(12) **APPLICATION**

(11) **20191122** (13) **A1**

(19) NO

NORWAY

(51) Int Cl.

B63C 11/26 (2006.01)
B63C 11/34 (2006.01)
B63C 11/44 (2006.01)
G10K 11/00 (2006.01)
G01V 1/20 (2006.01)

Norwegian Industrial Property Office

(21)	Application nr	20191122	(86)	Int. application day and application nr
(22)	Application day	2019.09.17	(85)	Entry into national phase
(24)	Date from which the industrial right has effect	2019.09.17	(30)	Priority
(41)	Available to the public	2021.03.18		

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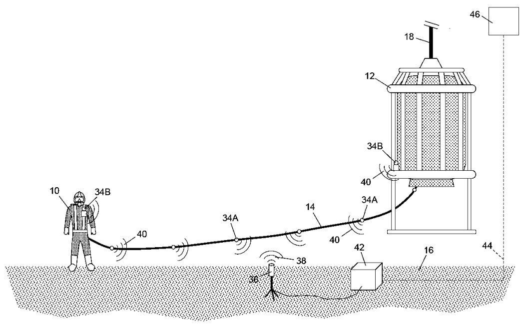
(54) Title **Monitoring diver umbilicals**

(57) Abstract

A method of monitoring a diver’s umbilical comprises determining the position of at least one beacon on the umbilical and calculating the path of the umbilical based on the position of the beacon. An alert is raised if the position of a clashing hazard, such as subsea equipment, is within a safety zone that maintains safe clearance around the calculated umbilical path. The beacon is positioned between the ends of the umbilical, and can generate and emit an electromagnetic or acoustic locating signal into surrounding water. The safety zone can be defined with reference to the position of a hazard, in which case the alert can be raised if the calculated umbilical path departs from the safety zone. Alternatively, the safety zone can be defined around the calculated umbilical path, in which case the alert can be raised if a mobile hazard such as an ROV enters the safety zone.



Monitoring diver umbilicals

This invention relates to umbilicals used in diving operations, especially in saturation diving operations as performed most commonly in the subsea oil and gas industry.

Saturation diving techniques enable divers to perform a succession of lengthy dives at great depths without having to undergo decompression at the end of each dive. Thus, between dives, the divers live in a pressurised environment and are transferred to the equivalent depth in a pressurised diving bell to perform tasks underwater. Saturation diving is typically performed at depths in a range of between 50m and about 300m, which is beyond the practical limits of scuba diving and of surface-supplied breathing gas.

The invention is particularly concerned with diver umbilicals that connect saturation divers to a diving bell during a dive. Diver umbilicals, also known as diver excursion umbilicals, are therefore to be distinguished from bell umbilicals that suspend a diving bell from the surface. Bell umbilicals are much longer and thicker than diver umbilicals, provide different functions and also comprise a lifting cable, as described in US 4111313 for example.

A diver umbilical is a vital flexible link that provides breathing gas and communications to a saturation diver during a dive. Commonly, such an umbilical also conveys electrical power or fluids for heating the breathing gas and/or the diver’s protective suit, in addition to electrical power for providing illumination via a lamp mounted on the diver’s helmet. In a variant of this principle, GB 1523163 discloses an umbilical that conveys microwave energy for heating the breathing gas or the diver’s suit.

A secondary purpose of a diver umbilical is to serve as a safety line. Thus, the path of an umbilical can guide a diver back to the diving bell in conditions of low visibility. Also, if needs be, an umbilical can be pulled in by a stand-by diver to recover an incapacitated or unconscious diver to the bell.

Typical diver umbilicals are offered by JFD Limited of Aberdeen, Scotland under the registered trade mark Divex. Such umbilicals comprise relatively narrow elongate link elements that are twisted together in a multi-helical arrangement, which may be over-braided with a polymer braid cover or shroud. The rope-like bundle structure of a twisted umbilical combines flexibility with strength while resisting kinking and abrasion.

Flexibility is important to allow a diver to move in three dimensions relative to the bell around a subsea work site.

The twisted elements of a diver umbilical invariably include at least one hose for conveying fluids including breathing gas and at least one cable for providing communications and power. For saturation diving, a typical diver umbilical may comprise several such elements such as a gas supply hose, a gas reclaim hose, a pneumofathometer or ‘pneumo’ hose, a hot water hose, a communications cable, a video cable and a lighting cable.

Saturation divers work in an intrinsically hazardous environment in which all safety risks must be controlled and minimised. The risks of working deep underwater are compounded by proximity to static or moving subsea structures and equipment, which increases the possibility of the diver’s umbilical being fouled, snagged or entangled. Accidents have been caused by an umbilical being damaged or becoming entangled due to inadvertent contact or clashing with structures and equipment. It is therefore essential to preserve the structural integrity and gas-tightness of a diver umbilical and to avoid clashing and entanglement by controlling its position relative to nearby hazards.

Whilst longer diver umbilicals can be used for diving in shallow water where breathing gas is supplied from the surface, the recommended practice in saturation diving is to keep the deployed length of the umbilical as short as possible, typically less than 45m and preferably no more than 30m. This has the disadvantage of limiting the radius of excursion of the diver relative to the bell. The diver is also required to monitor and control the path of the umbilical, to the extent that he is able, in particular to keep the portion of the umbilical extending between himself and the bell as short and straight as possible and as far away from hazards as possible. This further limits the diver’s radius of excursion, hinders his freedom of movement and has the additional disadvantage of adding to his physical and mental workload.

In any event, poor visibility underwater often means that it is not possible for a diver to see the full deployed length of an umbilical, or therefore to be aware of any clashing or snagging hazards beyond his limited field of view. Indeed, much of the length of the umbilical may remain entirely invisible to the diver throughout a dive. US 8475083 addresses this problem by inserting a side-emitting optical fibre into the umbilical to provide a source of light that is distributed along the length of the umbilical. However, even this solution cannot entirely overcome the problem of poor visibility.

Even if a diver could see the full length of the umbilical, maintaining constant control of the path of the umbilical is impractical in the dynamic environment of a congested work site in which there is relative movement between the diver and subsea hazards, especially if subsea currents deflect the umbilical. Umbilical management can take up significant amounts of valuable time during a dive, particularly in cases where an ROV is unable to monitor the work site, or the diver is working alone, or the visibility is poor.

To illustrate these challenges, Figures 1 to 3 of the drawings show a saturation diver 10 in the water at a subsea work site, connected to a bell 12 by a diver umbilical 14. The umbilical 14 has near-neutral but slightly negative buoyancy. The bell 12 is suspended above the seabed 16 by a thicker bell umbilical 18.

The diver 10 is shown in Figure 1 making his way across the seabed 16 from the bell 12 to a subsea structure that is exemplified here by a template 20. The umbilical 14 is deployed progressively from the bell 12 as the diver 10 moves toward the template 20. The template 20 comprises a frame 22 that supports, and provides over-trawl protection to, items of equipment 24 housed within the frame 22. In this example, the equipment 24 is in fluid communication with spools 26 that extend from the template 20 across the seabed 16, with fluid flow through the spools 26 being controllable by valves 28.

Figures 2 and 3 show the diver 10 now inside the template 20 and interacting with the equipment 24 within. A correspondingly greater length of the umbilical 14 is shown deployed into the water between the diver 10 and the bell 12. It will be apparent that to access the equipment 24, the diver 10 must navigate a route past the spools 26 and valves 28 and between members of the frame 22 and the equipment 24. The umbilical 14 must follow a corresponding route around those hazards, whose proximity introduces risks of clashing and entanglement.

The risks of clashing and entanglement must be controlled by keeping the umbilical 14 within a safety zone 30 in which at least a minimum clearance is maintained between the umbilical 14 and the nearby hazards. This is challenging, especially as an ROV cannot access an overhead environment such as the interior of the template 20 to monitor the portion of the umbilical 14 within.

As best appreciated in the plan view of Figure 3, the diver 10 will not be able to see all potential hazards even in conditions of good visibility, one example being the valves 28 on the spools 26. This presents a risk that the umbilical 14 could be deflected by a current 32 and drift into contact with the valves 28, as shown by the dotted line in Figure 3, which presents an entanglement hazard outside the diver's field of view. Deflection of the umbilical 14 could also bring the umbilical 14 into contact with sharp edges of the equipment 24, which risks snagging and potentially damaging the umbilical 14.

Even if the umbilical 14 remains stationary, it is possible that other, mobile hazards could approach or impinge upon the safety zone 30 and so potentially clash with the umbilical 14. For example, ROVs or subsea payloads such as tool baskets could be moved inadvertently too close to the umbilical 14 or could be encountered in unexpected locations as the umbilical 14 is being deployed. In this respect, a further challenge is that the shape, position and extent of the safety zone 30 is determined not only by the position of fixed hazards but is susceptible to change with movement of the umbilical 14 during a dive.

CN 107479601 discloses a system for monitoring an automatically-retractable umbilical that supports the operation of a remotely operated vehicle (ROV) as opposed to a diver. Audio signals are used to determine the position of the ROV and of the umbilical relative to a mother ship in real time. For this purpose, hydrophones are spaced apart from each other along the umbilical and an underwater acoustic beacon is disposed on the ROV.

