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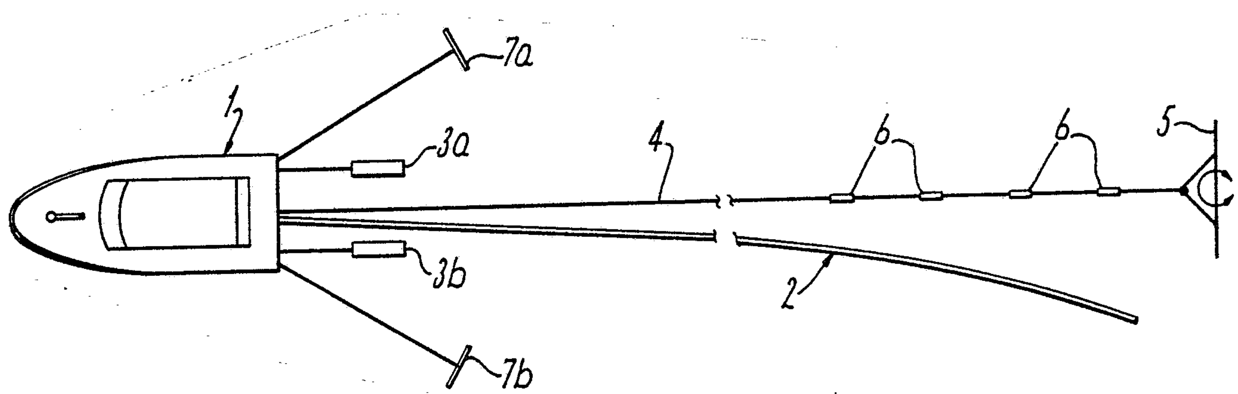

(57) Abstract

A device in a hydrophone cable which in connection with seismic surveys is towed through the water behind a vessel, the hydrophone cable comprising means for detecting echo signals which are reflected from the sea bed and various layers therebelow. For the purpose of improving the determination of the position of the hydrophone cable which can have a length of approx. 3000 meters, a transmission system is suggested, which comprises transmission elements arranged outside the hydrophone cable itself, the transmission elements serving to determine the position of the hydrophone cable in relation to the elements. In a simple embodiment of the device according to the invention the transmission elements are attached to or are constituted by a separate towing line (4) having a relatively small diameter, the towing line being equipped with stretching means (5) for achieving a relatively straight run. In an alternative embodiment the transmission elements can be implemented as reflectors (9a-9n) for preferably electromagnetic waves, for example in the form of light gas-filled balloons which can be attached to the hydrophone cable via thin, light lines, so that the balloons can be towed at surface positionor fairly high above the water surface. The transmission elements can also be included in a conventional radio and navigation system, possibly together with the system used by the towing vessel for its positioning, in addition to determination of distance and bearing by means of the radar system of the vessel. The transmission elements can also be included as elements in an adaptive control system for combined control of vessel and hydrophone cable.

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Device in a hydrophone cable for marine seismic surveys

The present invention relates to a device in a hydrophone cable which is adapted for marine seismic surveys and is towed through the water behind a vessel, the cable comprising means for detecting echo signals from the sea bed and various layers therebelow.

Such hydrophone cables which are used in connection with seismic methods for mapping possible hydrocarbon sources below the sea bed, can be approx. 3000 meters long and be towed at a depth of approx. 10 meters. At a distance of approx. 100 meters behind the vessel there are also towed so-called air guns, the air guns firing shots according to an appropriate programme. The sound waves which are transmitted from the air guns, are reflected from the obstacles against which they may impinge below the water surface, as well as from the sea bed and various layers therebelow. The echo signals which return to the hydrophone cable, are detected by a series of hydrophones which are arranged along the cable, and which after a suitable conversion transfer the echo signals via the cable to an appropriate processing device on the towing vessel.

The seismic methods can be carried out by firing lines having a mutual distance of approx. 50 meters, and the intervals between the shots from the air guns correspond to a distance of approx. 25 meters, for thereby achieving a very fine net of squares.

Aside from comprising means for detecting echo signals from the water bottom and various layers therebelow, the hydrophone cable also comprises a plurality of compasses which indicate the form of the cable during the towing operation, and which thus constitute reference points for the line to which a sweep operation is to be referred. However, such compasses suffer from some disadvantages, the direction indication of the compasses being apt to give significant errors, since the hydrophone cable has a substantial extension.

