that the cleaning is provided only when the housing has a negative pressure.

**13.** A cleaning system according to claim 12, wherein the logging unit receives pressure measurements from the pressure switch of the submergible cleaning device, indicating when the housing has a negative pressure, the control unit being configured to compare the pressure measurements to the data and/or positions from the navigation unit, so that an image of positions of the submergible cleaning device on the hull face is only presented when a negative pressure of the housing has been present.

**14.** A cleaning system according to any of the preceding claims, wherein the control unit is arranged on a work boat or the vessel, enabling an operator to control the submergible cleaning system and/or the ROV.

**15.** A cleaning system according to any of the preceding claims, wherein the control unit comprises a display (108) enabling the operator to follow a cleaning operation of the submergible cleaning device.

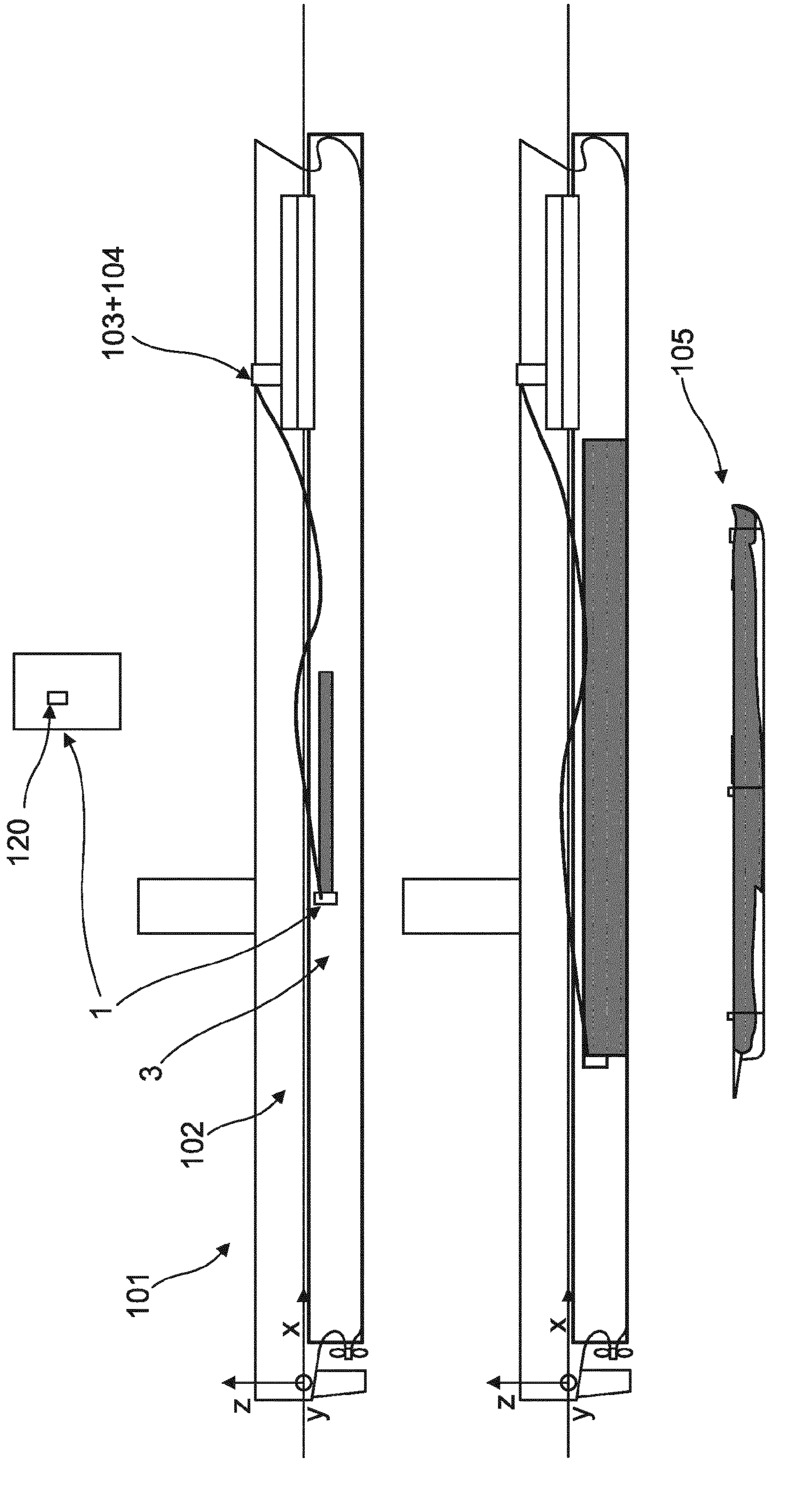


Fig. 1

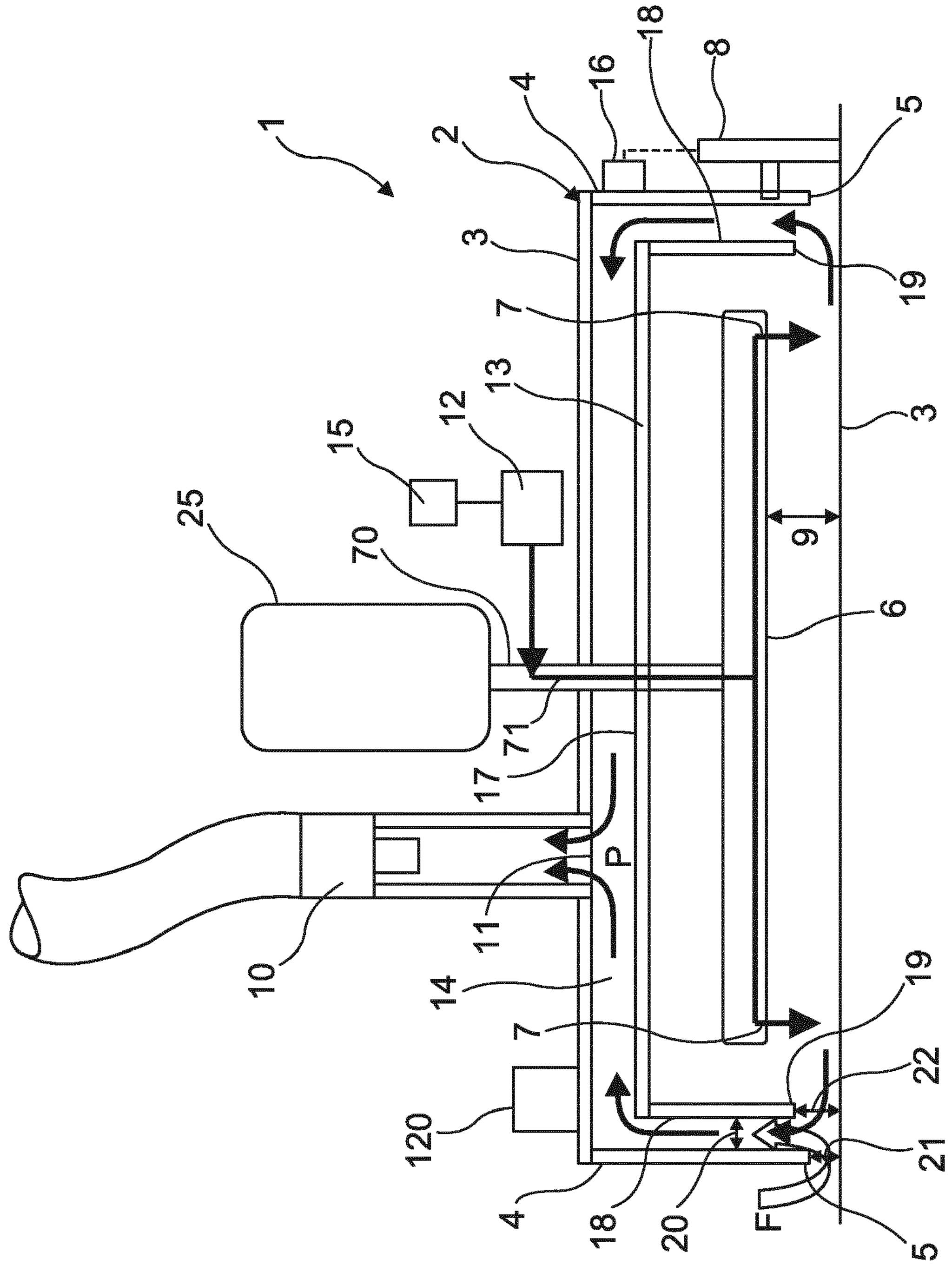
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Fig. 2