In use, a sound source on the mother ship broadcasts an acoustic detection signal underwater. The hydrophones on the umbilical receive that signal and transmit corresponding response signals back to the mother ship along a fibre-optic cable embedded in the umbilical. The propagation time between transmission of the acoustic detection signal and its reception by the hydrophones is used to determine the distances of the respective hydrophones from the sound source. Moreover, if the sound source is defined as the origin of a coordinate system, the three-dimensional coordinates of each hydrophone can be obtained. Similarly, the acoustic beacon is used to determine the position of the ROV, which is also the position of the corresponding end of the umbilical.

The objective of CN 107479601 is to determine the deployed length and shape of the umbilical and to control the deployed length accordingly using an automatically-controllable winch on the mother ship. This ensures that the umbilical is as long as it needs to be, for a given shape, to allow the ROV to move freely to perform a subsea task but is not unnecessarily long, which would increase the risk of entanglement. Length and shape data is also used to estimate the forces, such as drag or tension, that the umbilical exerts on the ROV so as to estimate the speed and direction of the ROV, having regard also to the thrust forces that the ROV exerts on the surrounding water.

The position of the ROV and the shape and deployed length of the umbilical can be represented as a three-dimensional simulation. The system can thereby control the winch automatically to wind in or to pay out the umbilical, having regard to the estimated speed and direction of the ROV.

Those skilled in the art know that an ROV umbilical is typically well over a kilometre long and so is two orders of magnitude longer than a diver umbilical. The system disclosed in CN 107479601 is too complex for the purposes of the invention and would not be suitable for a much shorter diver umbilical. Nor would the system disclosed in CN 107479601 be useful to prevent a diver’s umbilical being fouled, snagged or entangled in a congested and dynamic subsea environment. Indeed, the teaching of CN 107479601 to minimise the deployed length of the umbilical automatically could inadvertently pull the umbilical, and indeed the attached diver, into contact with a subsea hazard. It is essential that the diver retains control of his umbilical and that the umbilical moves to follow the diver’s movements rather than vice versa.

Against this background, the invention may be expressed as a method of monitoring a diver’s umbilical during a dive. The method comprises: determining the position of at least one beacon on the umbilical; calculating a path of the umbilical based on the position of the or each beacon; determining the position of at least one clashing hazard; and raising an alert if the position of the clashing hazard is within a chosen clearance distance from the calculated path of the umbilical.

A safety zone may be defined around the umbilical, within which the umbilical extends. The alert can then be raised if the clashing hazard impinges on the safety zone. For example, if the safety zone is defined with reference to the position of the clashing hazard, the alert can be raised if the calculated path of the umbilical departs from the safety zone. Conversely, if the safety zone is defined around the calculated path of the umbilical, the alert can be raised if the clashing hazard enters the safety zone.

The calculated path of the umbilical can be compared, in real time, with a model of a subsea environment in which the dive is performed. For example, the calculated path of the umbilical can be displayed on an image or representation of the subsea environment. Similarly, the location of the clashing hazard may be displayed on the image or representation of the subsea environment.

The position of the or each beacon may be determined by: emitting a locating signal, such as an acoustic signal or an electromagnetic signal, from the beacon through water; receiving the locating signal at a subsea sensor; and determining a heading and distance of the beacon from the sensor. The sensor may be positioned on the seabed or on a structure fixed relative to the seabed, or on a diving bell from which the umbilical extends, or on the umbilical. In the latter case, positional data from the sensor may be conveyed along the umbilical.

The sensor may be a first sensor that receives a first locating signal from a first beacon and that also serves as a second beacon, transmitting a second locating signal to a second sensor. In that case, the second sensor may conveniently also be positioned on the umbilical at a location spaced longitudinally from the first sensor. The path of the umbilical may, for example, be calculated by interpolating between the positions of the first and second beacons.

The method of the invention may further comprise determining the position of at least one supplementary beacon that is mounted on the diver or on a diving bell from which the umbilical extends. In that case, the path of the umbilical may be calculated by extrapolating from a beacon on the umbilical to the at least one supplementary beacon.

The method of the invention may also comprise: determining the position of a reference beacon; and determining the position of at least one other beacon relative to the position of the reference beacon. The reference beacon may be located off the umbilical.

The inventive concept also embraces a diver umbilical for connecting a saturation diver to a diving bell, wherein the umbilical comprises at least one beacon at an intermediate position between ends of the umbilical, the beacon being capable of generating and emitting a locating signal into water around the umbilical. In one sense, the umbilical may be characterised by at least one sensor that is configured to receive the locating signal. In another sense, the umbilical may be characterised by the locating signal being an electromagnetic signal at a wavelength outside the visible spectrum, or an acoustic signal.

The umbilical suitably further comprises a data cable for conveying positional data from the or each sensor. In that case, the or each beacon and the or each sensor may conveniently be supported by the data cable. The data cable may simply be bundled with other elongate elements of the umbilical in a helically-wound configuration.

The sensor may be a first sensor that is configured to receive a first locating signal from a first beacon of the umbilical and to act as a second beacon, transmitting a second locating signal to a second sensor of the umbilical.

The inventive concept also extends to a dive control system that comprises at least one umbilical of the invention. The system may further comprise at least one supplementary beacon that is located off the umbilical. The or each supplementary beacon may, for example, be mounted on a diver or on a diving bell from which the umbilical extends. The system may also comprise at least one supplementary sensor that is configured to receive the locating signal and that is located off the umbilical. The supplementary sensor may, for example, be positioned on the seabed or on a structure fixed relative to the seabed, or on a diving bell from which the umbilical extends.

The system of the invention may further comprise a processor that is configured to calculate the path of the umbilical from positional data representing the position of the or each beacon on the umbilical. The system may be configured to compare the calculated path of the umbilical, in real time, with a model of a subsea environment in which a dive is being performed, and to display the calculated path of the umbilical on an image or representation of the subsea environment. For example, the system may include a watertight diver-portable tablet that is configured to display the calculated path of the umbilical and the image or representation of the subsea environment.

The system of the invention may be configured to display the position of at least one clashing hazard on the image or representation of the subsea environment. The system may also be configured to raise an alert if the position of the clashing hazard is within a chosen clearance distance from the calculated path of the umbilical.

Thus, the invention improves the safety of a diver umbilical by monitoring its position, shape and configuration in water. The inventive concept may be exemplified by adding either a traceable cable or a series of small transponders along the umbilical. This allows for real-time monitoring of the position of the umbilical by a dive supervisor, typically on a surface support vessel, and potentially also by a diver himself. In conjunction with a live 2D or 3D model of items on the seabed close to the diver, the position of the umbilical relative to those items can be monitored and if necessary corrected. This reduces the risks of the umbilical clashing or becoming entangled with those items, for example by enabling the provision of guidance to the diver that the umbilical should be moved and, if so, in what way.

Real-time tracking of an umbilical, shown in 2D or 3D, reduces the need for continuous monitoring of the umbilical. Real-time tracking of an umbilical also introduces an added level of safety during dive operations, even if the deployed length of the umbilical exceeds 45m. By allowing safe use of a longer umbilical, the invention increases the diver’s radius of movement relative to the bell around a work site.

Embodiments of the invention implement a method to monitor the position of a diving umbilical during a diver’s subsea intervention. The method comprises the following steps: mounting at least one intermediate position sensor on the umbilical; assessing the location and configuration of the umbilical during the dive by extrapolating from a sensor signal; and raising an alert in case of a discrepancy with the expected location and configuration of the umbilical.

The configuration or geometry of the umbilical, which may be estimated from one or more sensor signals, is suitably monitored in real time. The configuration or geometry may be compared to a 3D model of the environment, including features such as subsea equipment, underwater vehicles and other divers. The configuration or geometry of the umbilical could, for example, be displayed in augmented reality on a monitor screen of a dive supervision system.

Embodiments of the invention also provide a diving umbilical that comprises: an umbilical capable of connecting a diver’s suit to a diving bell; and at least one position sensor between the ends of the umbilical. The or each position sensor may be at or on the outer surface of the umbilical or may be embedded within the braids or layers or between the tubes of the umbilical.

The or each position sensor suitably comprises a communication module to send a signal. The signal may be transmitted acoustically or electromagnetically through water, or optically or electrically via a wire or cable.

The or each position sensor may be an acoustic transponder that assesses the position and heading of the sensor relative to at least one reference transponder, such as a USBL (ultra-short baseline) stand, which could for example be positioned on the bell or on the seabed. In a USBL system, an acoustic pulse is transmitted by a transceiver and detected by the transponder. The transponder replies with its own acoustic return pulse, which is detected by the transceiver. The transceiver contains an array of transducers, for example three or more transducers separated by a baseline of up to 10cm. Range is inferred from the time lapse between transmission of the initial acoustic pulse and detection of the return pulse. A phase-differencing technique within the transducer array may be used to calculate the direction or heading to the transponder.

The position sensors may form nodes of a network that each communicate with the closest nodes, for example by electromagnetic waves such as WiFi, and relay signals to the diving bell or to the diver. For example, the sensors may form a network in which the position of a sensor *n* is assessed relative to a sensor *n-1*.

Signals from the or each sensor may be used to build a real-time 3D model of the umbilical. In an augmented reality system, the 3D model may then be superimposed onto actual camera pictures displayed to a dive supervisor or to the diver. Alternatively, the 3D model could be superimposed onto a 3D model of the dive environment displayed to the dive supervisor or to the diver.

