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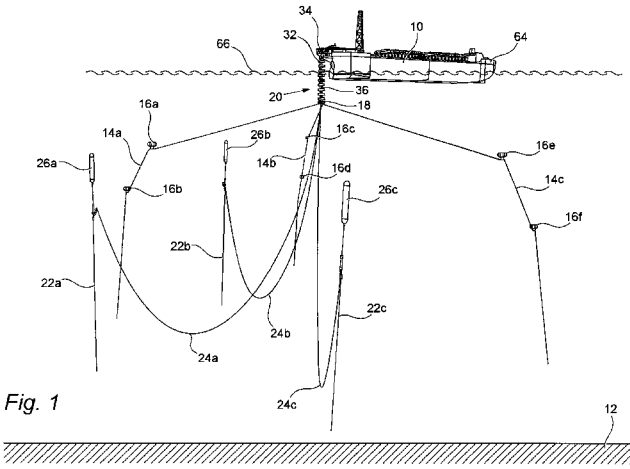


Fig. 1

(57) **Abstract**: A mooring and flowline system is disclosed for mooring a floating production and/or storage vessel (10) to the seabed (12) and one or more flowlines (22, 24) for connection to one or more producing wells or to a facility. The system comprises at least two anchors in the sea bed (12) and a respective anchor riser (14) extending from each of the anchors to a common mooring node member (18). A mooring pendant (20) extends from the common mooring node member (18), where the mooring pendant (20) has an upper end for connection, in use, to the vessel (10). Each flowline (22, 24) comprises a lower flowline (22) and a flowline riser (24) extending from the lower flowline (22) to the vessel (10). Each flowline riser (24) has part of its length secured to the mooring pendant (20) by one or more guide frames (32) to control sideways and rotational movement. Furthermore, buoyancy is provided on, in-between, for or by at least one of the guide frames (32), wherein the buoyancy is sufficient to support the common mooring node member (18) and mooring pendant (20) below the surface of the sea and above the seabed (12) when the mooring pendant (20) is disconnected from the vessel (10).

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DEEP WATER AND ULTRA DEEP WATER MOORING SYSTEM

This invention relates to a mooring and flowline system for use in floating facilities for handling petroleum and petroleum products. The system is particularly, but not exclusively applicable to the mooring and loading of floating production vessels operating in waters in excess of 1000m deep.

Production from offshore wells can be exported ashore by subsea pipeline, but this requires a very large capital expenditure. Recently there has been a move to exploiting more marginal fields by the use of a floating production, storage and offtake (FPSO) vessel. Commonly, the floating production facility has been provided by conversion of an existing tanker. Such arrangements have worked well, but there is a continuing need for a substantial reduction in installation costs in order to improve the economics of marginal field development and production.

Tanker conversions used hitherto have required extensive conversion. In some cases a turret mooring is used which includes a rotary oil flowline joint. This requires major structural work on the tanker in addition to the complex mooring turret. In other cases, a flexible riser to the tanker has been used, but has required large quick disconnect (QDC) valves with a physical size and weight requiring installation outboard of the tanker bow on a specially installed and relatively large structure.

A Tri-Catenary Mooring System has more recently been proposed in patents US 5,944,448 and US 6,435,124 (assigned to Mooring Systems Limited of Aberdeen, UK) and such a system has proved

very effective in operation in the Oudna field, offshore Tunisia, in approximately 260m water depth. However, it is acknowledged that it would not be technically possible to use the same Tri-Catenary Mooring Systems in water of a depth greater than 500m.

The exploitation of more marginal fields often requires operation in water at depths in excess of 500m and sometimes in excess of 1000m. Operating at these increased depths presents many challenges when using a FPSO vessel, including but not exclusively, the design and shape of the mooring lines, and risers used to transport the oil from the wellhead to the vessel.

An object of embodiments in accordance with the present invention is to provide an improved mooring and flowline system which is quickly and fully disconnectable from the FPSO vessel, which is simple and economical to install and which is suitable for use in Deep Water (i.e. at depths greater than 500m) and Ultra Deep Water (i.e. at depths greater than 1000m). It is also an object of embodiments in accordance with the invention to provide a system which requires minimum use of heavy lifting gear located on the FPSO vessel or other support vessel.

Accordingly, the present invention provides a mooring and flowline system comprising:

means for mooring a floating production and/or storage vessel to the seabed; and

one or more flowlines for connection to one or more producing wells or to a facility;

the mooring means comprising at least two anchors in the sea bed and a respective anchor riser extending from each of the anchors, each of the anchor risers having one end secured to its anchor and the other end secured to a common mooring node member, and a mooring pendant extending from the common mooring node member, the mooring pendant having an upper end for connection, in use, to the vessel;

each flowline comprising a lower flowline extending from the direction of the well or facility partway toward the vessel into the vicinity of the mooring means, and a flowline riser extending from the lower flowline to the vessel;

wherein each flowline riser has part of its length secured to the mooring pendant by one or more guide frames to control sideways and rotational movement so that, in use, each flowline riser is capable of helixing around the mooring pendant in response to turning of the vessel;

characterised in that buoyancy means are provided on, in-between, for or by at least one of the one or more guide frames, wherein the buoyancy afforded by the buoyancy means is sufficient to support the common mooring node member and mooring pendant below the surface of the sea and above the seabed when the mooring pendant is disconnected from the floating production and/or storage vessel.

Typically, the system comprises two or more guide frames and more preferably comprises more than two guide frames such as in the region of 6 to 12 guide frames.

Preferably, the buoyancy means are distributed along the length of the mooring pendant, between the common mooring node member and the upper end of the mooring pendant for connection to the vessel and more preferably are distributed substantially equi-distant along the length of the mooring pendant.

Preferably, the buoyancy means are provided on, in-between, for or by each of the one or more guide frames such that the one or more guide frames support the mooring pendant when disconnected from the floating production and/or storage vessel and more preferably, the buoyancy means are provided by each of the one or more guide frames.

