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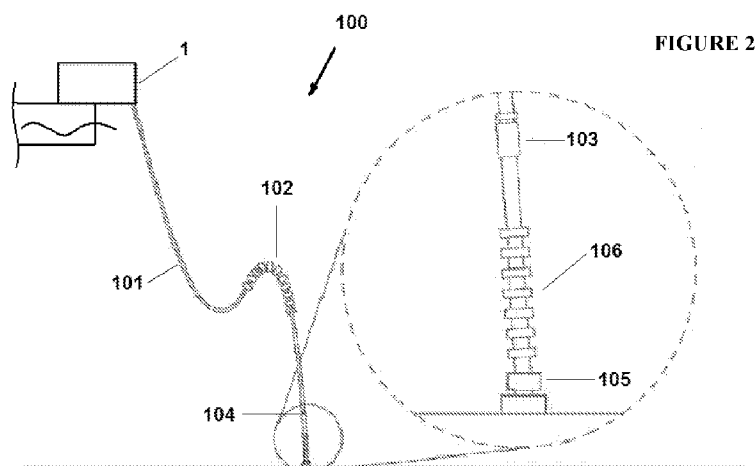


FIGURE 2

(57) Abstract: The present invention relates to a system to transport petroleum fluids using a riser, capable of operating with aggressive fluids, in regions of irregular sub-sea terrain, yet using low-complexity and low-cost components and connections. The hybrid reverse transfer system, comprises: a first, top, rigid riser section, a second, bottom, flexible riser section, connected to a bottom end of the rigid riser section, and a series of support buoys connected to the rigid riser section, wherein the lower end of the bottom, flexible, riser section connects to a bottom connector on the seabed.



HYBRID REVERSE TRANSFER SYSTEM

5 The present invention relates to a system to transport petroleum fluids using a riser, capable of operating with aggressive fluids, in regions of irregular sub-sea terrain, yet using low-complexity and low-cost components and connections. Because it is simple to install, such a system increases the entrepreneur's security that the job will be completed and that they will be able to secure a license from the environmental regulatory authorities.

10 Producing petroleum in offshore systems requires transferring the petroleum from wells in the bottom of the ocean to a stationary production unit (SPU) in pipes or tubes. This set of
15 pipes, normally known as production system lines, comprises electro-hydraulic umbilical lines, gas and water injection lines, and oil and gas pumping lines.

 The set of pipes that constitutes the production lines can be essentially split into two sections:

- 20 - the first section is predominantly horizontal (i.e. lying along the seabed) and static, and is known as the "horizontal section" or "flowline" in the technical jargon of this field of expertise.
- the second section, consisting primarily of vertical lines connected to the end of the horizontal section, rises from the seabed to the hull of the floating unit to which it will
25 be coupled, and is known as the "vertical section", hereinafter referred to by the technical name of "riser".

 It should be noted that the terms "horizontal" and "vertical" as used herein, and conventionally used in the technical field, should not be taken in their strict interpretation. In
30 particular, when considering the "vertical section", any horizontal distance between the rig on the surface of the ocean and the connection to the flowline on the seabed, along with the weight of the riser itself, requires that the riser assumes a substantially curved configuration, known as a catenary. The angle of the catenary is defined in the project design and depends on a number of factors. Nonetheless, such configurations are understood by the skilled person to be within the
35 meaning of the term "vertical section".

Risers may be rigid or flexible, and are coupled to a floating unit using anchoring structures specifically designed to support and resist the traction forces resulting from the weight of the riser and the dynamics of its movements. Horizontal forces and the moment of flexure, which complete the balance of the forces at work on the riser, are absorbed by specific structures on the SPU. These specific anchoring structures are known as riser supports when used with flexible risers.

It is well known that risers move relative to the supports, which is the result of different movements of the risers themselves and the floating units. These movements are created by marine currents, the rising and ebbing of tides, ocean waves and numerous other forces that act simultaneously on these structures. Thus the angle of the catenary expected at the point of coupling constantly changes, although it remains within a fixed and expected range. The same movements exist at the lower end of the riser; where it touches the seabed or at the bottom coupling, and consequently equivalent angular variations are observed.