Besides, the compass section of the cable is often significantly larger in diameter than the cable itself, and will therefore in itself be prone to generate noise. Further, the compasses necessitate a substantial number of surplus connections in the cable, which in itself is unfavourable. Further, the calibrating routine for the compasses is very sophisticated, and it is not unusual that several days are used for effecting the calibration and making all of the compass sections operable. In case magnet compasses are used, these may easily be disturbed by the magnetic fields occurring during the measuring work itself.

In connection with such known magnet compass hydrophone cables no direct visual indication of the position of the cable exists other than an end buoy which is towed freely at an arbitrary position approx. 200-300 meters behind the terminal of the hydrophone cable.

Other and more reliable and stable direction references than magnet compasses have been evaluated, for example gyro compasses, but these have not been in commercial use, since it is expected that they will constitute a means which makes the hydrophone cable more expensive.

The object of the present invention is to arrive at a device in a hydrophone cable which with simpler and less expensive means can determine the position of the hydrophone cable, the detection of the hydrophone cable's position being of importance not only during the sailing of the measuring lines itself, but also during the turning programmes after a terminated line, in connection with which significant extra distances have to be sailed before a new line is entered for thereby ensuring that the cable has a shape as straight as possible.

The object is achieved according to the invention in a device which is characterized in that it comprises a transmission system which is adapted to determine the position of the hydrophone cable, and which comprises transmission elements provided outside the hydrophone cable itself.

By using such a transmission system it is possible to achieve a less expensive and more direct measuring method, a fact which includes significantly reduced equipment expenses, especially compared to the type of compass sections used today. In a transmission system in which the transmission elements are provided outside the hydrophone cable itself, it is also possible to achieve a substantially greater operational safety. By means of the transmission system it is, aside from achieving better information about the position and shape of the hydrophone cable at any time, also possible to include the position signals in the manoeuvring operations of the vessel during the turning operation. Finally, the suggested transmission system can be made to co-operate with means serving to aligne the shape of the cable both during the line sweeping and the turning operations.

The transmission elements which are included in the proposed transmission system can either be stationarily anchored, or they may be provided on bodies floating more or less freely in the water. In the latter case the bodies carrying the transmission elements can then be connected to a continuous connection means facilitating the collection of the bodies after a measuring period.

Possibly, the transmission elements serving to transfer the position signals to or from the hydrophone cable can be provided on one or more bodies which are towed behind the vessel, the bodies being towed separately or in groups, and the bodies substantially being arranged along a straight line.

In an alternative embodiment the bodies carrying the transmission elements can be affixed to or be constituted by a separate towing line having a relatively small diameter, the towing line being provided with stretching means for achieving an approximately straight run.

The towing line with the transmission element carrying bodies can then extend at least along the overall length of the hydrophone cable.

It is to be understood that the towing line itself can be adapted for transmission of substantially longitudinal acoustic waves which are received by the hydrophone cable.

It is also to be understood that the transmission elements can comprise means for receiving position signals which are transmitted from signal elements in the hydrophone cable.

It is further to be understood that the transmission of position pulses can take place to or from the vessel, for example via radio or radar, and it is thereby achieved an electromagnetic positioning system which works independently of the seismic hydrophone system. The transmission elements indicating the position of the cable can for example be constituted by for example reflectors which are attached to the towing line, or with a suitable spacing are attached to the hydrophone cable and glide thereabove in or close to the surface by means of appropriate buoyancy means.

The position of the reflectors can then be determined by means of antennas mounted for example on the vessel itself or on paravans towed at a distance from the vessel.

Possibly the position of the reflectors can be determined by a system gliding above the hydrophone cable, for example wire controlled from the vessel.

The above described embodiments for determining the position of the hydrophone cable can in a simple manner be adapted to an adaptive regulating system for manoeuvring both the vessel and the hydrophone cable for thereby achieving a most favourable overall position at any time for covering the measuring area and complete measuring accuracy.

The signals from the transmission system can suitably be used for influencing the manoeuvring of the vessel and/or influencing a means on the vessel which can move relative thereto, or influencing means which are provided along the hydrophone cable and in this way aligne the position of the cable relative to the vessel.