Preferably, the mooring and flowline system is arranged such that when the mooring pendant is connected to the floating production and/or storage vessel, in use, at least one of the guide frames is located above the surface of the sea and at least one of the guide frames is located below the surface of the sea.

Preferably, the one or more guide frames are sealed pressure vessels. Optionally, the one or more guide frames consist of sealed chambers that are filled with air. Alternatively, the sealed chambers are filled with any suitable buoyant material, for example foam.

Optionally, the buoyancy of the one or more guide frames can be adjusted to control the position in use, of the common mooring node

member and mooring pendant below the surface of the sea and above the seabed, when the mooring pendant is disconnected from the floating production and/or storage vessel.

Preferably, further buoyancy means is provided for, on or by the mooring means to reduce the likelihood of the anchor risers clashing or interfering with the flowline risers when the system is connected to and disconnected from the vessel.

Preferably, the system is capable of operating at depths up to 1000m, and more preferably at depths greater than 1000m such as between 1000 and 1500m of water.

Optionally, disconnection of the system can be made without the need to lower the system into the water using a winch.

Preferably, when the mooring pendant is disconnected from the floating production and/or storage vessel, the one or more guide frames are located below the surface of the sea and above the sea bed and more preferably, the buoyancy provided by the buoyancy means of the one or more guide frames supports the mooring pendant and one or more flowline risers attached thereto when disconnected at a depth in the region of 50m to 100m and more preferably in the region of 70m. Preferably, once disconnected from the vessel, the system adopts a stable submerged configuration.

Optionally, the buoyancy on the flowlines is in the form of buoyancy tanks.

Preferably, yet further buoyancy means is provided for, on or by the anchor risers such that the profile of the anchor risers is increased in that the anchor risers are raised and held above the flowlines. Increasing the profile of the anchor risers helps to reduce the likelihood of the anchor risers clashing or interfering with the flowline risers.

Optionally, a riser jumper provides fluid communication between each riser tower and the floating production and/or storage vessel.

Optionally each riser jumper is a continuous conduit with a single axial rotational coupling, located between the uppermost guide frame and a riser jumper hang-off point on the vessel.

Optionally, the buoyancy tanks support a connection between the riser tower and the riser jumper at a depth of 150m.

Optionally the buoyancy tanks pull on the connection via 20m of chain.

Preferably the system is fully disconnectable in 10 hrs, more preferably in 8 hrs, and in less than 8 hrs being particularly preferred.

Preferably, there are at least three anchors in an angular array, three anchors at mutual 120° spacings being particularly preferred. The anchors may be arranged to point north, south-west and south-east.

Preferably, there is no mooring swivel between the anchors and the upper end of the mooring pendant; the common mooring node member may be a plain ring, shackle or plate.

In a preferred embodiment of the invention, a conventional tanker is used as the production vessel with minimal conversion, the chafe chain brought inboard of the tanker to a standard chain stopper or to a remotely controlled release stopper, the riser jumpers are brought inboard of the tanker over a chute to have their inboard ends lying near the tanker deck, and quick disconnect valves are located near the tanker deck between said riser jumpers and a tank manifold of the tanker.

Optionally, the chafe chain may comprise two parallel chains, one passing over each bow of the vessel.

Typically the anchor risers are chains between 120 and 147mm in diameter of Grade R3 or optionally of higher strength material.

Typically the chafe chain is 147mm in diameter of Grade R3 or optionally of higher strength material.

Preferably, the vessel is a tanker.

An embodiment of the invention will now be described, by way of example only, with reference to the drawings, in which:

Fig. 1 is a schematic side view of an embodiment of a mooring and flowline system in accordance with the present invention, in use with a production tanker;
Fig. 2 is a plan view corresponding to Fig. 1;
Fig. 3 is a schematic side view of the chafe chain and guide frames in particular of Fig. 1;

Fig. 4 is a schematic side view of the embodiment of Fig. 1, the mooring and flowline system having been disconnected from the production tanker;

Fig. 5 is a schematic perspective view of a guide frame of Fig. 3;

Fig. 6 is a schematic perspective view of the connection between the chafe chain and a guide frame of Fig. 3.

Referring particularly to Fig. 1, a floating production tanker or FPSO 10 is anchored to the sea bed 12 by means of a three-leg anchor system consisting of anchor risers 14a, 14b, 14c and mooring buoys 16a, 16b, 16c, 16d, 16e and 16f. The anchor risers 14a, 14b and 14c are connected to a common mooring node 18, from which a mooring pendant 20 is secured to the tanker 10. The anchor system is in the vicinity of a wellhead (not shown in the drawings) from which oil is transferred via a number of flowlines, as will now be described.

The flowlines consist of riser towers 22a, 22b and 22c and riser jumpers 24a, 24b and 24c. The riser towers 22a, 22b and 22c are provided with buoyancy tanks 26a, 26b and 26c. The riser towers 22a, 22b and 22c may be tensioned steel catenary risers.

The upper part of the riser jumpers 24a, 24b and 24c are secured along the mooring pendant 20 by the guide frames 32 that are each rigidly connected to plates 56 integral to the chafe chain 36 as shown in Fig. 6.

The riser jumpers 24a, 24b and 24c are taken aboard the tanker 10 via a turret 34. The riser jumpers 24a, 24b and 24c are flexible with

sufficient dynamic properties to accept movement of the ship's bow and movement of the anchor risers 14a, 14b and 14c.

The riser jumpers 24a, 24b and 24c are continuous conduits with a single axial rotational coupling (not shown), located between the uppermost guide frame 32 and a riser jumper hang off point (not shown) on the turret 34 of the tanker 10.

The mooring buoys 16a, 16b, 16c, 16d, 16e and 16f increase the profile of the anchor risers 14a, 14b and 14c such that anchor risers 14a, 14b and 14c are held above and clear of the riser jumpers 24a, 24b and 24c, reducing the likelihood of the anchor risers 14a, 14b and 14c clashing or interfering with the riser jumpers 24a, 24b and 24c.