In summary, the invention provides a method of monitoring a diver’s umbilical that comprises determining the position of at least one beacon on the umbilical and calculating the path of the umbilical based on the position of the beacon. An alert is raised if the position of a clashing hazard is within a safety zone that maintains safe clearance around the calculated umbilical path.

The beacon is positioned at an intermediate location between the ends of the umbilical, and can generate and emit an electromagnetic or acoustic locating signal into surrounding water. This signal is used to determine the heading and range, and hence the position, of the beacon relative to a sensor spaced apart from the beacon. The sensor can also be on the umbilical and can also serve as another beacon.

To describe the background to the invention, reference has already been made to Figures 1 to 3 of the accompanying drawings in which:

Figure 1 is a schematic side view of a saturation diver moving from a diving bell toward a subsea structure, with an umbilical extending between the diver and the bell and being deployed from the bell;

Figure 2 corresponds to Figure 1 but shows the diver interacting with equipment within the subsea structure, with a greater length of the umbilical deployed accordingly; and

Figure 3 is a schematic plan view that corresponds to Figure 2 and shows a safety zone within which the umbilical must be routed to avoid clashing hazards presented by the subsea structure and the equipment.

In order that the invention may be more readily understood, reference will now be made, by way of example, to the remainder of the accompanying drawings in which:

Figure 4 is a schematic side view of a first embodiment of the invention comprising an array of acoustic transponders spaced along the umbilical between the diver and the bell, the transponders responding to signals from a transceiver mounted on the seabed;

Figure 5 corresponds to Figure 4 but shows a variant in which the transponders respond to a transceiver mounted on the bell;

Figure 6 is a schematic side view of a second embodiment of the invention in which the position of each transponder is determined relative to another transponder on the umbilical;

Figure 7 is a schematic diagram showing the operation of the second embodiment shown in Figure 6;

Figure 8 is an enlarged schematic diagram of one of the transponders shown in Figures 6 and 7;

Figure 9 is a schematic detail perspective view of an umbilical of the invention; and

Figure 10 is a schematic view of a display unit of the invention showing a real-time virtual-reality image of the umbilical in relation to the safety zone and hazards shown in Figure 3.

Like numerals are used for like features in the description that follows.

Figures 4 to 6 show umbilicals 14 of the invention extending across the seabed 16 between a diver 10 and a bell 12. In accordance with the invention, each umbilical 14 comprises or supports one or more beacons 34 that facilitate determination of their position in three dimensions. In these examples, an array of beacons 34 is distributed along the length of the umbilical 14. Thus, there is mutual longitudinal spacing between the beacons 34, preferably substantially equal spacing as shown.

In the first embodiment shown in Figure 4, the beacons 34 are exemplified by transponders 34A, specifically acoustic transponders 34A that respond to a sensor in the form of a USBL transceiver 36 placed in a line-of-sight position with respect to all of the transponders 34A. Conveniently, the USBL transceiver 36 may be placed on the seabed 16 beside a subsea work site, preferably facing side-on to the anticipated path of the umbilical 14.

During a dive, the transceiver 36 broadcasts acoustic trigger signals 38 to the transponders 34A of the umbilical 14 and receives acoustic reply signals 40 from the transponders 34A in return. A processor 42 processes the reply signals received by the transceiver 36 to determine the heading and range of each transponder 34A with respect to the transceiver 36.

Determining its heading and range determines the position of each transponder 34A relative to the transceiver 36. This allows the processor 42 to infer the approximate 3D shape of the umbilical 14 by interpolation between the determined positions of the transponders 34A, especially as the longitudinal spacing between the transponders 34A along the arc of the umbilical 14 is a known and fixed characteristic. If the position of the transceiver 36 is known, the position of the umbilical 14 as a whole is therefore also known.

The processor 42 is shown here on the seabed 16 beside the transceiver 36 but could instead be integrated with the transceiver 36 or located elsewhere, for example on a surface vessel. A data link 44 provides for transmission of data between the processor 38 and a monitoring and control system 46, which may be at any convenient location, for example in a dive control room aboard a surface vessel that supports the bell 12. Indeed, elements of the monitoring and control system 46 could be distributed between the dive control room and the diver 10, for example by providing the diver 10 with a display and control tablet as will be explained later with reference to Figure 10.

Figure 4 shows the optional feature of supplementary beacons in the form of further transponders 34B that are carried by the diver 10 and/or mounted on the bell 12 to respond with acoustic reply signals 40 to acoustic trigger signals 38 sent from the transceiver 36. The positions of the diver 10 and the bell 12 can therefore also be determined by the transceiver 36 and the processor 42, and so can be made known to the monitoring and control system 46. The approximate positions of the ends of the deployed length of the umbilical 14 can also be inferred from the positions of the diver 10 and the bell 12, by extrapolation from the closest transponders 34A on the umbilical 14.

Figure 5 shows a variant of the first embodiment in which the transceiver 36 is mounted on the bell 12 instead of being placed on the seabed 16. Thus, acoustic trigger signals 38 are broadcast from the bell 12 to the transponders 34A of the umbilical 14 and the transponder 34B on the diver 10, and acoustic reply signals 40 from the transponders 34A, 34B are received back at the bell 12. The processor 42, the data link 44 and the monitoring and control system 46 have been omitted from this simplified view but will all be present in practical implementations of the invention. In this case, it will be apparent that the data link 44 could, conveniently, be implemented via the bell umbilical 18.

In principle, it would be possible to transmit non-acoustic signals, such as electromagnetic signals, from the transceiver 36 to the transponders 34A, 34B or vice versa. However, acoustic signals have the benefit of a longer range of transmission in water than electromagnetic signals.

Whilst acoustic signals allow the transceiver 36 and the transponders 34A, 34B to be a considerable distance apart, transmitting signals over a long range increases the possibility that those signals will be blocked or otherwise disrupted by intervening objects. Thus, ideal line-of-sight transmission may not always be possible. This is a particular challenge in congested environments, for example where the diver 10 and a portion of the umbilical 14 are within a subsea structure such as the template 20 shown in Figures 2 and 3, or otherwise close to subsea equipment 24.

The problem of signal blockage or disruption is addressed by the second embodiment of the invention shown in Figure 6 and in more detail in Figures 7 and 8. Here, the beacons 34 arrayed on the umbilical 14 are transceivers 34C that are each configured to transmit a reply signal 40 into the surrounding water and to receive such a reply signal 40 from a neighbouring transceiver 34C on the umbilical 14. Short-range transmission of signals in this way lends itself to the use of electromagnetic signals, which may be at wavelengths outside the visible spectrum.

Thus, each transceiver 34C positioned between neighbouring transceivers 34C in opposite longitudinal directions serves as a beacon and also as a sensor. The transceiver 34C serves as a beacon to emit locating signals to one of the neighbouring transceivers 34C and also as a sensor to receive and respond to locating signals emitted from the other neighbouring transceiver 34C.

The direction from which the reply signal 40 is received at a first transceiver 34C allows the heading 48 of a second transceiver 34C relative to a first transceiver 34C to be calculated. The distance of the second transceiver 34C from the first transceiver 34C can also be calculated, hence determining the position of the second transceiver 34C relative to a first transceiver 34C. This information is then conveyed as a data signal 50 back along the umbilical 14 to the processor 42 shown in Figure 7.

More generally, therefore, the position of a beacon *n* can be determined with reference to the position of a neighbouring beacon *n – 1* in an array of beacons spaced along the umbilical 14.

If the position of the first transceiver 34C is known, the position of the second transceiver 34C can therefore also be known. In this example, the position of the first transceiver 34C is determined from its heading 48 relative to a reference transceiver 34D, which may for example be mounted on the bell 12 as shown in Figure 6. The position of the reference transceiver 34D, in turn, may conveniently be determined acoustically from its heading 48 relative to a transceiver 36 on the seabed 16. Although not shown in Figure 6, the transceiver 36 suitably communicates with a processor 42, a data link 44 and a monitoring and control system 46 as shown in Figures 4 and 7.

The transceivers 34C may also be configured to transmit a trigger signal 38 to a neighbouring transceiver 34C as shown in Figure 7; alternatively, the trigger signal 38 could be broadcast to all of the transceivers 34C from a single source such as the processor 42 shown in Figure 7. The trigger signal 38 could be transmitted through water but may conveniently be transmitted to the transceivers 34C along a data cable such as a fibre-optic cable 52 in the umbilical 14, as shown in Figure 8 and also in Figure 9.

Figure 8 shows that each transceiver 34C comprises: a transmitter 54 for transmitting a reply signal 40 through water surrounding the umbilical 14; a receiver 56 for receiving a similar reply signal 40 from a neighbouring transceiver 34C; a local processor 58 for generating a data signal 50 indicative of the relative position of the neighbouring transceiver 34C; and an interface 60 with the fibre-optic cable 52 for sending the data signal 50 back along the umbilical 14 to the processor 42 shown in Figure 7. Figure 8 also shows the trigger signal 38 being conveyed along the fibre-optic cable 52.

Beacons such as transceivers 34C may be attached to or incorporated into an umbilical 14 in various ways. Figure 9 shows one convenient way, which is for a fibre-optic cable 52 carrying the transceivers 34C to be incorporated as one of the helical twisted bundle elements of the umbilical 14.