If the means influencing the hydrophone cable are to constitute an as little a noise source as possible for the hydrophone system, these means may appropriately be influenced during time intervals in which the hydrophone cable is close to inactive as regards the detection of echo signals.

The invention will in the following be further described, reference being had to the drawing, which in diagrammatical form illustrates various embodiments of the present invention.

Figure 1 illustrates diagrammatically a plurality of embodiments of the device according to the present invention.

Figure 2 is similarly a sketch illustrating further embodiments of the device according to the present invention.

Figure 3 illustrates diagrammatically further embodiments of the device according to the present invention.

Figure 4 is a sketch illustrating further embodiments of the present invention.

Figure 5 is a sketch illustrating how the hydrophone cable can be influenced in co-operation with the present device.

Referring to Figure 1, a vessel which is designated by 1, moves along the surface of a larger body of water for surveying the bottom of the body of water and areas therebelow, the vessel 1 towing a hydrophone cable 2 which can have an overall extension of for example 3000 meters. The towing of the cable 2 takes place preferably at a depth of 10 meters, and an even depth is sought maintained by means of for example active fins controlling the height direction of the cable, the specific weight of the cable being adjustable on the one hand by means of the paraffin type which is used for filling the cable, and on the other hand by ballast, for example in the form of lead plates arranged therearound.

After the vessel there are also towed a couple of air guns 3a, 3b, said guns being adapted for firing in accordance with a predetermined programme for the transmission of sound waves, which are scattered towards the sea bed and are reflected therefrom and from various geological layers therebelow. The reflected sound waves or echo signals are received by the hydrophones which are mounted in the hydrophone cable

2, and the signals from the hydrophones are passed through the hydrophone cable to a combined storage and computing machine on the vessel for further processing to appropriate values giving a picture of the sea bed and the formations thereof.

In order to achieve an as accurate result as possible it is of greates importance to know where the various hydrophone positions of the hydrophone cables 2 are relative to the vessel and the air gun groups 3a, 3b which are found for example approx. 100 meters after the vessel 1. This accuracy is especially of great importance in the cases wherein the lines over which the hydrophone cable 2 is to be passed, are arranged as close as 50 meters, and wherein the air guns are fired at 25 meters intervals while undertaking a so-called three-dimensional seismic survey.

In Figure 1 there is as a first embodiment of a transmission system for supervising the position of the hydrophone cable 2 depicted a relatively thin steel wire 4 which preferably has a somewhat longer extension than the hydrophone cable 2 itself. Appropriately, the steel wire 4 can be equipped with a braking plate 5 or a suitable form of a controlled braking device serving to keep the wire in an as straight as possible shape during the towing operation.

In a first utilization of the thin steel wire 4 this may constitute a carrier means for substantially longitudinal mechanical sound waves which are generated at the attachment points at the vessel 1, the acoustic waves or pulses which follow the wire 4 being registered by the hydrophones in the hydrophone cable 2, since the distance between the wire and the hydrophone cable in the utmost case usually runs to approx. 100 meters.

Possibly the braking device or the plate 5 at the free end of the wire 4 can be controlled in such a way that it not necessarily finds itself in an extension of the centre line of the ship, but can be swung out in the proximity of the microphone cable, so that the signal communication between the wire 4 and the hydrophone cable 2 is amplified. Since the wire 4 is relatively thin and is kept under tension, the drift of the wire can be made very small, but it should in connection with the use of acoustic transmission signals be towed in a position below the water surface, so that signal communication with the microphone cable is made as favourable as possible, while at the same time reducing wave noise. The distance between the wire 4 and the cable 2 should be adjusted so that no interference occurs between the means being included in the present transmission system and the hydrophone cable.

As an alternative to the transmission of mechanical pulses along the wire 4 there might thereon be mounted small signal generators 6 which preferably can be initiated from the vessel, for example in those periods wherein the echo sound waves from the bottom are on a relatively inactive level, so that the distance between the signal generators 6 on the wire 4 and the corresponding hydrophones on the hydrophone cable 2 can be detected.

It is to be understood that the acoustic signal generators can also be arranged in the hydrophone cable at the same time as signals therefrom are registered in suitable receivers in elements provided on the wire 4. However, it might be appropriate to utilize existing hydrophone groups in the hydrophone cable 2, a fact which includes an advantage in connection with signal sources in systems outside the hydrophone cable 2.