The riser jumpers 24a, 24b and 24c can be unbonded or bonded pipes of a wide variety of sizes and specifications.

When the mooring pendant 20 is connected to the vessel 10, some of the guide frames 32 are located above and some of the guide frames 32 are below the surface of the sea 66.

The mooring pendant 20 is particularly for use with a mooring and flowline system as described herein that can be operated in Ultra Deep Water. The mooring pendant 20 can also be used with a lazy-wave arrangement of flowlines such as that described in patents US 5,944,448 and US 6,435,124 (assigned to Mooring Systems Limited of Aberdeen, UK), and such systems could be operated in Deep Water (but would not likely be suited for Ultra Deep Water).

As seen in Fig. 2, the anchor system is set such that a 120° angle may be presented towards the sea bed 12 with one leg of the anchor system pointing north. Fig. 2 also shows umbilicals 28a, 28b and 28c provided with flotation collars 30a, 30b and 30c. The umbilicals 28a, 28b and 28c provide communication between the vessel 10 and wellhead (not shown).

The anchors (not shown) may be any suitable form of conventional mooring anchor. At least some of the length of each anchor riser 14a, 14b and 14c is chain. In this embodiment the on-bottom section is chain, the lower part of the anchor risers 14a, 14b, 14c is chain and the upper 350m of the anchor risers 14a, 14b, 14c is preferably of synthetic rope.

The use of rope for part of the anchor riser 14a, 14b, 14c has several advantages. Principally, it reduces the weight which has to be lifted when the tanker 10 is connecting to the system, as is discussed more fully below. It also simplifies stowage on the vessel 10 used to deploy the system. When rope is used it is desirable to have the final 30 metres or so of anchor riser 14a, 14b, 14c nearest the node 18, of chain, to reduce the risk of kinking the rope.

Referring to Fig. 3, the node 18 is a plate that connects together the three anchor risers 14a, 14b and 14c and the pendant 20 with adequate mechanical strength. A suitably sized master ring may be used, or a triangular plate arrangement, together with conventional shackles. No swivel is incorporated in the node 18. The lower most end of the chafe chain 36 is secured to the node 18 with a suitable shackle or the like. Guide frames 32 are secured to the chafe chain 36 as shown in Fig. 6 and described below.

Fig. 3 shows the disposition of the three riser jumpers 24a, 24b and 24c passing through nine guide frames 32, although ten guide frames 32 are shown in Fig. 1, secured to the chafe chain 36. This shows how the riser jumpers 24a, 24b and 24c approach the node 18 from different directions and are brought into a parallel array at the vessel's bow at position 40. The guide frames 32 are evenly distributed along the length of the chafe chain 36. In this particular embodiment, as shown in Fig. 3, there are nine guide frames 32 secured to the chafe chain 36 at 4.5m intervals along a 51m length of chafe chain 36.

In a typical installation, the tanker 10 is a segregated ballast tanker of 600,000 to 750,000 bbl capacity and the mooring is designed to hold the node 18 at a depth of 30 metres, and thus up to about 15 metres beneath the tanker hull. In these circumstances, the chafe chain 36 will be of the order of 40 to 60m in length.

The preferred form for the mooring pendant 20 comprises a single large-size chafe chain 36 extending from the node 18 and connected to the tanker 10. A suitable chain has a diameter in the region of 120mm to 147 mm, which will fit many standard chain stoppers (not shown). This arrangement simplifies the design of the node 18 and minimises modification to the tanker 10.

A suitable tanker bow installation or turret is used that requires minimum modification of standard shipping practices, as described in for example US 6,435,124.

Installation of the system requires each anchor (not shown) to be laid in turn, and the anchor risers 14a, 14b, 14c to be run back to a

common point. As it is laid, each anchor riser 14a, 14b, 14c is buoyed off on a pendant wire (not shown). Tensioning of the anchors can be achieved using the bollard pull of suitable vessels or with the inclusion in the system of a standard chain tensioner. One of the mooring legs (not shown) includes a standard seabed chain stopper for correct pre-tensioning of the system. When all three anchor risers 14a, 14b, 14c have been laid, the anchor handler (not shown) recovers all three anchor risers 14a, 14b, 14c over the stern roller (not shown).

Fig. 4 depicts the mooring and flowline system disconnected from the vessel. The buoyancy provided by the guide frames 32 provided on the mooring pendant 20; mooring buoys 16a, 16b, 16c, 16d, 16e and 16f; and buoyancy tanks 26a, 26b and 26c, maintain the necessary profile of the riser jumpers 24a, 24b and 24c and anchor risers 14a, 14b and 14c. In a preferred embodiment, once disconnected from the vessel 10, the system adopts a stable submerged configuration, the mooring pendant 20 preferably being arranged to sink to a depth of 70m.

Fig. 4 illustrates a pick-up rope 42 attached to the upper end of the mooring pendant 20 and a buoy 46.

In use, when tanker 10 approaches location, the pick-up rope 42 is recovered from buoy 46, either by the tanker 10 itself or by a support vessel (not shown) and fired across to the tanker using a compressed air rocket gun (not shown). The tanker 10 pulls on the pick-up rope and starts to retrieve the mooring pendant 20, securing the chafe chain 36 in the chain stoppers (not shown). The winches (also not shown) of a typical tanker 10 can be supplemented by a block and

tackle or a temporary winch to achieve sufficient pull for this application, which may require a pull of up to 400 tonnes. The guide frames 32 provide buoyancy and therefore an upward force which reduces the pull or recovery force required to lift the mooring pendant 20, and the rest of the mooring and flowline system, from a depth of 70m up to the sea surface 66. Therefore, the guide frames 32 provide sufficient buoyancy to the mooring and flowline system such that the force provided by the buoyancy of the guide frames 32 (when the upper most guide frame 32 is in the region of 70m water depth) is substantially equal and opposite to the weight of the rest of the mooring and flowline system and thus provides stability to the mooring and flowline system in the water after it has been disconnected from the tanker 10.