Rigid risers are often formed as thin tubular elements made of metal, usually steel. In particular, rigid risers are commonly made of extruded steel. They are considered rigid since they are more resistant to deflection than the so-called flexible risers, which are often made of alternating layers of woven steel and polymer. Flexible risers often have inserted steel tubes, and the riser can flex in the spaces between tubes. As such 'rigid risers' have an elastic flexibility due to the inherent properties of the metal used, whereas 'flexible risers' can undergo greater changes in shape. However, due to the long distances and large forces involved, it is well understood in the technical field that rigid risers do bend during use. Indeed, the skilled person can readily distinguish between a "rigid riser" and a "flexible riser".

Compared to flexible risers, rigid risers are a lower cost option. They are also more resistant to high sub-sea pressures, and are quite durable, even when used to transport fluids rich in contaminants, of low pH or even at high temperatures.

These three factors of contamination, low pH and high temperature can be very damaging to flexible risers, as they change the mechanical properties of the polymer and metal components, making them more vulnerable to operating tensions, especially in regions where most of the forces concentrate, such as the segments close to the SPU supports.

Among current riser configurations, the one most often used in Brazil, being generally the less costly option and the one that is easiest to install, is the free catenary configuration. Configurations are also available for greater depths, in situations where the weight of the riser becomes critical. In cases such as these, buoys attached to the mid-section of the riser may be used, changing the angle of elevation of the riser at the point where it touches the seabed.

This technique, known in the petroleum industry as lazy-wave (because the presence of the buoys introduces a wave into the otherwise catenary shape of the riser), also reduces the load on the upper end of the riser.

Given the need to produce crude oil from wells located at greater depth, many different riser configurations have been developed to enable petroleum production in these new scenarios. Among the diverse configurations for deep water fields, those using rigid risers, include: Top Tension Risers (TTR), Steel Catenary Risers and hybrid configurations, which comprise part rigid and part flexible risers.

Hybrid configurations are often provided with the buoys in lazy-wave type configurations, or variations thereof. Basically, these systems are composed of a flexible top riser assembly, and a rigid bottom riser assembly. The rigid riser sections may be completely vertical, primarily vertical or even assume a traditional catenary configuration.

One of the greatest advantages of this type of configuration is that the effects of the dynamic movements of the floating unit and of the currents are concentrated on the upper, flexible portion of the riser, while the rigid portion is more protected from the majority of these cyclical movements, thus minimising fatigue failure in this section of the riser.

In particular, Freestanding Hybrid Risers (FHR), or riser-towers consisting of a vertical rigid riser supported by sub-surface buoys and connected to a floating unit via a flexible riser, is one of the configurations under study to be applied to oil wells in ultra-deep waters.

The advantage of such a system is that it enables a leaner sub-sea arrangement, with no line congestion where risers start their trip up to the surface. This also eliminates any risk that risers might collide in mid-water. However, the system has a cost disadvantage compared to other, existing riser configurations. Installing a freestanding hybrid riser assembly may require major job sites that connect to the sea. Such an undertaking could pose potential problems in

terms of obtaining licenses from the environmental authorities, in particular if there are coral reefs within the area of influence.

5 Another solution, which nowadays might be more suited to deep-water fields and irregular terrains, is the steep-wave system.

10 This configuration consists of a rigid line in the bottom riser assembly, with the configuration otherwise being in a traditional lazy-wave configuration. As such, the difference between the steep wave configuration and the lazy wave configuration is that, in the steep wave configuration, the rigid riser connects to the bottom connector but does not contact the seabed at any point, having a “vertical” connection to the seabed. In contrast, in the lazy wave configuration, part of the bottom portion of the riser may lie along the seabed.

15 The advantage of such a steep-wave system is that it eliminates the section where the riser touches down on the seabed, especially in situations where there are major geological failures or depressions in the region where one would like to place the riser. This solution enables connecting the lines to floating production units at azimuths that would not be achievable with other configurations, due to the terrain of the seabed. However, using rigid lines for the bottom riser assembly in such situations requires that bottom connections consist of
20 connection equipment capable of keeping up with riser movements. Furthermore, equipment must be extremely robust to eliminate the possibility that corrective maintenance interventions may be required.

25 When using rigid lines, the best structure for such a connection would be a flexible joint, known in technical jargon as a flexjoint. However, even this equipment, which is normally used for the top connection of rigid risers, has rotation limitations, in addition to reliability problems. Not only are such connections more costly, but flexjoints present another problem, in that they normally have a limit of rotation of around 23° , which is less than the potential angular movement of the lower section of a riser in a steep-wave system.