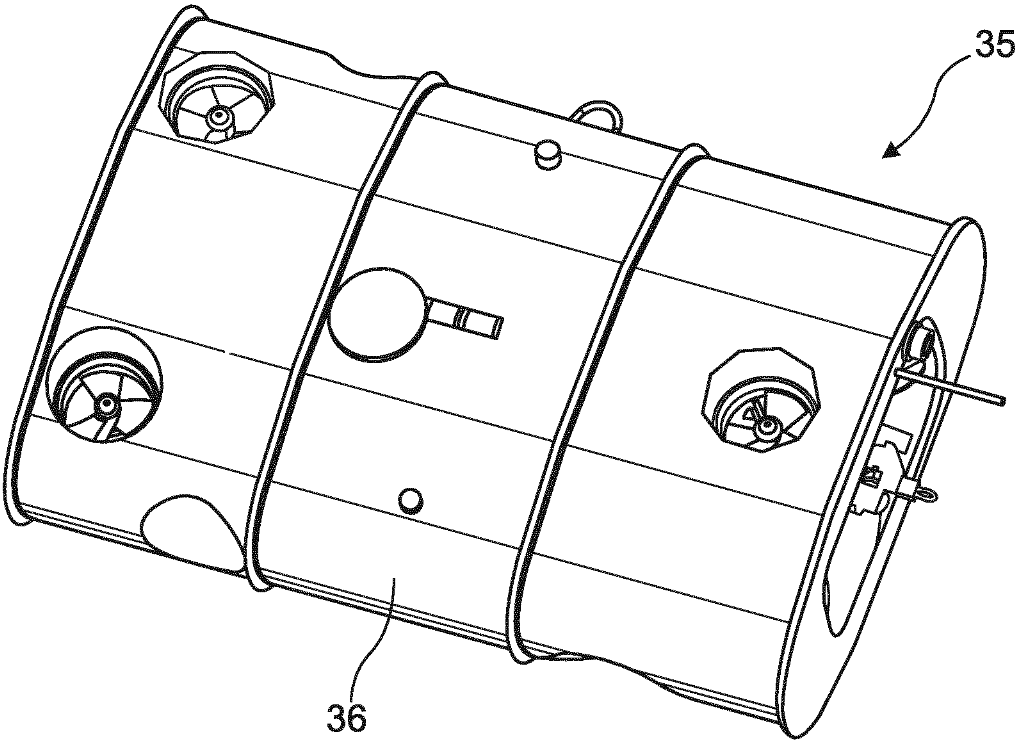


Fig. 3

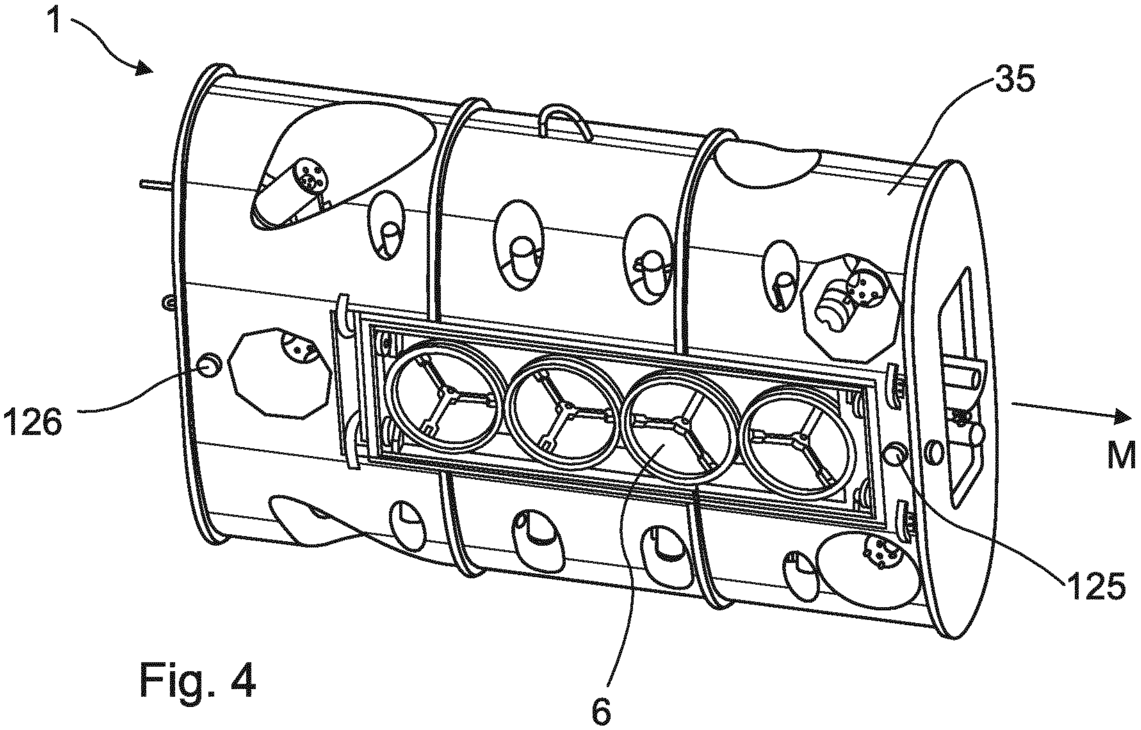