Fig. 5 shows a guide frame 32 in more detail. The guide frame 32 is a sealed pressure vessel. The central slot 48 receives the chafe chain (not shown). Ports 50a, 50b and 50c receive riser jumpers 24a, 24b and 24c. Ports 52a and 52b receive two of the umbilicals 28a, 28b and 28c. Port 54 receives a gas export pipe (not shown).

Fig. 6 further depicts the plate 56 used for connecting the guide frame 32 to the chafe chain 36. The embodiment of the invention shown in Fig. 6 comprises chambers 60 filled with air, although they could be partially or fully evacuated to provide a partial or full vacuum. The chambers 60 are sealed to provide buoyancy. The chafe chain 36 is secured to the guide frame 32 by bolts 62 that pass through plate 56 and guide frame 32.

A breakaway-cum-emergency release unit (not shown) may be provided, suitably a Gall-Thomson coupling is included and consists

of bolts which shear at a predetermined axial load, a chute and a short section of flexible pipe ensuring that the load on the coupling is always axial. The breakaway-cum-emergency release unit (not shown) also seals the pipe both sides of the unit as the unit breaks apart. A manually operated ball valve would be used to close the connection in normal disconnection routines. The hydraulically or gas pressure activated release system (not shown) within the breakaway-cum-emergency release unit can be operated remotely, for example, from the bridge of the vessel, when it is decided to make an emergency disconnection of the tanker. The emergency shutdown valve is included to provide shutdown of flow without disconnection and would normally be part of the tanker's equipment even if not located close to the release system.

It will be appreciated from the foregoing description that the arrangement in operation will cause the riser jumpers 24a, 24b and 24c to helix around the mooring pendant 20. There will therefore be a restriction on the number of turns the vessel 10 can make, since turning full circle will effectively twist the riser jumpers 24a, 24b and 24c and the mooring pendant 20 round each other. Contrary to previous practice, the present inventors believe and can demonstrate that the limit of this helixing is not a practicable restriction in a floating production situation. It is believed that the weather patterns actually found in practice may make a vessel 10 do complete turns; however there are more than sufficient lighter weather periods when the tanker 10 can turn back, either using its own engines and rudder (not shown), or being pulled round by a tug (also not shown).

During normal operation the vessel 10 aligns with its stern 64 meeting the waves (not shown). The vessel 10 is able to weathervane up to

three times before it must turn back to unwind the riser jumpers 24a, 24b and 24c; umbilicals 28a, 28b and 28c; and gas export pipe (not shown) from around the chafe chain 36.

The invention provides a mooring and flowline system which can handle one or more flowlines making use of a minimally converted tanker and relatively small, standard components. In particular the present invention may use individual hose swivels each typically 600mm long, weighing 120kg and costing about GBP 20,000, made as standard components by manufacturers such as Woodfield. In contrast, prior art systems require the use of a multi-path (toroidal) flowline swivel which can be up to 10m high, weigh several tens of tons, and cost GBP 3-4 million.

Modifications and improvements may be made to the embodiments hereinbefore described without departing from the scope of the invention. For instance, buoyancy can be added to the chafe chain 36 in-between guide frames 32 either instead of the inherent buoyancy provided by the sealed pressure vessel guide frames 32 disclosed herein or in addition thereto, to support the mooring pendant 20 when disconnected from the vessel 10 and submerged.

CLAIMS

1. A mooring and flowline system comprising:
means for mooring a floating production and/or storage vessel to the seabed; and
one or more flowlines for connection to one or more producing wells or to a facility;
the mooring means comprising at least two anchors in the sea bed and a respective anchor riser extending from each of the anchors, each of the anchor risers having one end secured to its anchor and the other end secured to a common mooring node member, and a mooring pendant extending from the common mooring node member, the mooring pendant having an upper end for connection, in use, to the vessel;
each flowline comprising a lower flowline extending from the direction of the well or facility partway toward the vessel into the vicinity of the mooring means, and a flowline riser extending from the lower flowline to the vessel;
wherein each flowline riser has part of its length secured to the mooring pendant by one or more guide frames to control sideways and rotational movement so that, in use, each flowline riser is capable of helixing around the mooring pendant in response to turning of the vessel;
characterised in that buoyancy means are provided on, in-between, for or by at least one of the one or more guide frames, wherein the buoyancy afforded by the buoyancy means is sufficient to support the common mooring node member and mooring pendant below the surface of the sea and above the seabed when the mooring pendant is

disconnected from the floating production and/or storage vessel.

2. A system according to claim 1, wherein the buoyancy means comprises two or more sealed pressure vessels.

3. A system according to claim 2, wherein the buoyancy means comprises between six and twelve sealed pressure vessels.

4. A system according to claim 2 or 3, wherein the buoyancy of the one or more sealed pressure vessels can be adjusted to control the position in use, of the common mooring node member and mooring pendant below the surface of the sea and above the seabed, when the mooring pendant is disconnected from the floating production and/or storage vessel.

5. A system according to any of claims 2-4, wherein the mooring and flowline system is arranged such that when the mooring pendant is connected to the floating production and/or storage vessel, in use, at least one of the sealed pressure vessels is located above the surface of the sea and at least one of the sealed pressure vessels is located below the surface of the sea.

6. A system according to claim 2-5, wherein one or more of the sealed pressure vessels support the mooring pendant when disconnected from the floating production and/or storage vessel.

7. A system according to any of claims 2-6, wherein the sealed pressure vessels are filled with air or foam.

8. A system according to any preceding claim, wherein the buoyancy means are distributed along the length of the mooring pendant.

9. A system according to claims 8, wherein the buoyancy means are distributed between the common mooring node member and the upper end of the mooring pendant for connection to the vessel.

10. A system according to claim 8 or 9, wherein the buoyancy means are distributed equi-distant along the length of the mooring pendant.