30

Flexjoints enabling a wider angle of movement are higher in cost and consist of numerous moving parts, increasing the risk of failure.

35 US 6,869,253 describes a hybrid configuration with a rigid top riser assembly, and a flexible bottom riser assembly. This is a tower-type configuration, with buoys attached to the

flexible section of the riser. The object of the US 6,869,253 invention is not concerned with the possible drift of the riser and how this would influence the durability of the connections.

5 US 2011/0155383 describes an arrangement wherein the seabed connection is protected by means of a structure that is fixed to the seabed and supports the connection.

Neither of these proposals, or any of the other systems available in the market, is a low-cost solution that is simple to implement and maintain.

10 Given these technical challenges, the emerging concern was to develop a hybrid steep-wave system for deep waters, capable of withstanding the scenario described, and of complying with safety and durability requirements.

15 The present invention was developed based on the concept of using components well known to the person skilled in the art, which are simple and low cost, but which can be combined to provide a new petroleum fluid transfer configuration to the portfolio of technical options available to the petroleum industry.

20 The invention described below is the result of continuous research in this field, focused on simplifying the structure so that it can be easily installed and operated in balance, even when subjected to random movements

Other goals of the hybrid reverse transfer system that is the object of this invention are listed below:

- 25 a) Operate with a rigid riser in a steep-wave configuration;
b) Provide a transfer configuration that is based on a rigid riser, placed at a wide angle of elevation from the seabed;
c) Achieve a steep-wave configuration with a rigid riser and low-cost bottom connection;
30 d) Achieve a steep-wave configuration with a rigid riser and highly reliable bottom connection;
e) Ensure a durable top connection and support of the riser assembly;
f) Provide a riser with a wide angle of elevation from the seabed, with no need to assemble large, underwater construction sites;
35 g) Facilitate the approval of environmental licenses for project installation.

The present invention relates to a reverse hybrid transfer system for use in deep water, capable of resisting exposure to high sub-sea pressures, and that is quite durable, even when used to transfer fluids rich in contaminants, of low pH or even at high temperatures.

According to an aspect of the present invention there is provided a hybrid reverse transfer system, comprising: a first, top, rigid riser section, a second, bottom, flexible riser section, connected to a bottom end of the rigid riser section, and a series of support buoys connected to the rigid riser section, wherein the lower end of the bottom, flexible, riser section connects to a bottom connector on the seabed. This arrangement allows the transfer system to be used in areas of the seabed with an irregular surface, but also provides for a strong joint at the seabed that can handle a large angular variation.

The buoys can cause a portion of the rigid riser section to assume a wave configuration.

The assembly of the first and second riser sections takes on a steep-wave configuration.

The bottom riser section can connect to a Vertical Connection Module type of bottom connector.

Preferably, the thrust provided by the support buoys is such that the flexible riser has a large angle of elevation with respect to the seabed, at the point it connects to the connector at the seabed. The angle of elevation can be of from 35° to 90°, optionally from 45° to 90° and further optionally from 60° to 90°.

The lower end of the top riser section can be fitted with a mechanical connector, such as a flange, for connecting to the bottom riser section

The rigid riser section can be made of steel pipe.

The rigid riser section can comprise up to 94% of the total length of the hybrid reverse transfer system.

The flexible riser section can be made of flexible tubing.

The flexible riser section can comprise at least 6% of the total length of the hybrid reverse transfer system.

5 Hybrid reverse transfer system according to any one of the previous claims, wherein the support buoys are attached to a bottom portion of the top riser. That is, the buoys are attached to a portion of the top riser in the bottom half of the top riser.

10 The top end of the hybrid reverse transfer system can be connected to a floating structure.

According to another aspect, the invention provides a steep-wave riser system, comprising: a rigid riser section, a flexible riser section connected to a bottom end of the rigid riser section, and wherein the lower end of the flexible riser section connects to a bottom connector on the seabed.

15 According to another aspect, there is provided a method of providing a transfer system, comprising: providing a first, top, rigid riser section, providing a second, bottom, flexible riser section, connected to a bottom end of the rigid riser section, providing a series of support buoys connected to the rigid riser section, and connecting the lower end of the bottom, flexible, riser
20 section to a bottom connector on the seabed.