Still another embodiment of the device comprising a transmission system which is adapted for determining the position of the hydrophone cable and which comprises transmission elements provided outside the hydrophone cable 2 itself, is illustrated in Figure 1 and takes the form of transponders 7a, 7b, which are towed on paravans located approx. 200-300 meters behind the ship and defining an angle of approx. 45°. The signals from the transponders 7a, 7b will at suitable intervals be picked up by the hydrophones in the hydrophone cable 2 and the relative strength and the shape of the signals received by the hydrophone cable 2, will give a picture of the shape and the position of the cable relative to the towing vessel 1. The length of the paravan lines must here be adjusted so as to achieve a best possible signal/noise ratio, since longer paravan lines can give a shorter signal path to the hydrophones in the hydrophone cable, but bring the sources of noise closer thereto.

It is to be understood that the above discussed embodiments of a transmission system in which the transmission elements are provided outside the hydrophone cable itself, is to be operated with signal frequencies and types thereof which make them easily recognizable in the registration pictures from the hydrophones.

In Figure 2 there is illustrated an alternative embodiment of a device according to the present invention. As previously, 1 designates a vessel which behind itself tows a hydrophone cable 2. The signal communication to the hydrophone cable 2 is here suggested implemented by means of freely floating buoys 8a-8n, which aside from being equipped with hydroacoustic transponders, are also equipped with radar reflectors. The buoys are dropped from the vessel when this passes the area to be investigated, and the buoys will of course drift off by stream, wind and waves, but they will not give rise to noise. The transponders in the floating buoys can be adapted for transmission of hydroacoustic signals during given periods of times, preferably during period of times in which the registration of the echo signals is not critical.

If buoys are dropped at a distance of approx. 500 meters, a number of twenty buoys could cover a sailing line of approx. 10 km in a seismic surveying net.

The buoys can preferably be connected by means of a rope 8' which appropriately can slide through an eye in the stem of the bouy until the hydrophone cable has passed by. Thereafter the buoys can be collected in a group and be hauled in during the turning operation for another seismic line. In this period of turning the signal means in the buoys can possibly be reenergized if required.

It is to be understood that a corresponding system can comprise transponders which instead of floating on the surface of the water are dropped to the sea bed to known bottom positions for therefrom transmitting signals to the hydrophone cable. After use the transponders can be collected by means of a line and be brought to the towing vessel.

Still another variant of the transmission system according to the present invention is illustrated in Figure 3, in which reflectors for example in the form of light gass-filled balloons 9a-9n are attached to the hydrophone cable 2 which also in this case is towed behind a vessel 1. The balloons 9a-9n are attached to the hydrophone cable 2 by means of thin, light lines, so that the balloons can be towed at surface positions or at a fair height above the water surface, if required.

Such a system including floating or gliding balloons can be made very economically and can be contemplated used as a supplemental system to another transmission and measuring system. By means of the radar equipment on the vessel the position of the various balloon reflectors can be detected, and the detected echo signals from the reflectors will form a picture of the shape and position of the cable behind the towing vessel 1.

For further improving the detection of the floating reflectors radar antennas 10a, 10b can be arranged on towed paravans, as this appears from Figure 4. As previously, 9a-9n designate the floating reflecting elements which glide above the hydrophone cable 2, which on the other hand is towed by the vessel 1.

Possibly, the radar antenna can be arranged gliding in the air above the vessel 1, as this appears from Figure 3, the radar antenna here being attached to a gliding drone 11 which is located at a suitable distance and height behind the vessel 1 towing the hydrophone cable 2. The drone 11 can suitably be controlled from the vessel 1. Further, it is to be understood that the reflector elements can co-operate with means forming a basis line established outside the vessel for thereby avoiding the uncertainty in the angular determination from a vessel in moving sea.

The determination of the position of the buoys or reflectors can also be carried out by means of for example conventional radio and navigation systems, possibly by the system used by the ship itself for the positioning thereof. These systems can be used in addition to the distance and angular determination of the buoys by means of the radar system of the ship.

On the basis of the information obtained by the above discussed embodiments as regards the position and shape of the hydrophone cable it is possible by suitable means to let the hydrophone cable be included in an adaptive control system which manoeuvres the cable in such a way that this will be positioned as favourably as possible in relation to the reference line from which data is wanted in the sailing programme.