11. A system according to any of the preceding claims, wherein further buoyancy means is provided for, on or by the mooring means and/or the anchor risers.

12. A system according to any preceding claim adapted for operation at depths between 1000 and 1500m of water.

13. A system according to any preceding claims, adapted for disconnection to be made without the need to lower the system into the water using a winch.

14. A system according to any preceding claim, comprising a riser jumper which provides fluid communication between each riser tower and the floating production and/or storage vessel.

15. A system according to claim 14, wherein each riser jumper is a continuous conduit with a single axial rotational coupling, located between the uppermost guide frame and a riser jumper hang-off point on the vessel.

16. A system according to claim 11 wherein the further buoyancy comprises buoyancy tanks.

17. A system according to claim 16, wherein the buoyancy tanks support a connection between the riser tower and the riser jumper at a depth of 150m.

18. A system according to claim 16 or 17, wherein the buoyancy tanks pull on the connection via 20m of chain.

19. A system according to any preceding claim comprising at least three anchors in an angular array,

20. A system according to claim 19, comprising three anchors at mutual 120° spacing.

21. A system according to claim 20, wherein the anchors are arranged to point north, south-west and south-east.

22. A system according to any preceding claim wherein the common mooring node member is a plain ring, shackle or plate.

23. A system according to any preceding claim, wherein the production vessel is a tanker

24. A system according to any preceding claim, wherein the anchor risers are chains between 120 and 147mm in diameter of Grade R3 higher strength material.

25. A system according to any preceding claim, wherein the mooring pendant comprises a chafe chain which is 147mm in diameter of Grade R3 or higher strength material.

26. A mooring and flowline system substantially as hereinbefore described with reference to and as shown in any of Figs. 1-6 of the accompanying drawings.