In essence, the present invention consists of a first top riser assembly, preferably made of
25 steel pipe, and preferably comprising up to 94% of the total length of the riser, and a second bottom assembly made of flexible jumpers. This second section preferably comprises at least 6% of the total length of the hybrid reverse transfer system.

30 Close to the lower end of the top riser assembly, the steel pipe is fitted with a series of support buoys so that said portion of steel pipe takes on a lazy-wave type configuration (although the overall configuration is more like a steep-wave configuration).

The top end of the hybrid reverse system is anchored to a floating structure using traditional rigid riser anchoring structures.

35

The lower end of the top riser assembly is provided with a simple mechanical connector, to which is affixed the second, bottom section made of flexible jumper.

5 The lower end of the bottom riser assembly, made of flexible jumpers, goes down to a bottom connector and remains in contact with the seabed at a wide angle of elevation.

Overall, this hybrid reverse transfer system is in a steep-wave configuration.

10 A hybrid reverse transfer system is disclosed, characterised by consisting of: a first top section made of steel pipe, comprising up to 94% of the total length of the riser, and a second bottom section of flexible tubing, comprising at least 6% of the total length of the hybrid reverse transfer system, wherein: close to the bottom end of the top riser assembly, the steel pipe is connected to a series of support buoys so that that portion of the steel pipe assumes a lazy-wave configuration; the top end of the hybrid reverse transfer system is connected to a floating
15 structure using anchoring structures; the bottom end of the top riser assembly is fitted with a simple mechanical connector, to which is affixed the bottom riser assembly made of flexible jumper; the lower end of the bottom riser assembly made of flexible jumpers goes down to a bottom connector and from there connects to the bottom lines using suitable equipment; the bottom riser assembly made of flexible jumper maintains a wide azimuth at the point where it
20 touches the seabed.

The hybrid reverse transfer system, can be characterised in that the thrust provided by the support buoys is enough to keep the bottom riser assembly made of flexible jumpers at a wide azimuth, between 35° and 90°.
25

The hybrid reverse transfer system can be characterised in that the lower end of the top riser assembly is fitted with a simple mechanical connector, such as a flange.

The hybrid reverse transfer system can be characterised in that the bottom riser assembly
30 of flexible jumpers goes down to a VCM (Vertical Connection Module)-type bottom connector.

The hybrid reverse transfer system can be characterised by an assembly that takes on a steep-wave type configuration.

35

A more particular description of the invention, by way of example only, is provided below, together with the drawings listed below:

5 Figure 1A is a simulation of the typical drift paths of a steep-wave configuration.
Figure 1B is a second simulation of the typical drift paths of a steep-wave configuration.
Figure 2 illustrates the hybrid reverse transfer system that is the object of this
invention.

10

The reverse hybrid transfer system that is the object of the present invention was developed to fill a gap in the currently available options for transferring petroleum fuels from great depths. The invention provides a new way of positioning a riser at a wide angle of
15 elevation to the seabed so as to avoid or bypass geological depressions, coral reefs and other interferences on the seabed, without the need for major underwater job sites.

Figure 1A and Figure 1B show charts for two simulations of typical drift paths for a steep-wave configuration. As can be seen from the charts, in the steep wave configuration the
20 riser meets the seabed at the attachment point/connector and does not lie along the seabed. These simulations demonstrate the angular variation imposed on the bottom riser assembly. This constitutes a problem when choosing to use a steep-wave configuration and specifying rigid risers as the main characteristic of the transfer system to be used because the rigid risers would need to be able to cope with the large angular variation, which is difficult to design for.

25

Nonetheless, a number of operating factors may be part of the oilfield production scenario, which could make rigid risers (such as rigid steel pipes) the preferred option for use in the transfer system. The main factors that would suggest this option are the characteristics of the fluids produced, such as higher temperatures, high concentration of contaminants or even low pH
30 - these are all factors that can quickly degrade the structure of flexible jumpers (also referred to as flexible hoses or flexible tubing), especially when exposed to forces such as those found close to the point where the riser is supported.

Flexible jumpers, on the other hand, are quite resilient to the movements imposed by the
35 drift of a steep-wave configuration, such as shown in Figures 1A and 1B.