Fig. 4

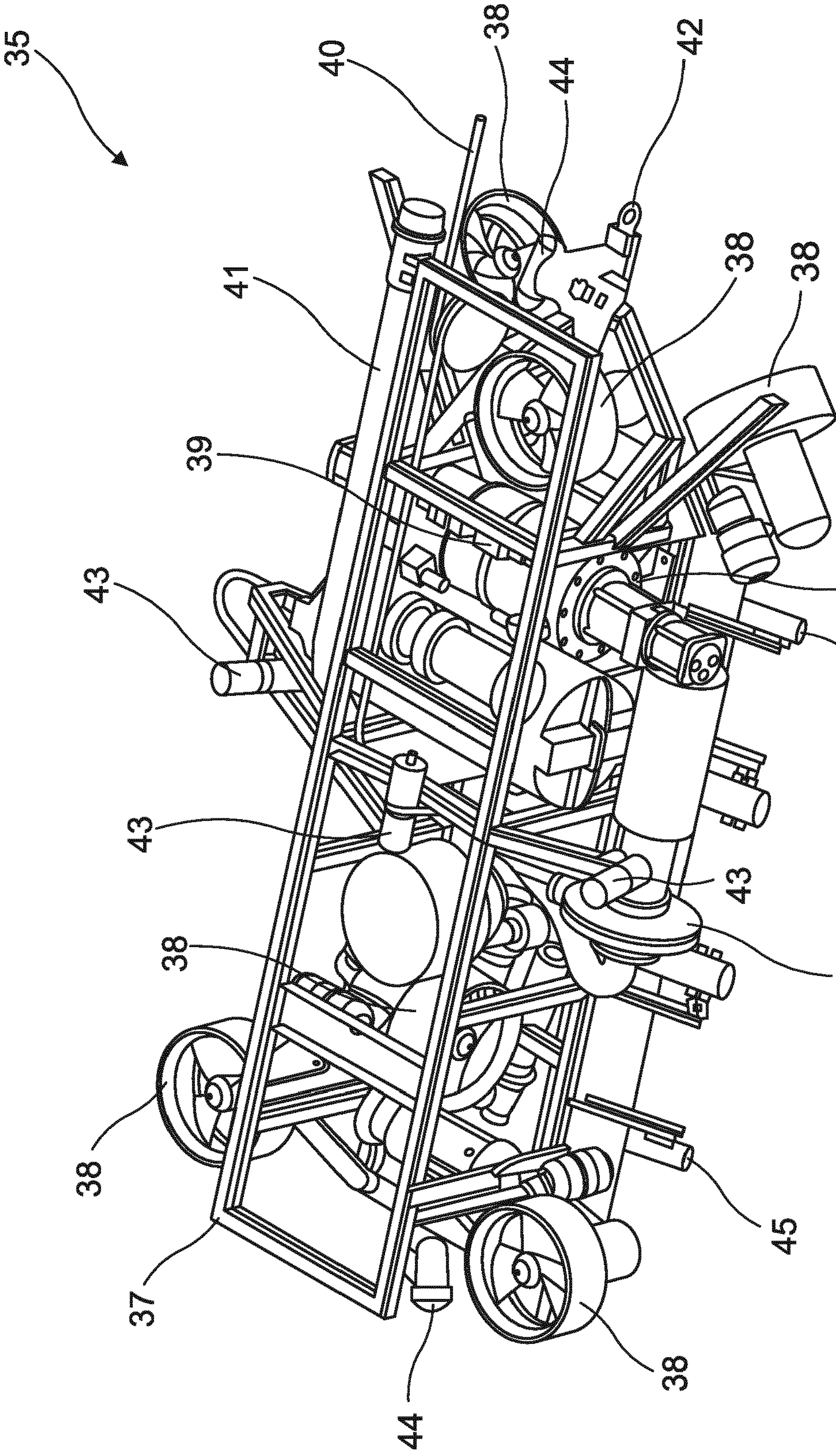


Fig. 5

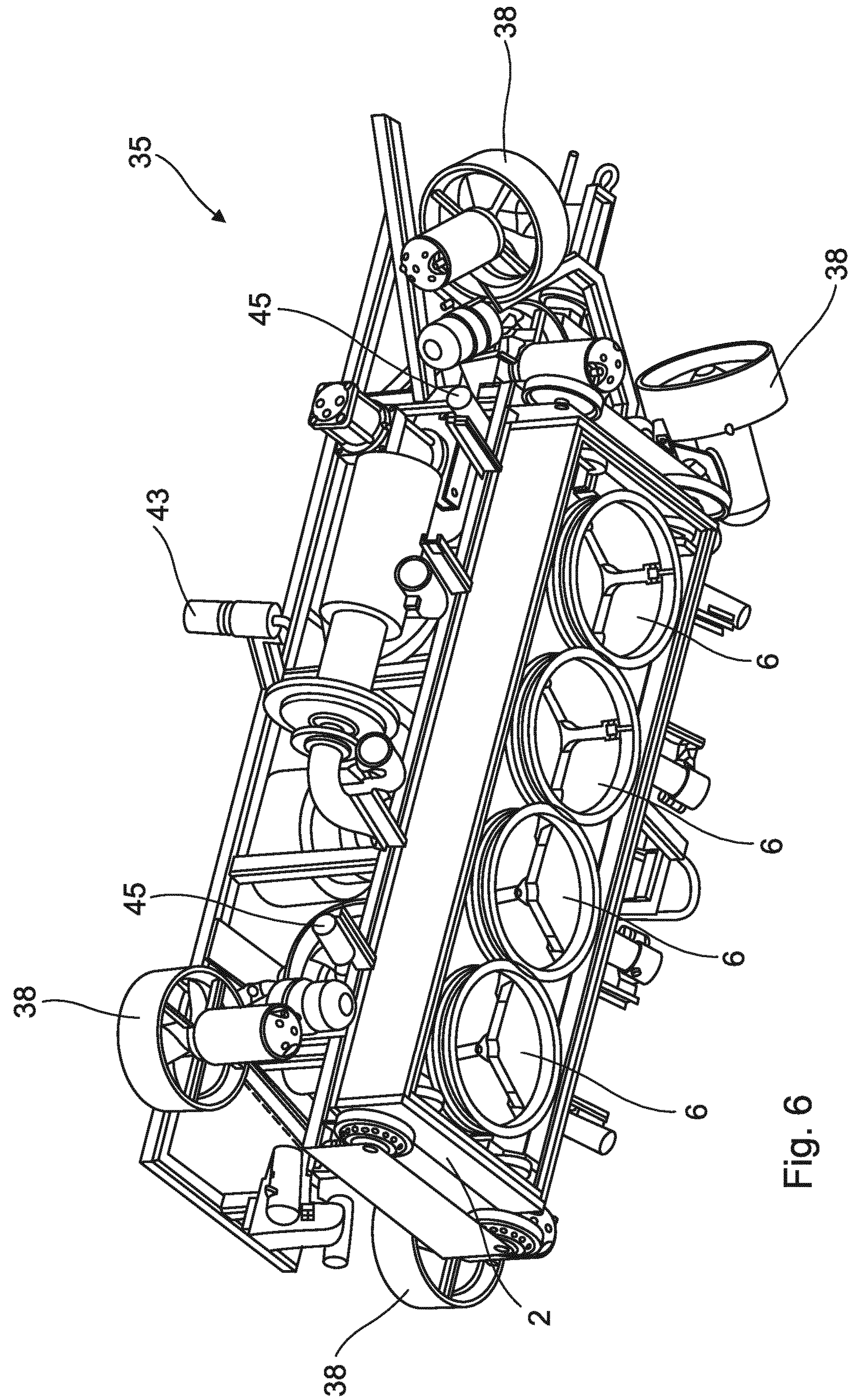