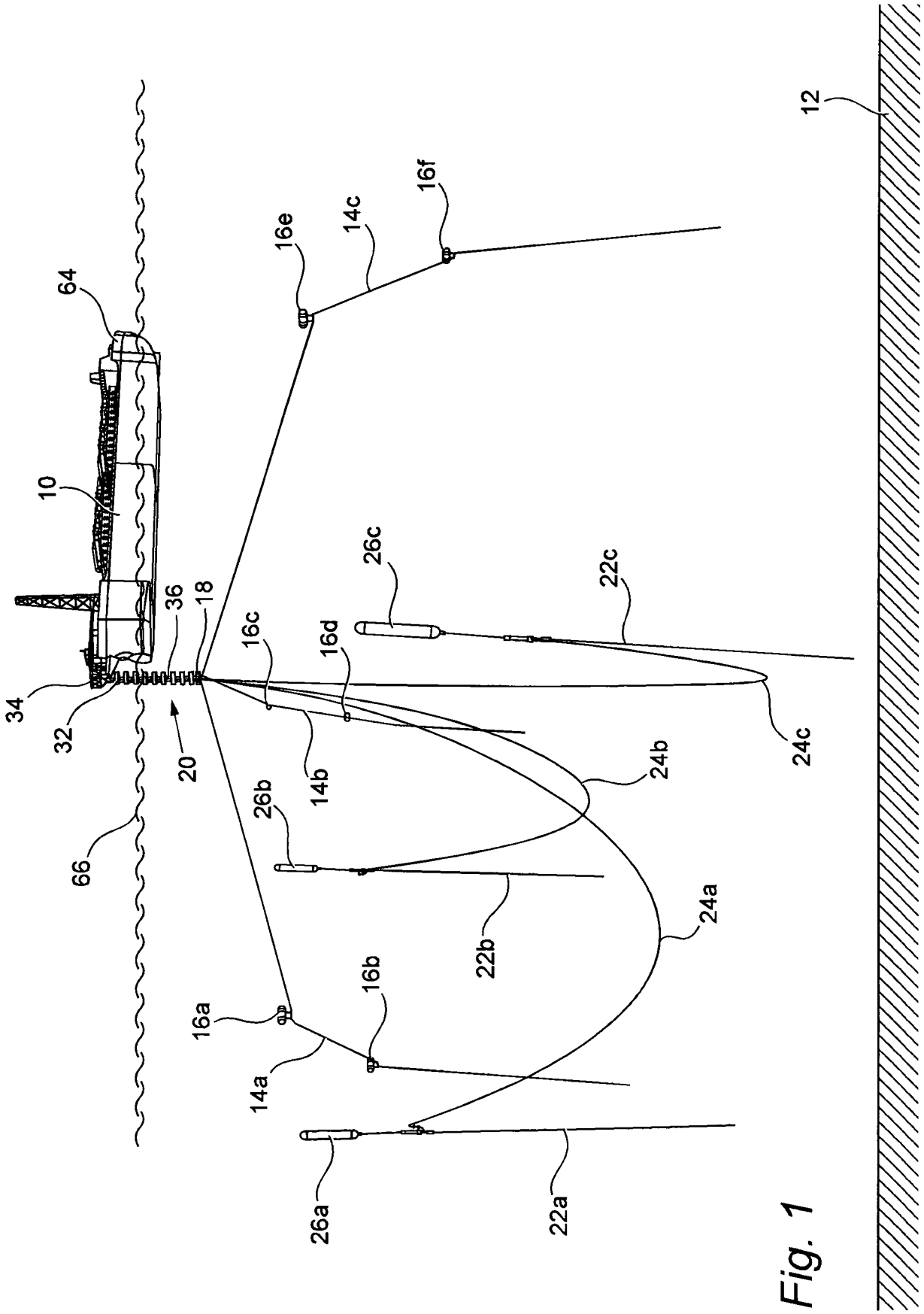

12
64
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14a
26a
22a

Fig. 1

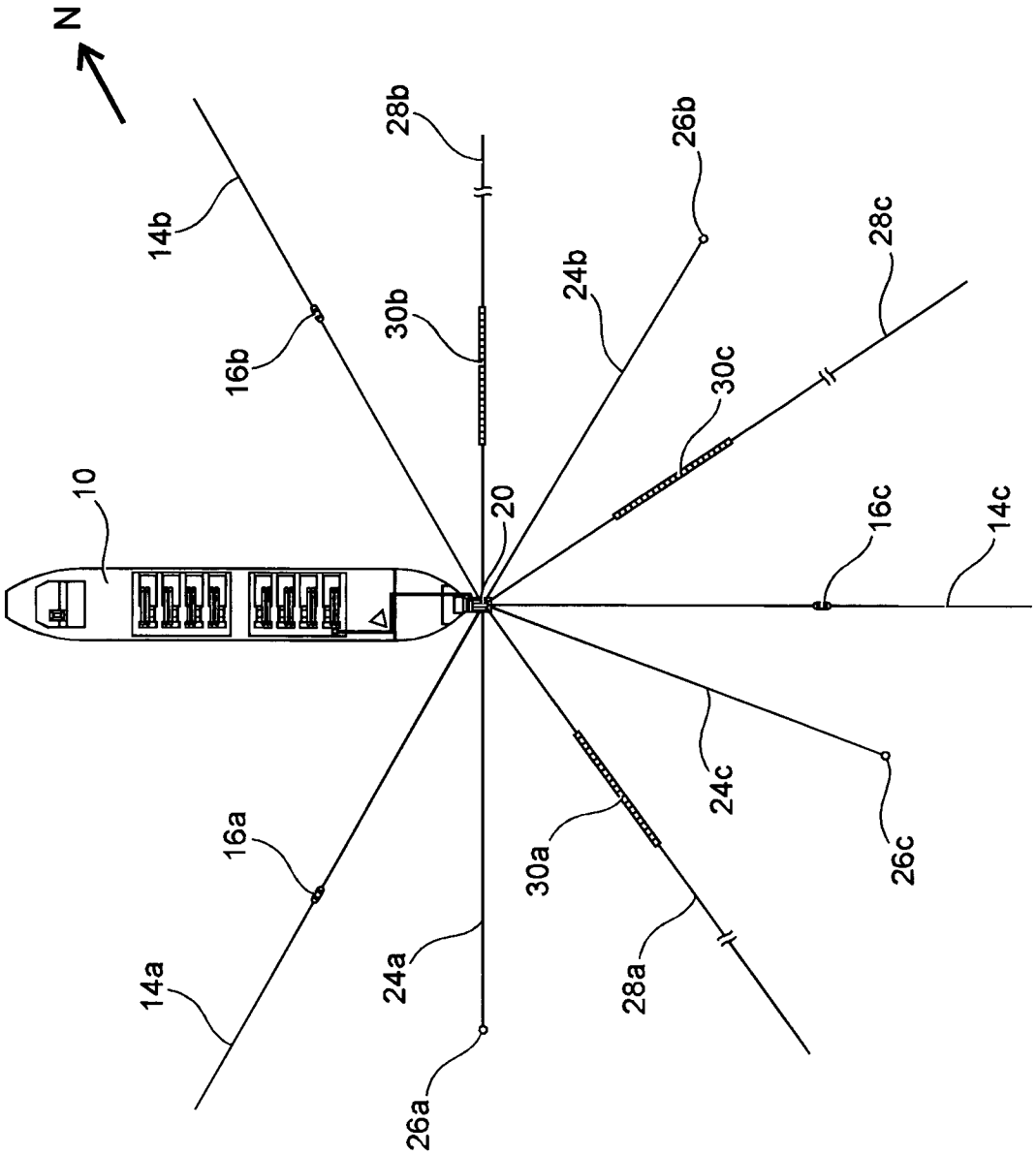

N
10
14a
16a