Finally, Figure 10 shows a display 62 forming part of the monitoring and control system 46 as shown in Figures 4 and 7. As noted above, the monitoring and control system 46 could be at any convenient location, for example in a dive control room of a dive support vessel. Thus, the display 62 could be implemented among the various displays that are visible to operators aboard the vessel. As also noted above, elements of the monitoring and control system 46 could be distributed to include the diver 10. In this respect, Figure 10 shows the display 62 implemented by a tablet 64 that the diver 10 can hold, view and control.

In this example, the display 62 shows the diver 10 a simplified representation of the subsea work site that is shown in Figure 3. The display 62 shows pictorial information such as:

the locations of the diver 10 and the bell 12;

the actual path of the umbilical 14 deployed between the diver 10 and the bell 12, as determined in accordance with the invention;

the location of the nearby clashing hazards presented by the frame 22 of the template 20, the equipment 24 housed within the frame 22 and the spools 26 that extend from the template 20; and

the safety zone 30 in which the umbilical is deemed to have safe clearance with respect to the clashing hazards.

Optionally, the display 62 could also show an ideal path for the umbilical between and around the clashing hazards.

The location and extent of the clashing hazards can be entered into the system as a predetermined 3D model of the subsea environment, for example derived from construction plans or prior surveys. The location and extent of the clashing hazards can also be monitored in real time, for example with beacons or by sonar. The latter solution has the advantage of detecting unexpected and potentially mobile clashing hazards, such as subsea payloads or ROVs. The information obtained by the system can be supplemented with real-time positional information from other systems. For example, the known location of an ROV may be provided by an ROV control system.

When all is well, the display 62 can show an ‘UMBILICAL OK’ icon 66. However, in this instance, the system has detected anomalies and so is flashing an ‘UMBILICAL ALERT’ icon 68. Two anomalies are shown on the representation of the work site of the display 62 and involve:

a clashing hazard 70 where the umbilical 14 has drifted out of the safety zone 30 and into proximity with the spools 26; and

a potential clashing hazard where an ROV 72 has strayed into the safety zone 30 and so could be approaching the umbilical 14.

On being alerted to these anomalies, the diver 10 or a support diver can pull the umbilical 14 away from the spools 26. Similarly, an ROV pilot can be told to take corrective action to move the ROV 72 away from the safety zone 30.

Whilst the subsea work site and the path of the umbilical 14 are represented in 2D in the simplified view of Figure 10, it is possible for those features to be represented in 3D instead. Indeed, it is possible for the path of the umbilical 14 and the location of any clashing hazards to be displayed to a diver or other observer in virtual or augmented reality, for example by being superimposed onto an image of the diver’s immediate surroundings.

Many other variations are possible within the inventive concept. For example, as the distance between beacons along the curve of the umbilical is known, it may not be necessary to measure the ranges of, or distances between, the beacons through the water surrounding the umbilical. A processor may instead infer the overall shape of the umbilical by determining the relative headings of multiple beacons along the umbilical. Then, the processor can fit the curve of the umbilical, including the known relative longitudinal positions of the beacons along the umbilical, to those determined headings.

In principle, a trigger signal could be omitted. In that case, each beacon may broadcast a respective signal, intermittently or continuously, that is detected by a receiver and processed to determine the current position of that beacon relative to the receiver. In any event, where there are multiple beacons on an umbilical, each beacon may emit a unique locating signal.

Each beacon could comprise a device such as an accelerometer to determine the orientation of the beacon relative to a vertical axis. This provides an additional datum for measuring relative headings between neighbouring beacons of an array.

Claims

1. A method of monitoring a diver's umbilical during a dive, the method comprising:

determining the position of at least one beacon on the umbilical;

calculating a path of the umbilical based on the position of the or each beacon;

determining the position of at least one clashing hazard; and

raising an alert if the position of the clashing hazard is within a chosen clearance distance from the calculated path of the umbilical.

2. The method of Claim 1, comprising defining a safety zone within which the umbilical extends, and raising the alert if the at least one clashing hazard impinges on the safety zone.

3. The method of Claim 2, comprising:

defining the safety zone with reference to the position of the at least one clashing hazard; and

raising the alert if the calculated path of the umbilical departs from the safety zone.

4. The method of Claim 2 or Claim 3, comprising:

defining the safety zone around the calculated path of the umbilical; and

raising the alert if the at least one clashing hazard enters the safety zone.

5. The method of any preceding claim, comprising comparing the calculated path of the umbilical, in real time, with a model of a subsea environment in which the dive is performed.

6. The method of Claim 5, comprising displaying the calculated path of the umbilical on an image or representation of the subsea environment.

7. The method of Claim 6, comprising displaying the location of the at least one clashing hazard on the image or representation of the subsea environment.

8. The method of any preceding claim, comprising determining the position of the at least one beacon by:

emitting a locating signal from the beacon through water;

receiving the locating signal at a subsea sensor; and

determining a heading and distance of the beacon from the sensor.

9. The method of Claim 8, wherein the sensor is positioned on the seabed or on a structure fixed relative to the seabed.

10. The method of Claim 8, wherein the sensor is positioned on a diving bell from which the umbilical extends.

11. The method of Claim 8, wherein the sensor is positioned on the umbilical.

12. The method of Claim 11, wherein the sensor is a first sensor that receives a first locating signal from a first beacon and also serves as a second beacon, transmitting a second locating signal to a second sensor.

13. The method of Claim 12, wherein the second sensor is also positioned on the umbilical at a location spaced longitudinally from the first sensor.

14. The method of Claim 12 or Claim 13, comprising interpolating between the positions of the first and second beacons to calculate the path of the umbilical.

15. The method of any of Claims 11 to 14, wherein positional data from the or each sensor is conveyed along the umbilical.

16. The method of any of Claims 8 to 15, wherein the locating signal is an acoustic signal.

17. The method of any of Claims 8 to 15, wherein the locating signal is an electromagnetic signal.

18. The method of any preceding claim, further comprising determining the position of at least one supplementary beacon mounted on the diver or on a diving bell from which the umbilical extends.

19. The method of Claim 18, comprising extrapolating from a beacon on the umbilical to the at least one supplementary beacon to calculate the path of the umbilical.

20. The method of any preceding claim, comprising:

determining the position of a reference beacon; and

determining the position of at least one other beacon relative to the position of the reference beacon.

21. The method of Claim 20, wherein the reference beacon is located off the umbilical.

22. A diver umbilical for connecting a saturation diver to a diving bell, wherein the umbilical comprises at least one beacon at an intermediate position between ends of the umbilical, the beacon being capable of generating and emitting a locating signal into water around the umbilical, and further comprises at least one sensor that is configured to receive the locating signal.

23. A diver umbilical for connecting a saturation diver to a diving bell, wherein the umbilical comprises at least one beacon at an intermediate position between ends of the umbilical, the beacon being capable of generating and emitting a locating signal into water around the umbilical, the locating signal being an electromagnetic signal at a wavelength outside the visible spectrum, or an acoustic signal.

24. The umbilical of Claim 22 or Claim 23, further comprising a data cable for conveying positional data from the or each sensor.

25. The umbilical of Claim 24, wherein the or each beacon and the or each sensor are supported by the data cable.

26. The umbilical of Claim 25, wherein the data cable is bundled with other elongate elements of the umbilical in a helically-wound configuration.

27. The umbilical of any of Claims 22 to 26, wherein the sensor is a first sensor that is configured to receive a first locating signal from a first beacon of the umbilical and to act as a second beacon, transmitting a second locating signal to a second sensor of the umbilical.

28. The umbilical of any of Claims 22 to 2, wherein the or each beacon is configured to generate an electromagnetic locating signal.

29. A dive control system comprising at least one umbilical of any of Claims 22 to 28.

30. The system of Claim 29, further comprising at least one supplementary beacon located off the umbilical.

31. The system of Claim 30, wherein the or each supplementary beacon is mounted on a diver or on a diving bell from which the umbilical extends.

32. The system of any of Claims 29 to 31, further comprising at least one supplementary sensor that is configured to receive the locating signal and that is located off the umbilical.

33. The system of Claim 32, wherein the supplementary sensor is positioned on the seabed or on a structure fixed relative to the seabed.

34. The system of Claim 32, wherein the supplementary sensor is positioned on a diving bell from which the umbilical extends.

35. The system of any of Claims 29 to 34, further comprising a processor that is configured to calculate the path of the umbilical from positional data representing the position of the or each beacon on the umbilical.

36. The system of Claim 35, being configured to compare the calculated path of the umbilical, in real time, with a model of a subsea environment in which a dive is being performed.

37. The system of Claim 36, being configured to display the calculated path of the umbilical on an image or representation of the subsea environment.

38. The system of Claim 37, further comprising a watertight diver-portable tablet that is configured to display the calculated path of the umbilical and the image or representation of the subsea environment.

39. The system of Claim 37 or Claim 38, being configured to display the position of at least one clashing hazard on the image or representation of the subsea environment.

40. The system of Claim 39, being configured to raise an alert if the position of the clashing hazard is within a chosen clearance distance from the calculated path of the umbilical.

41. The system of Claim 40, being configured to raise the alert if the calculated path of the umbilical departs from a safety zone that is defined with reference to the position of the clashing hazard.