Fig. 6

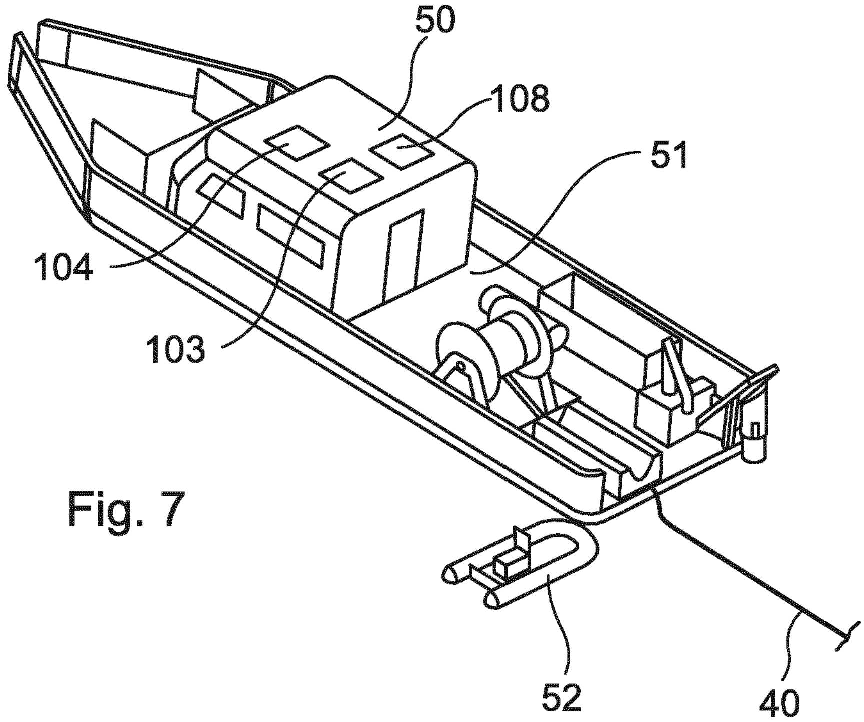


Fig. 7

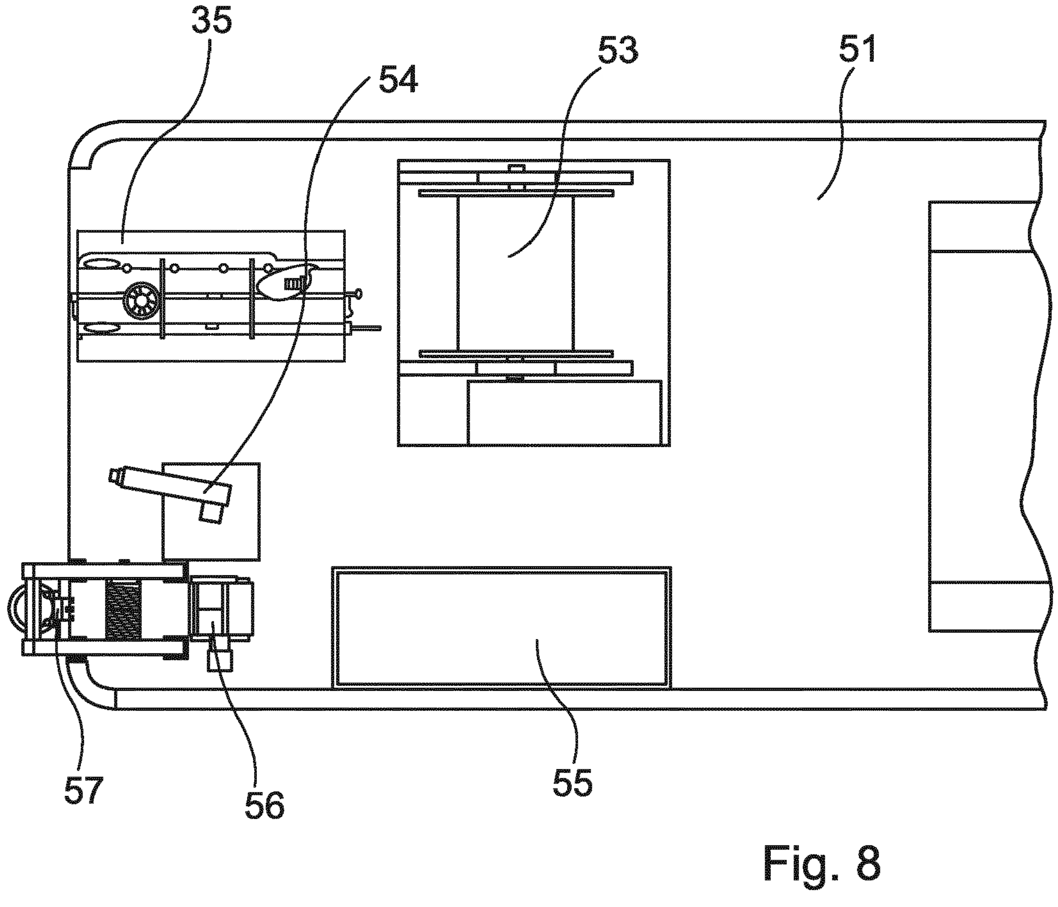


Fig. 8

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# EUROPEAN SEARCH REPORT

Application Number
EP 17 19 9109

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