24a
26a
28a
30a
14b
16b
24b
26b
28b
30b
14c
16c
24c
26c
28c
30c
20

Fig. 2

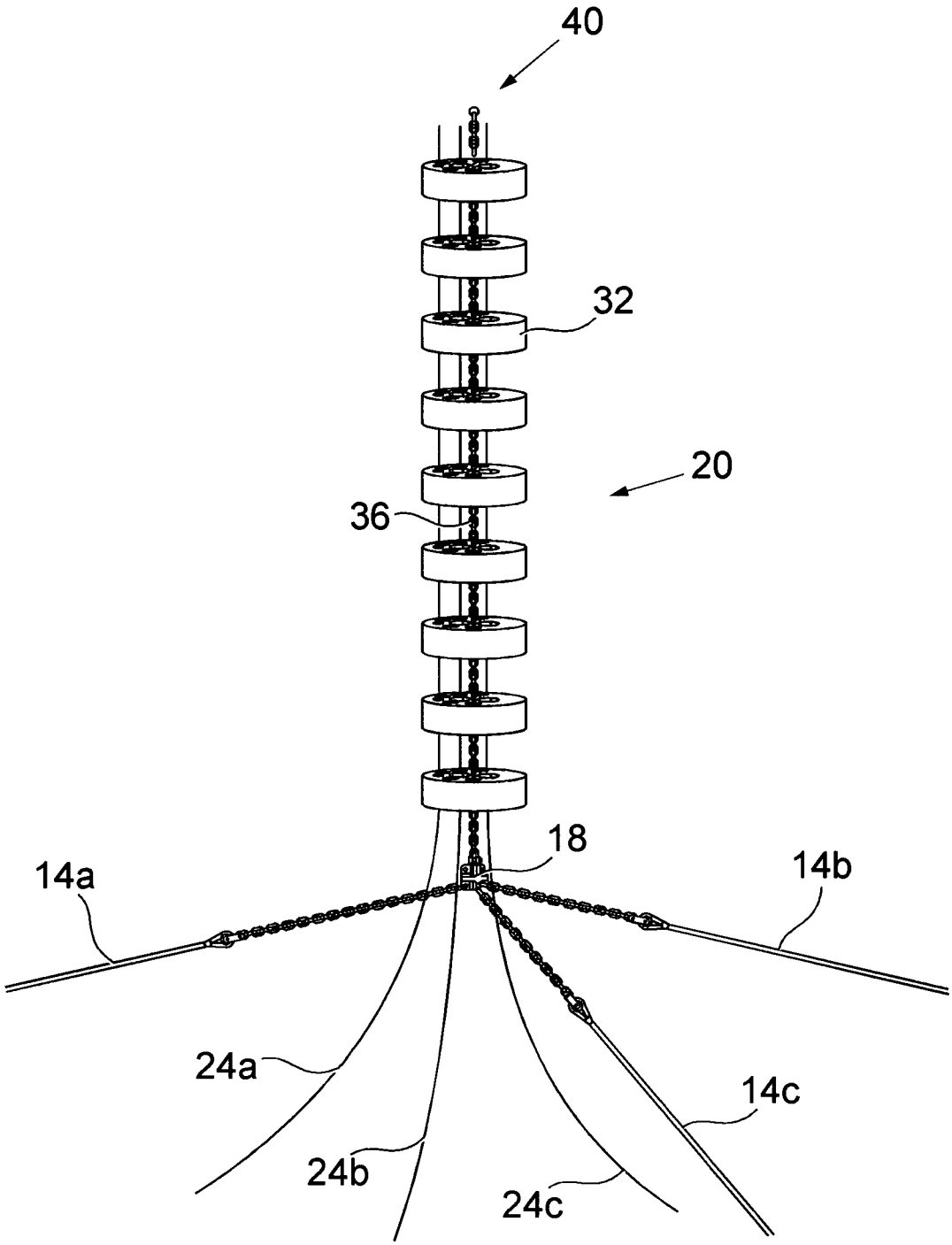


Fig.3

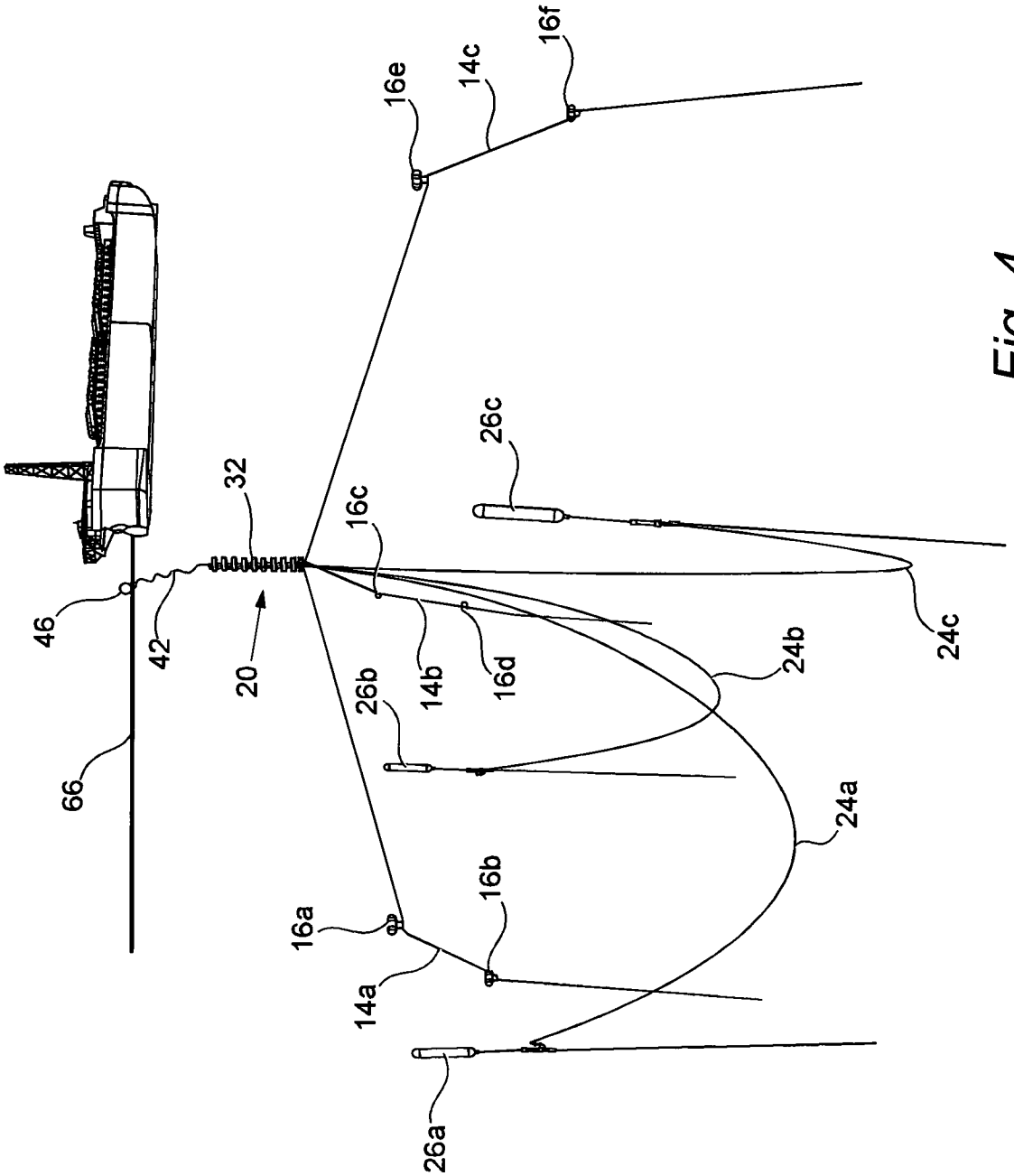

16f
14c