The hybrid reverse transfer system 100 proposed herein may be understood from Figure 2. The system show has, overall, a typical steep-wave configuration, but the implementation of the system is different to prior steep-wave configurations. In this case, up to 94% of the riser length consists of rigid steel pipes and, unintuitively, a short lower section consists of flexible jumpers. That is, where a conventional steep-wave configuration would use a rigid riser at the bottom, to ensure that the riser extends away from the seabed without lying on it or sagging towards it, the system 100 uses a flexible riser at the bottom, but nonetheless allows for a steep-wave configuration to be obtained.

Figure 2 is merely a schematic representation of the proposed hybrid reverse transfer system 100. In it, a floating structure 1 is depicted, as sea level, with the upper end of the hybrid reverse transfer system 100 connected to it using anchoring structures that are traditionally used with rigid risers or light weight submarine anchoring equipment.

The hybrid reverse transfer system 100 itself can comprise a top section 101. The top section 101 is a rigid riser section or assembly. The top section 101 can be made of steel pipe, for example. The top section 101, can comprise up to 94% of the riser's total length. Close to the bottom end of this top riser assembly 101 the steel pipe is fitted with a series of supporting buoys 102 so that a portion of the riser takes on a lazy-wave type configuration (although, as discussed above, the overall system is in a steep-wave configuration). The buoys 102 are optionally positioned in the bottom 50% of the top riser assembly, further optionally in the bottom 30%, and still further optionally in the bottom 10%. The thrust resulting from the supporting buoys 102 is used to keep the section of the riser below them at a wide angle of elevation to the seabed, preferably in the range of from 35° to 90°, more preferably from 45° to 90°, and even more preferably from 60° to 90°.

The lower end of the top riser assembly 101 is provided with a mechanical connector 103, such as for example a flange. To this can be affixed the bottom riser section or assembly 104 made of flexible jumpers. This second/bottom section 104 preferably comprises at least 6% of the total length of the hybrid reverse transfer system 100, and is optionally in the range of 6 to 10% of the total length of the hybrid reverse transfer system 100. If the flexible riser length is too long, the joint will experience undesirably high fatigue stresses. If the flexible riser length is too small, the use of other joints and connectors becomes necessary to allow the riser to curve properly. The bottom section 104 is used to couple the overall system to the seabed.

The second, bottom, riser assembly 104, made of the flexible tubing for example, can connect to a VCM (Vertical Connection Module)-type connector, 105. The VCM-type connector can in turn connect to the lines coming from the bottom of the well (not shown) using equipment known to the skilled person from prior art.

The VCM-type connector 105, proposed above as the bottom connector, is a piece of equipment widely used with flexible jumpers and its performance is known from prior art. However, it is conventionally used for the top connection of said flexible jumpers. In the hybrid reverse transfer system 100, the VCM-type bottom connector 105 will perform its role on the seabed. The VCM-type connector, keeps the bottom flexible riser assembly 104 from the type of drift typical of a steep-wave configuration, and has a lower risk of failure. This is because the VCM-type connector has a swivel system that allows better orientation during the flexible riser connection.

The hybrid reverse transfer system 100 can also use a curvature limiter 106 next to the lower end of the bottom riser assembly 104. This device is commonly used in flexible lines and serves to keep the flexible line from exceeding its radius of curvature due to significant riser movement. The system proposed has the same function, reducing the risk of stress on the flexible portion of the system 100, particularly at the seabed connection point.

Compared to existing transfer systems, the proposed system is better suited to scenarios where the characteristics of the fluid carried by the system has a high temperature, a high concentration of contaminants or a low pH. The system is also of benefit where riser settling might suffer some limitation due to characteristics of the seabed such as depressions, major geological failures or even the presence of coral formations.

Thus the invention, by using a flexible jumper in the bottom of the riser assembly, eliminates the use of highly complex connection equipment, and presents a low-cost solution for irregular underwater arrangements that produce aggressive fluids.

The invention is described herein with reference made to its preferred embodiments. It should be clear however that this invention is not limited to these embodiments, and those skilled in the art will immediately realise that changes and substitutions are possible within the scope of the claims.