42. The system of Claim 40 or Claim 41, being configured to raise the alert if the clashing hazard enters a safety zone that is defined around the calculated path of the umbilical.

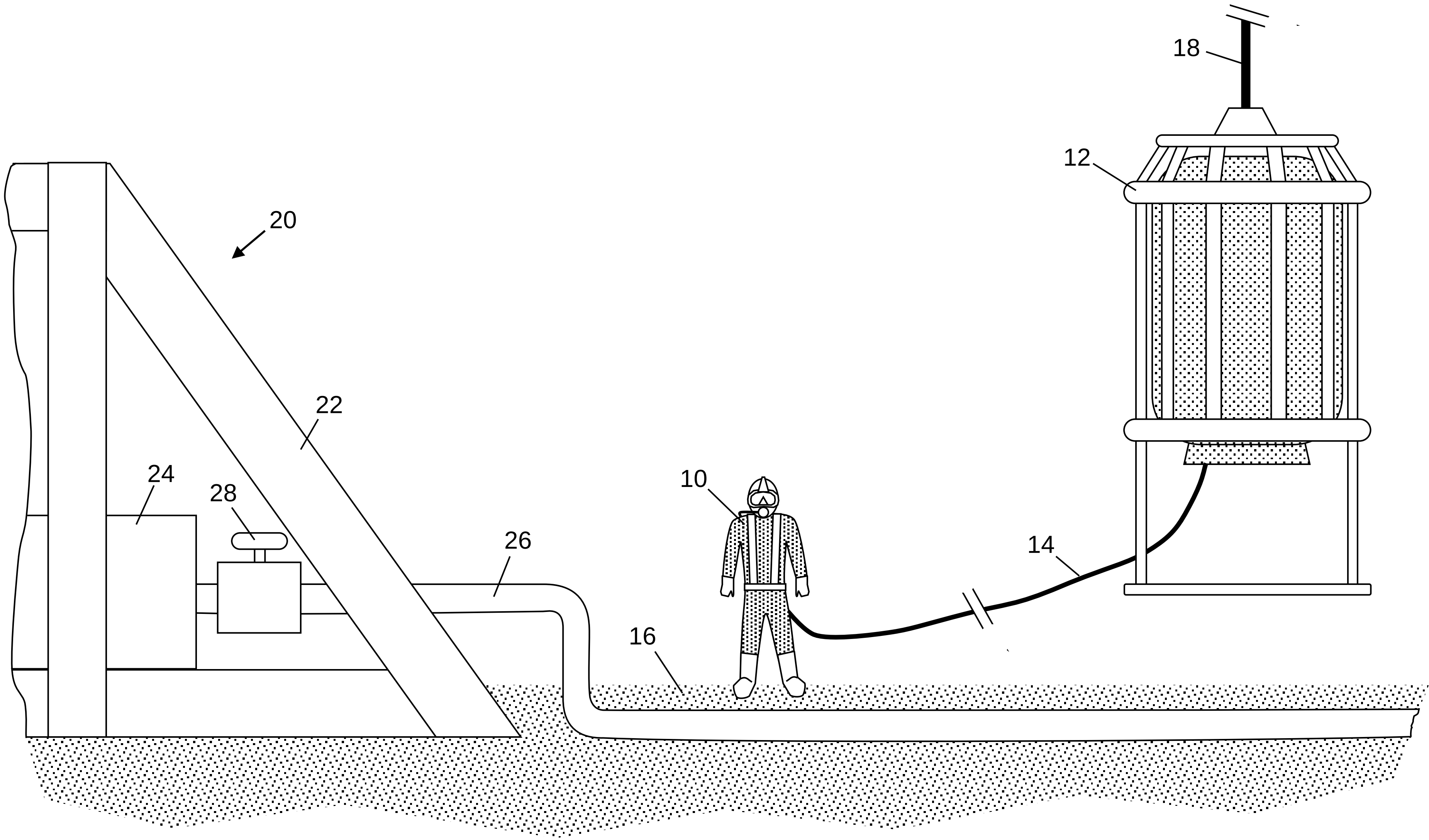


Figure 1