16e
26c
32
16c
46
42
20
14b
16d
24b
24c
26b
66
24a
16b
16a
14a
26a

Fig. 4

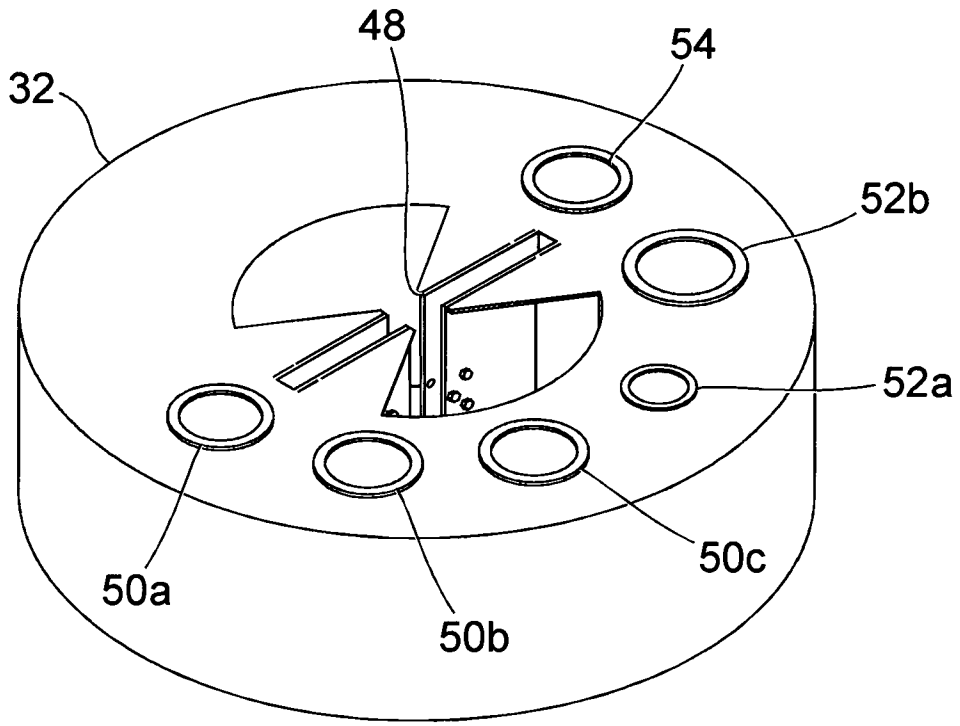


Fig.5

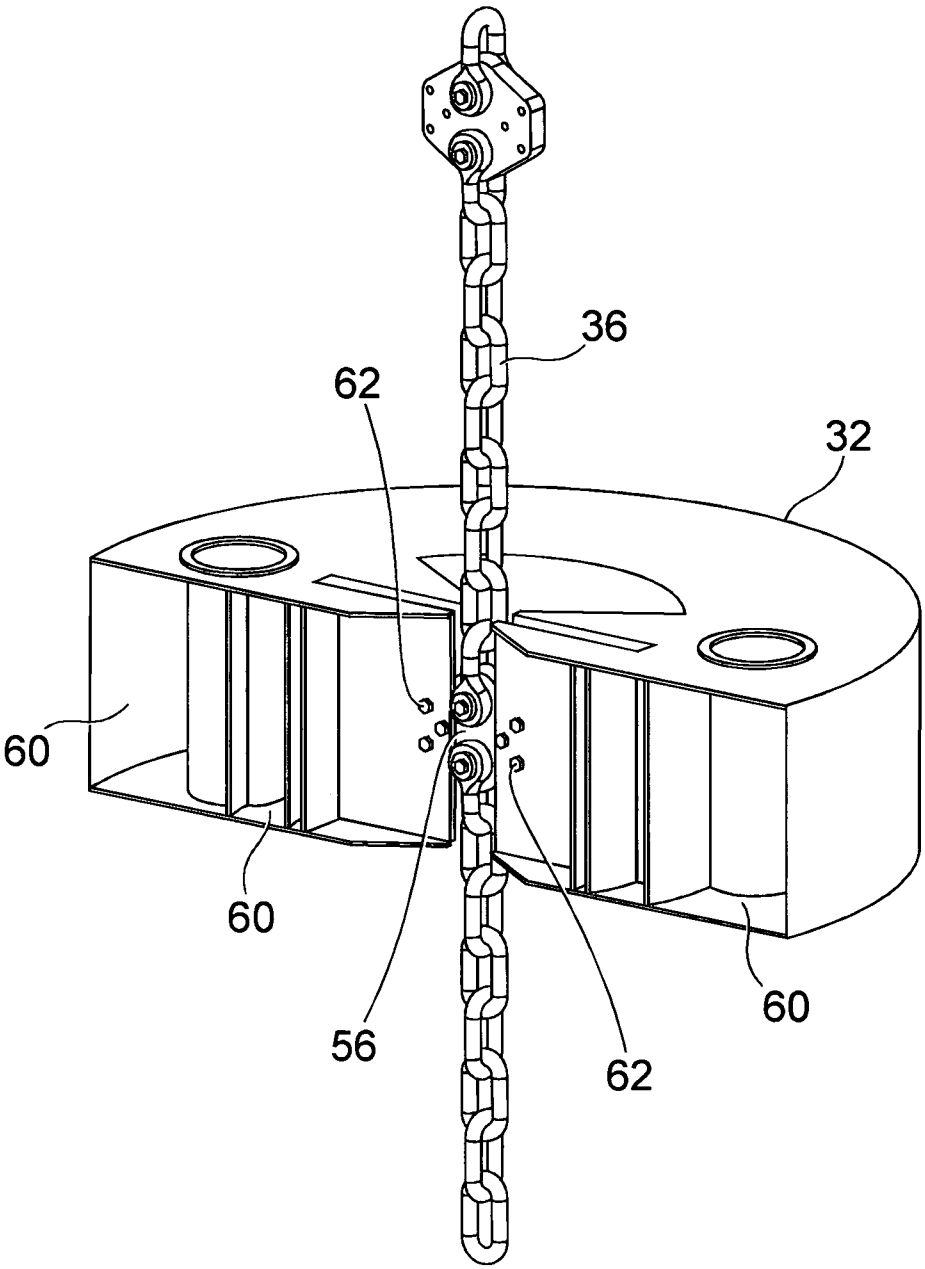


Fig. 6