CLAIMS

1. Hybrid reverse transfer system, comprising:
 - a first, top, rigid riser section,
 - a second, bottom, flexible riser section, connected to a bottom end of the rigid riser
 - 5 section, and
 - a series of support buoys connected to the rigid riser section,
 - wherein the lower end of the bottom, flexible, riser section connects to a bottom connector on the seabed.
- 10 2. Hybrid reverse transfer system according to claim 1, wherein the buoys cause a portion of the rigid riser section to assume a wave configuration.
3. Hybrid reverse transfer system according to claim 1 or 2, wherein the assembly of the first and second riser sections takes on a steep-wave configuration.
- 15 4. Hybrid reverse transfer system according to any one of the preceding claims, characterised in that the bottom riser section connects to a Vertical Connection Module type of bottom connector.
- 20 5. Hybrid reverse transfer system according to any one of the previous claims, wherein the thrust provided by the support buoys is such that the flexible riser has a large angle of elevation with respect to the seabed, at the point it connects to the connector at the seabed.
- 25 6. Hybrid reverse transfer system according to claim 4, wherein the angle of elevation of the flexible riser at the point it connects to the seabed is from 35° to 90°, optionally from 45° to 90° and further optionally from 60° to 90°.
7. Hybrid reverse transfer system according to any one of the previous claims, characterised
- 30 in that the lower end of the top riser section is fitted with a mechanical connector, such as a flange, for connecting to the bottom riser section
8. Hybrid reverse transfer system according to any one of the previous claims, wherein the rigid riser section is made of steel pipe.

35

9. Hybrid reverse transfer system according to any one of the previous claims, wherein the rigid riser section comprises up to 94% of the total length of the hybrid reverse transfer system.
- 5
10. Hybrid reverse transfer system according to any one of the previous claims, wherein the flexible riser section is made of flexible tubing.
11. Hybrid reverse transfer system according to any one of the previous claims, wherein the flexible riser section comprises at least 6% of the total length of the hybrid reverse transfer system.
- 10
12. Hybrid reverse transfer system according to any one of the previous claims, wherein the support buoys are attached to a bottom portion of the top riser.
- 15
13. Hybrid reverse transfer system according to any one of the previous claims, wherein the top end of the hybrid reverse transfer system is connected to a floating structure.
14. A steep-wave riser system, comprising:
- 20
- a rigid riser section,
- a flexible riser section connected to a bottom end of the rigid riser section, and
- wherein the lower end of the flexible riser section connects to a bottom connector on the seabed.
- 25
15. A method of providing a transfer system, comprising:
- providing a first, top, rigid riser section,
- providing a second, bottom, flexible riser section, connected to a bottom end of the rigid riser section,
- providing a series of support buoys connected to the rigid riser section, and
- 30
- connecting the lower end of the bottom, flexible, riser section to a bottom connector on the seabed.

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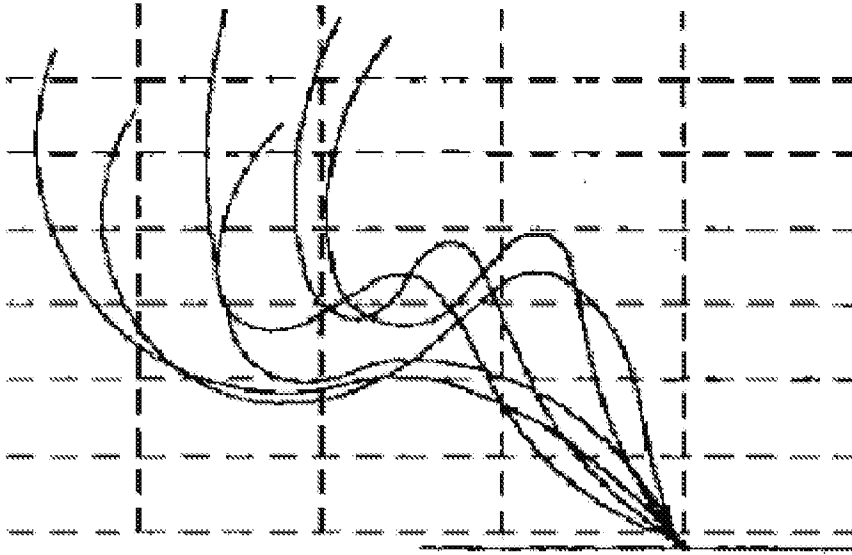