Via mathematical modelling of the hydrophone cable the vessel can be steered automatically in relation thereto, since this steering is also based on an adaptive control system. Such systems render dynamic compensation for wind, current and sea, as well as for the influences to which the vessel and the hydrophone cable ohterwise are subjected. Contrary to steering the vessel substantially along straight heading lines it is possible by co-operating the shape of the hydrophone cable and the heading of the vessel to obtain a most favourable shape and position of the hydrophone cable relative to the desired surveying line in the sailing programme.

When a survey line has been shot the vessel must be turned so that the hydrophone cable can enter another surveying line. This turning process is very time consuming, since the turning must be carried out in such a way that the cable must be sufficiently straight before starting a new line. By means of mathematical modelling and adaptive regulation technique based on the signals provided by means of the above discussed transmission system, such a turning programme can be put in as a completely controlled programme. In other words, the vessel can then be steered along a track which is as short as possible and renders an optimum shape of the cable prior to the commencement of another line. It is to be understood that the changing from one line to another not necessarily relates to two adjacent lines but lines which are located in various parts of the area in which the seismic surveys are to be carried out.

In Figure 5 there are diagrammatically illustrated embodiments wherein the vessel 1 towing the hydrophone cable 2 therebeind, is equipped with a suspension 12 which is adapted to influence the cable 2 for thereby either cancelling or resisting the deflections which at any time can occur during the towing operation. Possibly, the hydrophone cable 2 can be equipped with actuators, for example in the form of a steerable end rudder 13 or steerable fins provided in the longitudinal direction of the cable.

However, the use of steerable fins can pave the way for undesired acoustic noise, since in connection with seismic reflections one operates with signal levels in the magnitude range of ± 5 microbar.

However, the steering fins or the actuators can be inserted in such a way that they are active during given time intervals between the shots from the air guns, in which the accuracy, as regards the measuring technique, is of less importance. In other words, the control of the fins or the actuators will be excluded in the periods in which the feeble reflexes from the deep formations below the seabed are received, since during these periods of time a strongest possible reduction of all possible sources of noise is desired for the achievement of a most favourable signal/noise ratio.

If the cable prior to the commencement of a line sailing is sufficiently aligned, short intervals of influence of some seconds' duration can be sufficient for the cable to maintain an approximately straight shape. The fins or actuators should then be kept in a neutral noise-reduced position during the periods in which the seismic signals from the air guns are received.

As regards the rudder device 13 illustrated in Figure 5, such a towed steering device which either is located at or below the surface of the water, can be at a substantial distance from the hydrophone cable 2 for thereby constituting a noise source with minimum influence. The controlled rudder device 13 can suitably be equipped with a transmission element for determining the free end point of the cable in relation to a reference point on the vessel. Possibly, the controlled rudder device can comprise or constitute stretching means for the towing line.

It is to be understood that the above discussed transmission elements can be adapted for side detection, i.e. detection of the side at which the elements are, in relation to the hydrophone cable. Further, the system can be adapted so as to detect whether certain reference elements are approaching or moving towards and apart from each other, respectively.

Patent Claims

1. Device in a hydrophone cable (2) which is adapted for marine seismic surveys and is towed through the water behind a vessel (1) and comprises means for detecting echo signals which are reflected from the sea bottom and various layers therebelow, characterized in that the device comprises one or more supporting bodies which are provided outside or at a distinct distance from the hydrophone cable itself and from the sea bed, and that the supporting bodies comprise transmission elements which are included in a reference system for determining the position of the hydrophone cable.

2. Device as claimed in claim 1, characterized in that the transmission elements which are included in the reference system and which serve to transfer positioning signals to or from the hydrophone cable (2), are arranged stationary ashore.

3. Device as claimed in claim 1, characterized by transmission elements arranged on supporting bodies (8a-8n) floating approximately freely in the water.

4. Device as claimed in claim 1 or 3, characterized in that the bodies (8a-8n) supporting the transmission elements are connected to a continuous connection means (8') which facilitates the gathering of the bodies (8a-8n) after a measuring period, and which aids in aligning the transmission elements towards a straight line.