PRIOR ART

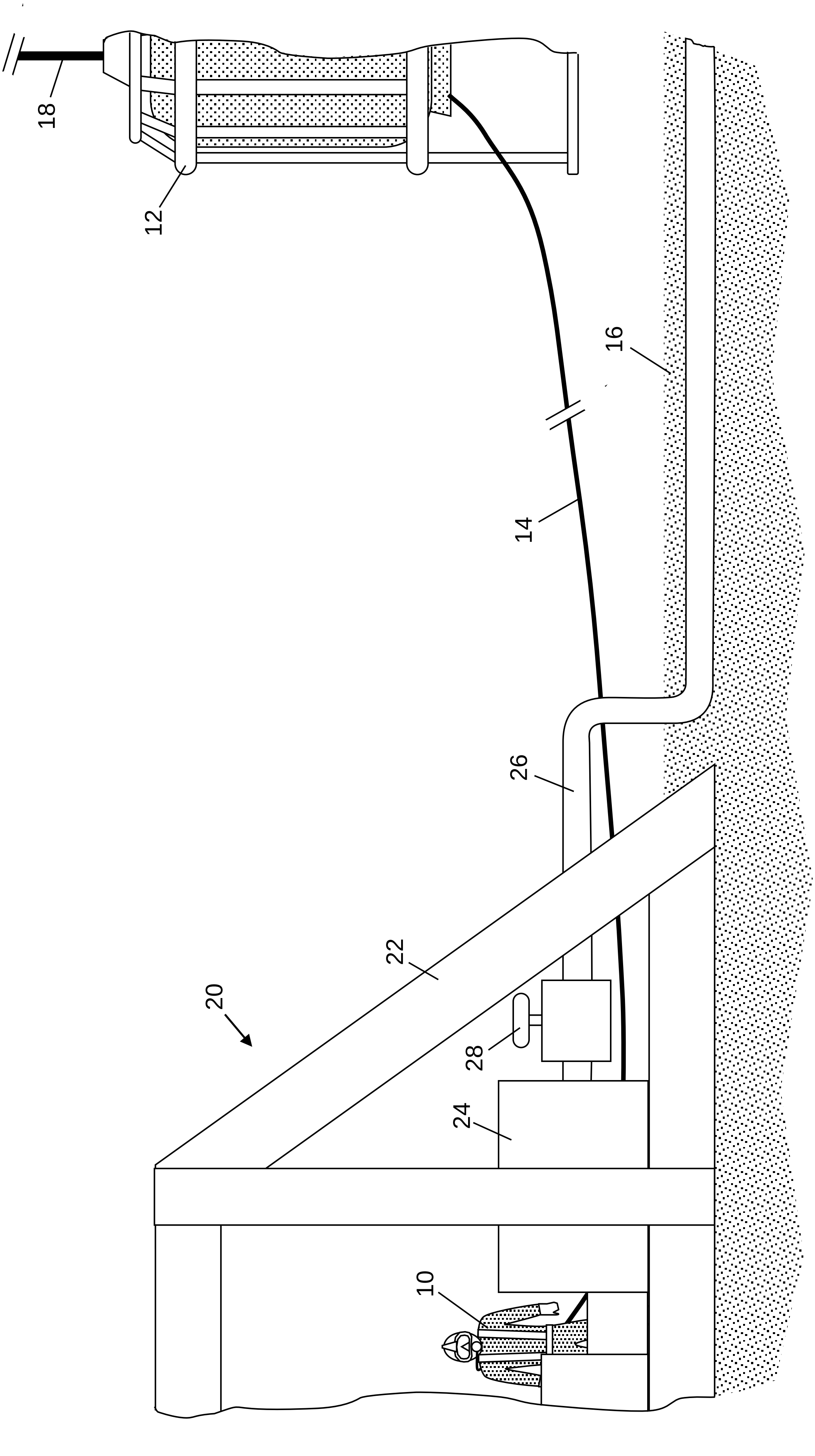


Figure 2
PRIOR ART

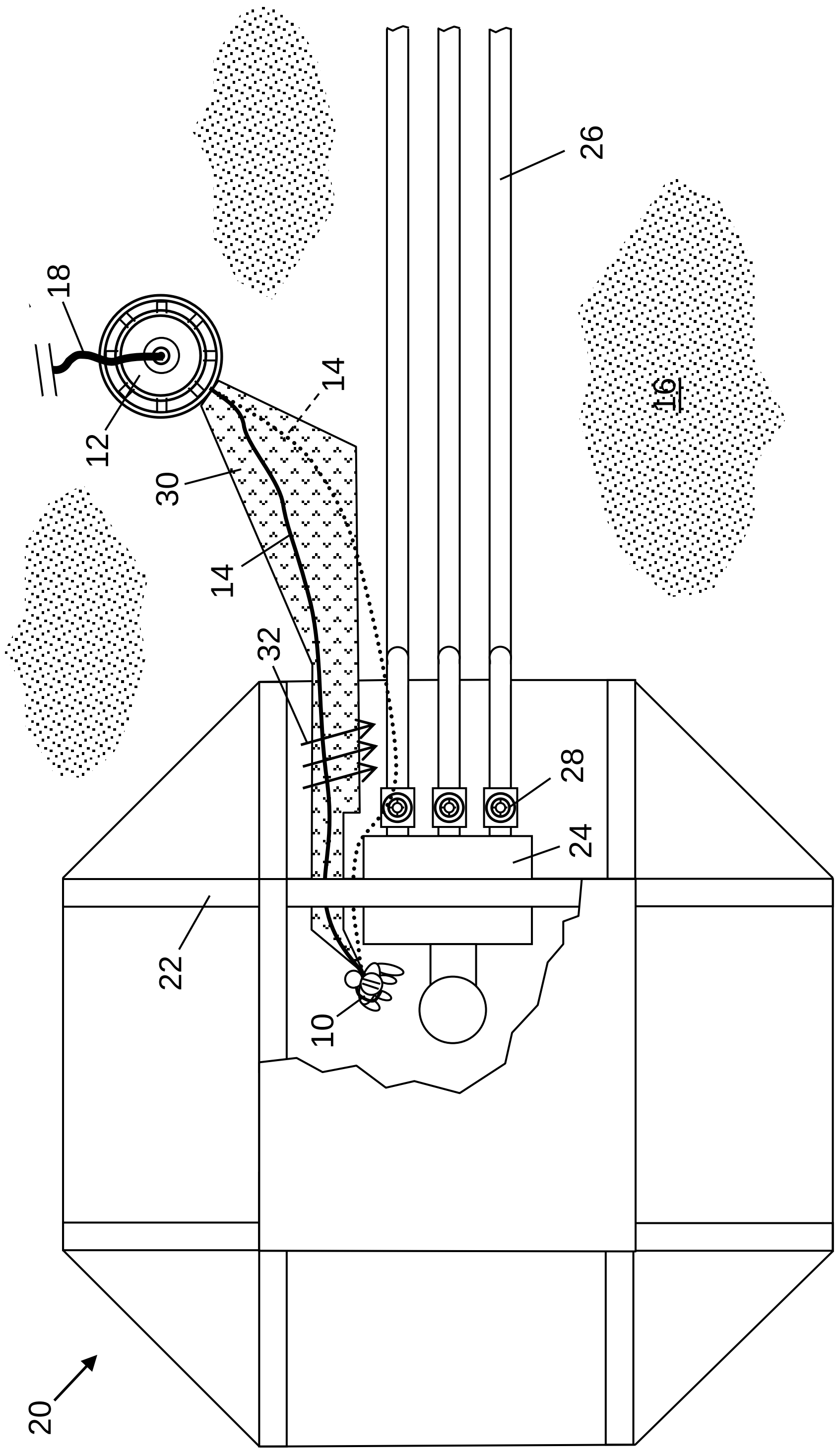


Figure 3
PRIOR ART

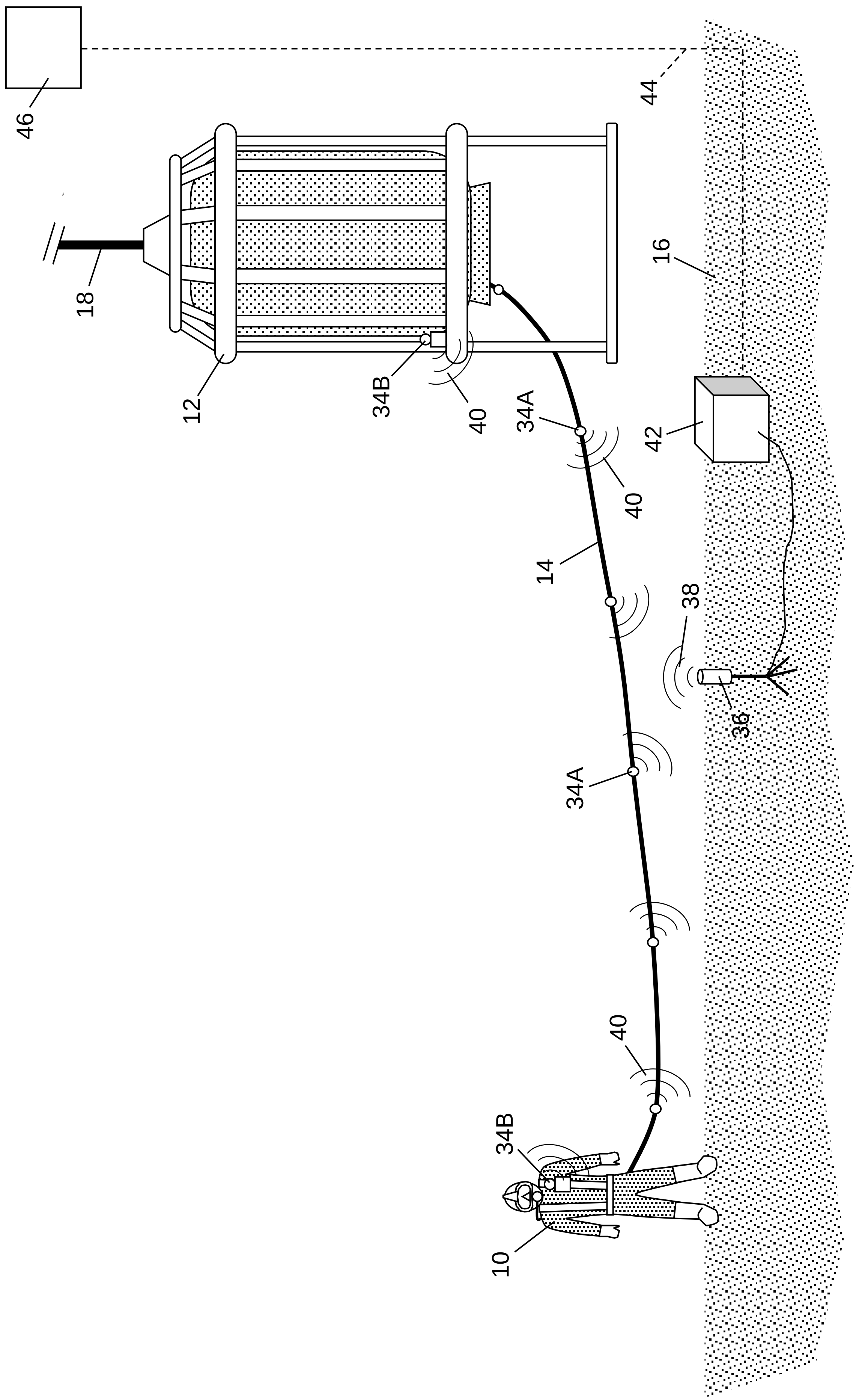


Figure 4

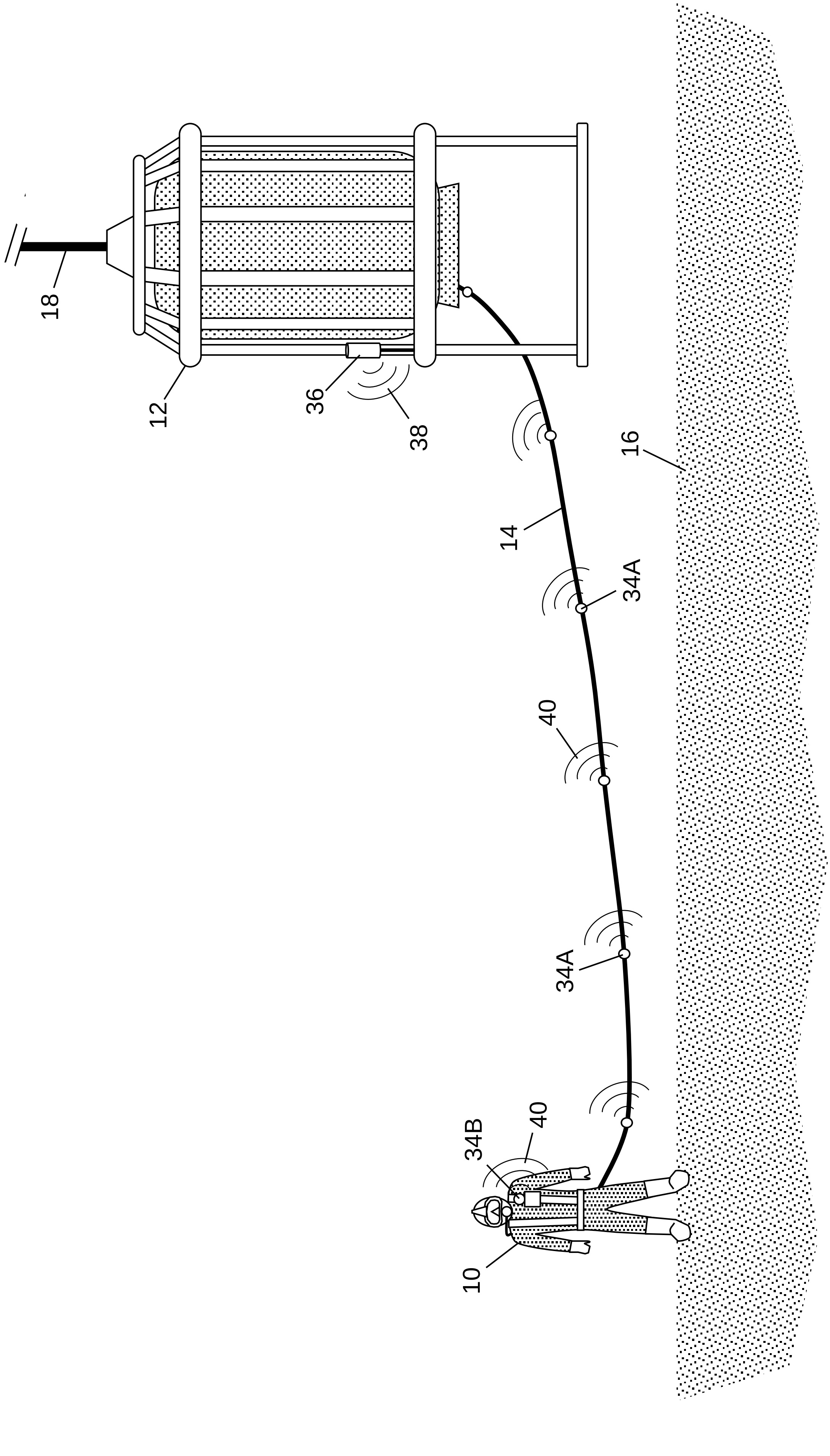