FIGURE 1A

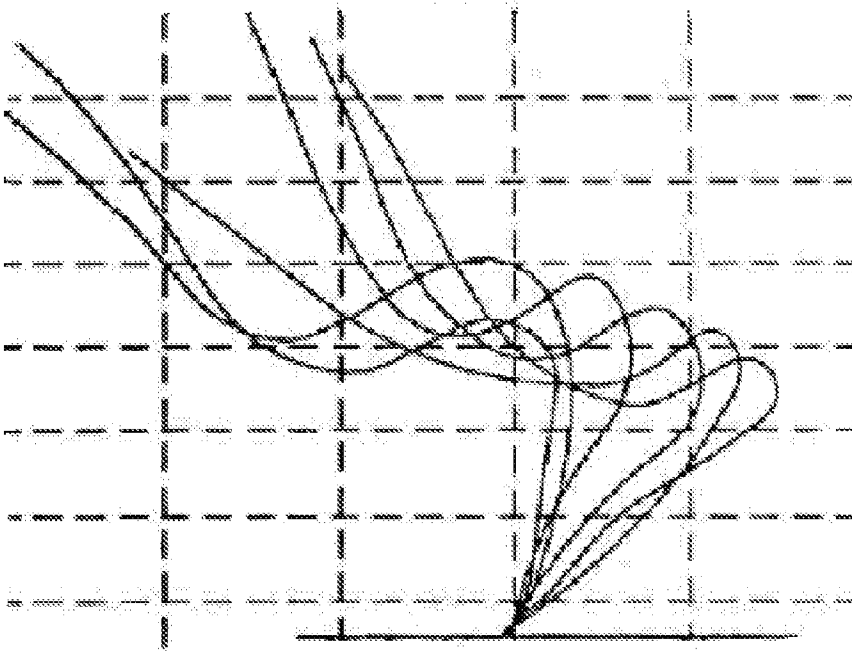


FIGURE 1B

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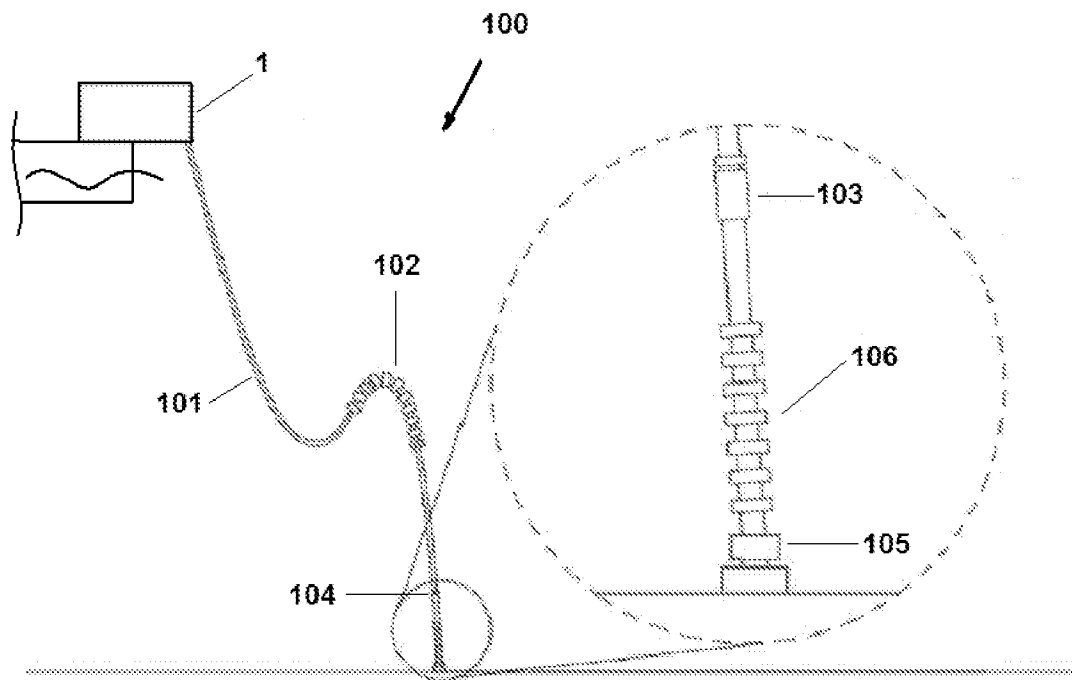


FIGURE 2