5. Device as claimed in claim 1, characterized in that the transmission elements are arranged on one or more bodies (6) which are towed behind the vessel (1), the bodies (6) being towed separately or in groups arranged substantially on a straight line.

6. Device as claimed in claim 1 or 5, characterized in that the bodies supporting the transmission elements are attached to or are constituted by a separate towing line (4) having a relatively small diameter, the towing line (4) being equipped with possibly controllable stretching means (5) for achieving an approximately straight run.

7. Device as claimed in claim 5 or 6, characterized in that the towing line (4) with the transmission element supporting bodies (6) extend along at least the overall length of the hydrophone cable (2).

8. Device as claimed in claim 7, characterized in that the towing line (4) itself is adapted for transmitting longitudinal acoustic waves which are picked up by the hydrophone cable (2).

9. Device as claimed in any of the claims 5-7, characterized in that the transmission elements comprise means for receiving positioning signals transmitted from signalling elements in the hydrophone cable.

10. Device as claimed in any of the claims 1-7 or 9, characterized in that the transmission elements are adapted for co-operating with radio and navigation systems or the system which the ship itself utilizes for the positioning thereof, possibly in addition to distance and direction determination by means of the radar of the ship.

11. Device as claimed in any of the claims 5-7 or 10, characterized in that the line formation of the transmission elements is determined by position detection of a point, for example an end point, in relation to the position of the vessel or with reference to a navigation

system, the line (4) which connects the transmission elements, possibly comprising controlled manoeuvring means (5) serving to bring the line (4) in a favourable position relative to the hydrophone cable (2).

12. Device as claimed in claim 1 or 5, c h a r a c t e r i z e d i n that the transmission elements are supported by or are constituted by floating or gliding supporting bodies or reflectors, for example gass-filled reflector elements (9a-9n) which are attached to the hydrophone cable (2) and are towed thereby at or above the water surface.

13. Device as claimed in claim 10 or 12, c h a r a c t e r i z e d i n that the reflector elements (9a-9n) co-operate with antennas (10a-10b) which are located in the proximity of the vessel (1), for example on paravans which are towed at a distance from the vessel or mounted stationarily relative to the vessel.

14. Device as claimed in claim 12 or 13, c h a r a c t e r i z e d i n that the reflector elements (9a-9n) are adapted to co-operate with a detection system (11) gliding above the hydrophone cable (2) and for example being controlled from the vessel (1).

15. Device as claimed in any of the claims 1-14, c h a r a c t e r i z e d i n that the transmission elements are adapted for co-operating with an adaptive regulation system for manoeuvring the vessel and/or the hydrophone cable.

16. Device as claimed in claim 15, c h a r a c t e r i z e d i n that the hydrophone cable (2) comprises actuator means (12) for optimum manoeuvring of the cable (2) in relation to the vessel (1), the actuator means (12) being arranged

on the vessel for influencing the hydrophone cable at its attachment point to the vessel.

17. Device as claimed in claim 16, characterized in that the hydrophone cable comprises means for controlled movement of the hydrophone cable in relation to the vessel, the control means being actuated substantially in intervals in which the hydrophone cable receives echo signals which are not critical.

18. Device as claimed in claim 15, characterized in that the hydrophone cable (2) is equipped with a controllable means (13) at its free towing end, the controllable means (13) possibly comprising a transmission element for position settlement of the end point of the hydrophone cable and possibly also at the same time comprising or constituting stretching means for towing lines.