Figure 5

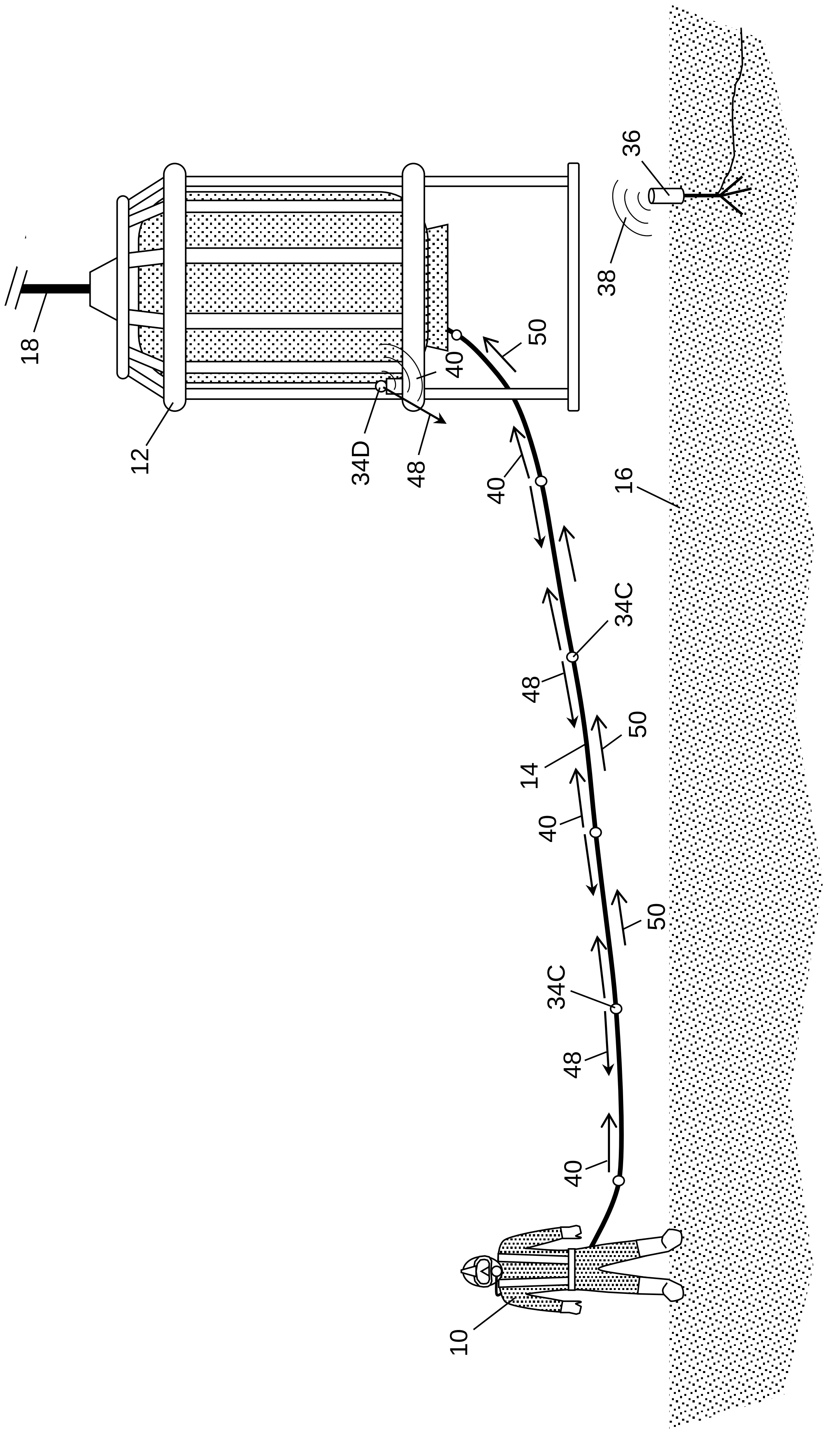


Figure 6

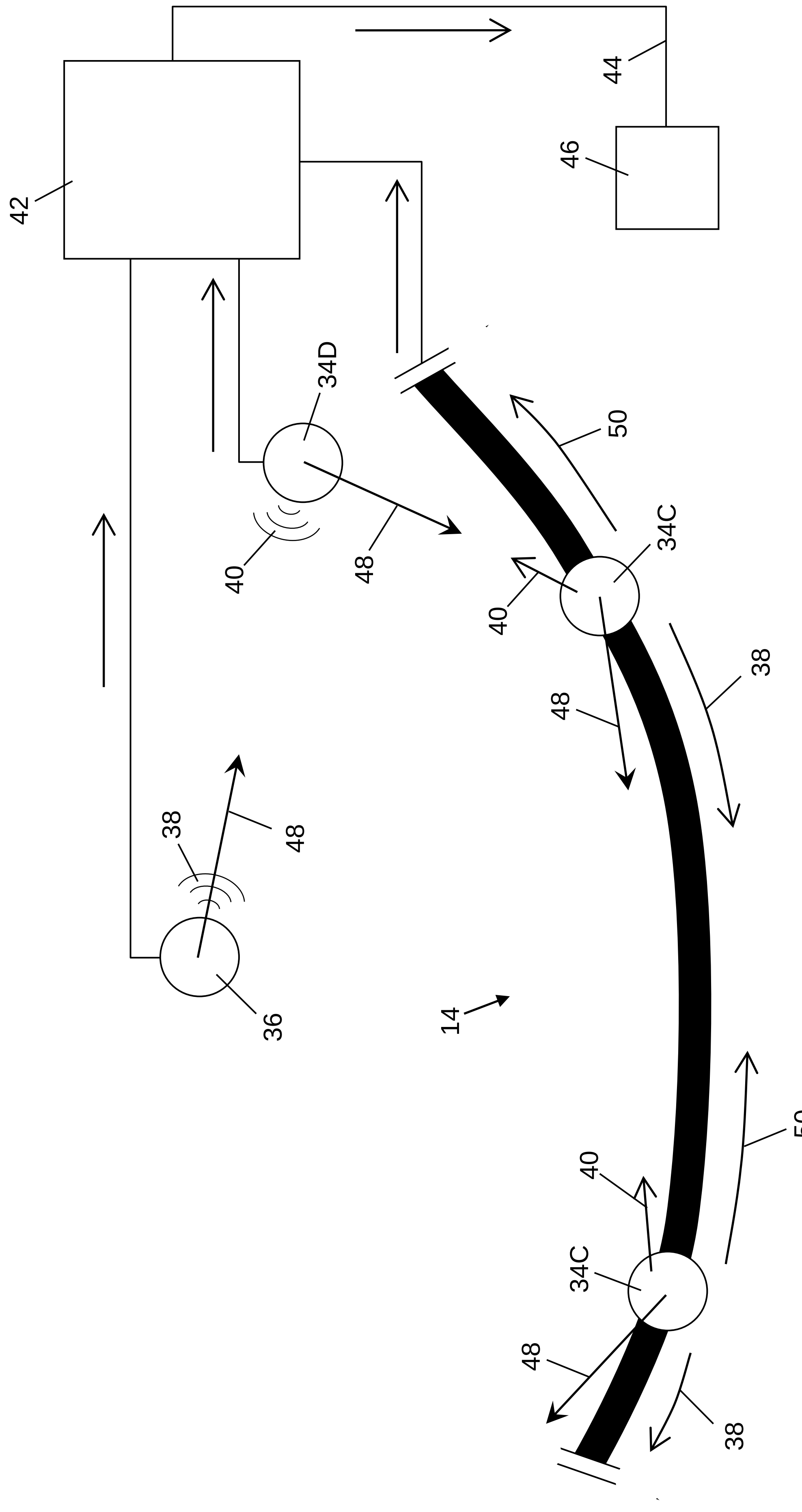


Figure 7

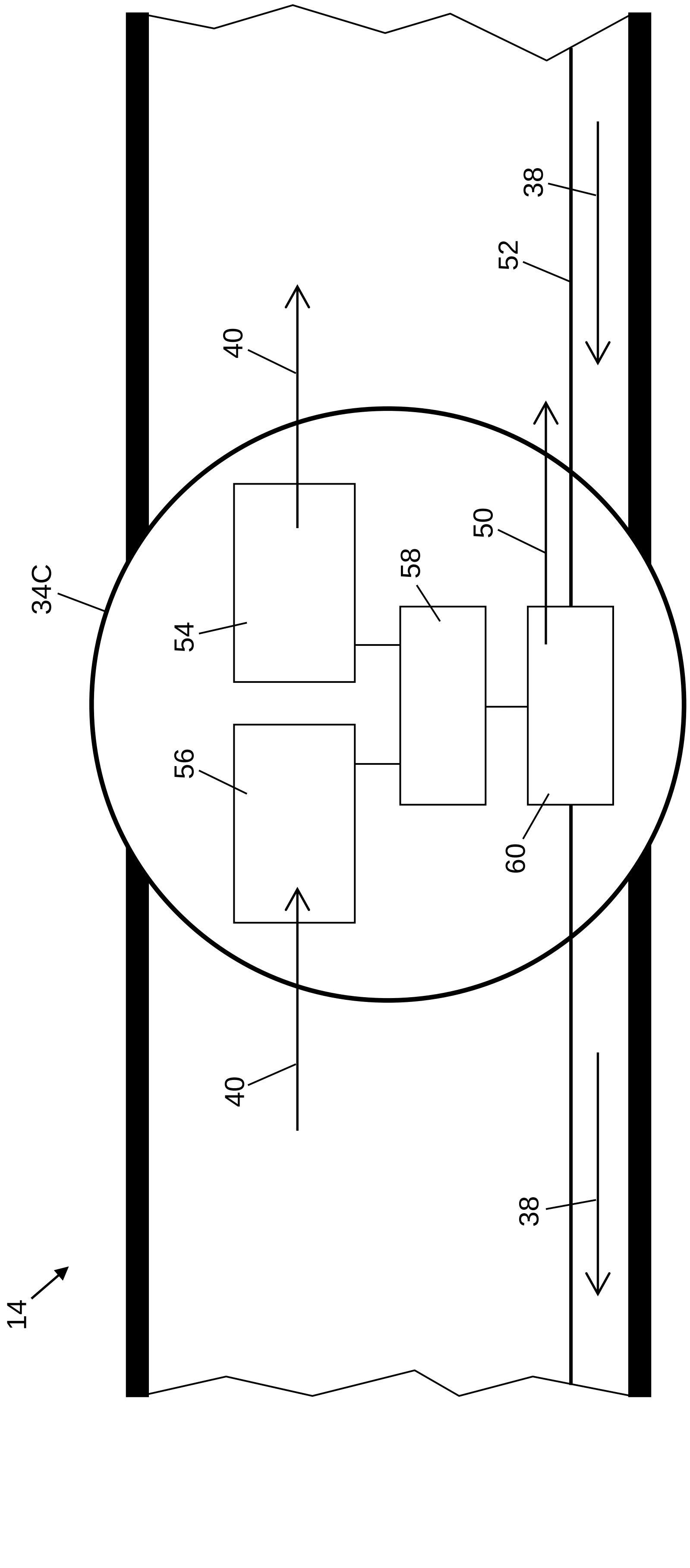


Figure 8

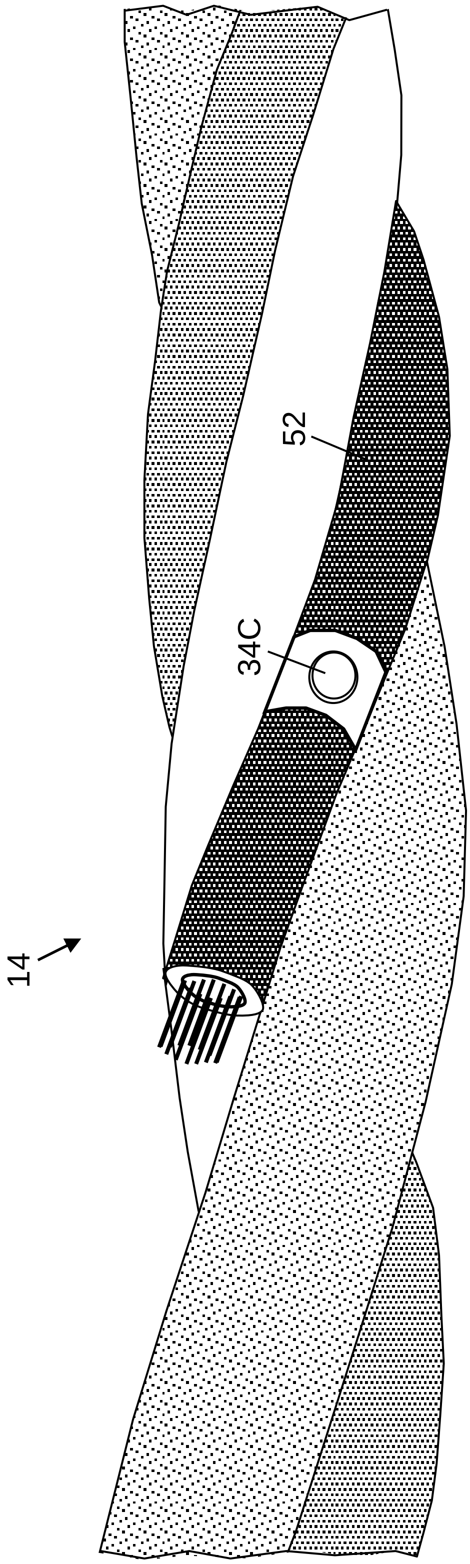
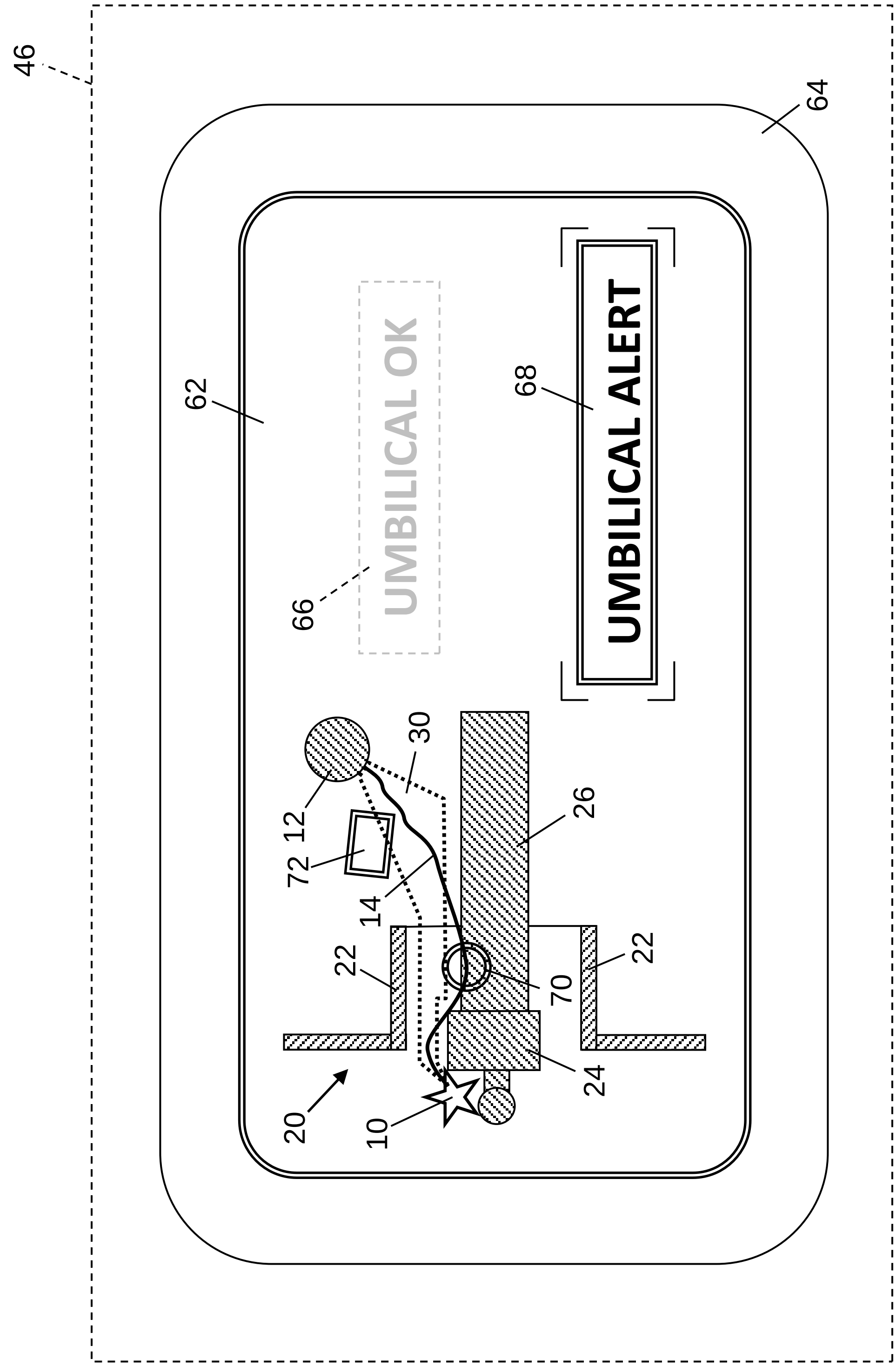


Figure 9


46
64
62
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68
UMBILICAL ALERT
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12
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Figure 10