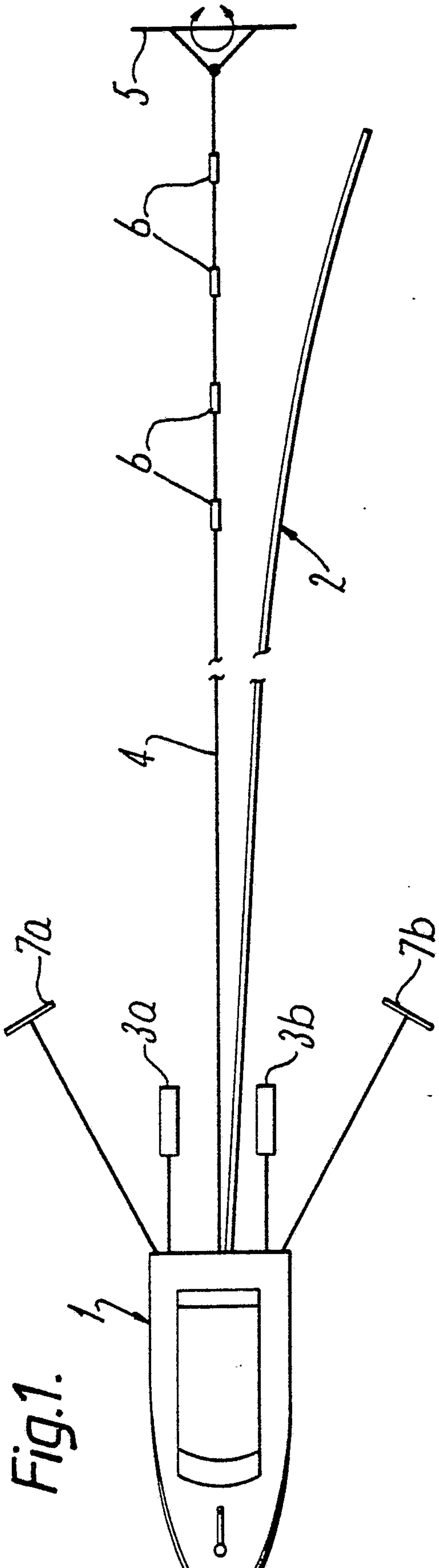

Fig.1.

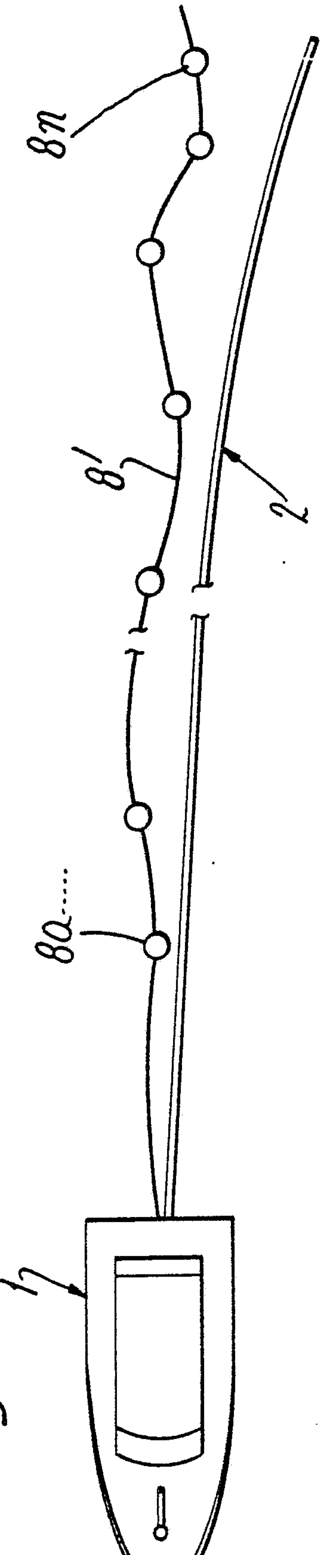

Fig.2.

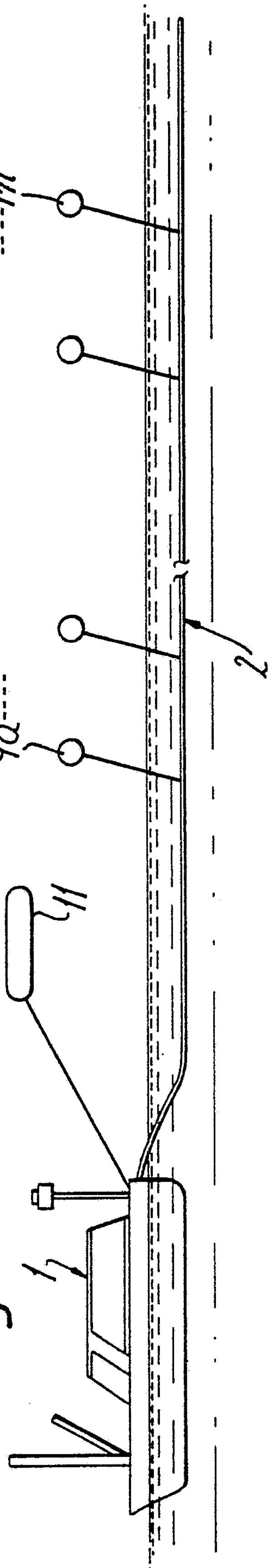

Fig.3.

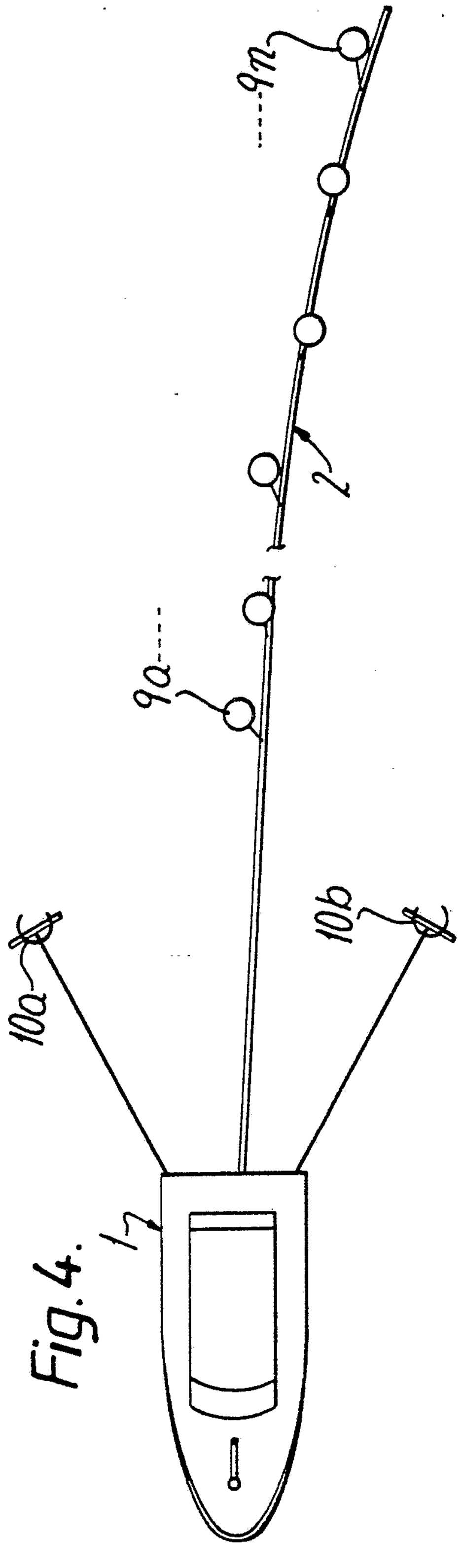

Fig.4.

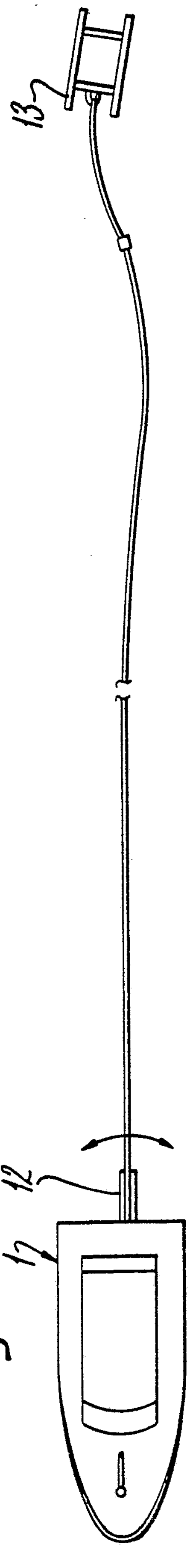

Fig.5.

INTERNATIONAL SEARCH REPORT

International Application No PCT/NO84/00007

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC 3

G 01 V 1/38

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
IPC 3	G 01 V 1/38
National Cl	42c: 42
US Cl	181: 110; 340: 3T, 7; 367: 19

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

SE, NO, DK, FI classes as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X	NO, B, 147 618 (INSTITUT FRANCAIS DU PETROLE) 31 January 1983	1
A	SE, B, 410 126 (TEXACO DEVELOPMENT CORPORATION) 24 September 1979	1

* Special categories of cited documents: [15]

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IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
1984-04-09	1984-04-16
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