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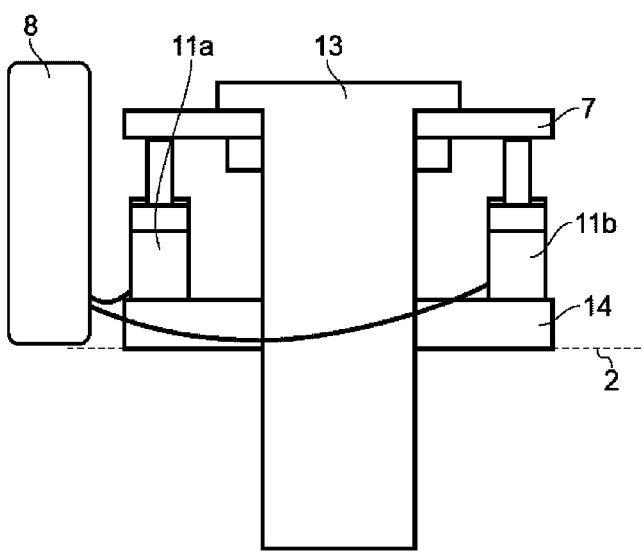
(54) Title **RISER RESONANCE PREVENTION DEVICE**

(56) References Cited:

WO 2013137743 A1
WO 2012016765 A2
WO 2011074984 A1
WO 2014122526 A2
WO 2012148289 A1

(57) Abstract

The invention relates to a resonance prevention device for a tubular suspended from a floating vessel, the device having at least one compression element which is pre-tensioned in an end stroke position such that when subjected to a tubular force below a pre-defined threshold force, the at least one compression element forms a rigid hang-off for the tubular, and when subject to a force higher than the threshold force the Device forms a compressible hang-off for the tubular.



RISER RESONANCE PREVENTION DEVICE

The invention relates to a riser resonance prevention device, hereafter called RRP, for use in a hoisting arrangement in a derrick, an arrangement on a deck on a floating unit/vessel, or as a system for preventing resonance-based loads from a riser supporting a heavy load from a floating unit.

Background

Drilling in deep waters involves other and more complex challenges compared to drilling in shallow waters. This is also the situation for the risers to be used in such deep waters, where risers have to withstand potentially higher tension loads and pressures etc. Additionally, the vessels heave motion may coincide – or nearly coincide – with the riser strings natural frequency resulting in even higher tension loads. This is a challenge in situations where the riser string has a free end, i.e. when it is not connected the sea bottom. Such situations may occur when using the riser for hoisting or lowering of equipment, e.g. a blow out preventer (BOP) from the surface to the sea bottom, or when the riser has been disconnected from a BOP or manifold. On drilling vessels, a critical load condition is hoisting/ lowering of the BOP, or during other heavy lifts, with risers. In this load condition, no heave compensation systems are connected, resulting in that the heavy load (BOP) will try to follow the vessels heave motion. The length of the risers with BOP depends on the water depth, but could be more than 3000 meters. The riser connection to the vessel is stiff and either connected to the DDM (Derrick Drilling Machine) or on the spider or other hang-off plate on deck (drill floor). Due to this hard hang-off system, the vertical naturally frequency of the riser string could meet the frequency of the heave motion on the floating vessel with a considerably dynamical load amplification factor as result.

Prior art solutions include GB 2294713 A, which discloses a deep water riser string that has a central tube, peripheral lines and a base located at the lower end of the central tube. The central tube is fitted with means for retaining the said peripheral lines in a position relative to the central tube. The lower ends of the said peripheral lines are linked to a device arranged on the base, permitting a certain axial movement of at least one of the lines relative to the central tube. The string is fitted with damping means.

WO 2013/137743 A1 describes a device for compensation of wave induced distance variations to a drill string between a floating drill rig and a seabed-fixed installation. WO 2012/016765 describes an apparatus for controlling movements of a free-hanging tubular suspended via at least a connector element by at least one compensator member which is connected to a buoyant vessel.

An objective of the present invention is to overcome the shortcomings of the prior art and to obtain further advantages. More specifically, an objective of the present invention is to provide a solution which renders possible deep water drilling without having to replace the existing riser string by another specific riser string to be used for a hoisting/lowering operation. Another objective is to provide a solution which is adaptable to be used on new vessels as well as for retrofitting existing vessels.

Summary of the invention

The invention is set forth in the independent claim, while the dependent claims describe other characteristics and advantageous embodiments of the invention. The invention relates to a resonance prevention device (RRP) for a tubular suspended from a floating vessel, the device having at least one compression element which is pre-tensioned in an end stroke position such that when subjected to a tubular force below a pre-defined threshold force, the at least one compression element forms a rigid hang-off for the tubular, and when subject to a force higher than the threshold force the device forms a compressible hang-off for the tubular.

A riser resonance prevention device for a free-hanging riser string suspending heavy loads can minimize the possibility of experiencing that the vertical natural frequency of the riser string meets the frequency of heave motion on the floating vessel. This reduces the load in the riser string and on the supporting structure. The RRP according to the invention is suitable for use both on new vessels or can be installed on existing vessels, i.e. any floating installation. The RRP is easily installed on existing floating installations, thus older vessels may be upgraded to permit drilling in deeper waters. Additionally, the hoisting weight or stress level in the risers in new projects may be reduced.

The RRP according to the invention may thus be in a “passive mode” during normal operations, i.e. remain stiff without any resonance prevention effect, but in situations of hoisting or lowering heavy loads (such as e.g. BOPs) with a riser and specific sea conditions, the RRP may reduce the amplitudes of the riser with load. I.e. the RRP according to the present invention, will only influence the riser with load if excess loads are reached, and hence prevent the riser and loads from reaching larger amplitudes, beyond a threshold interval by altering the natural frequency of the riser string. In other words, the RRP acts as a rigid support until it is made subject to a certain predefined threshold load. When the threshold load is reached, the RRP may act as a spring supporting the riser string, thereby altering the natural frequency of the system and preventing resonance in the riser string.

In one embodiment, the at least one compression element comprises at least one cylinder coupled to an accumulator, whereby the pressure in the accumulator can be varied to adjust the pre-determined threshold force. Advantageously, this permits adjusting the characteristics of the device according to the operating conditions at any time. The pre-defined threshold force may be set based on at least one of the factors: (i) a weight of the tubular, (ii) a length of the tubular, (iii) a weight of a load suspended by the tubular, and (iv) a wave period for waves acting on the floating vessel. In a further aspect, the RRP is designed to be activated only when a certain load is reached, which load is dependent of the max static load (weight) of the riser string and BOP, and the threshold force is preferably set 5-30% above a max static load. In a further advantageous embodiment, the threshold force is set 5-10% above the max static load.

In an embodiment of the invention, the RRP may comprise a preloaded spring which is designed to be activated when a given tension load in the riser string is reached and then limit the maximum tension load to a chosen value when handling riser and BOP.

These and other characteristics of the invention will be clear from the following description of a preferential form of embodiment, given as a non-restrictive example, with reference to the attached drawings.

Brief description of the drawings

Figure 1 shows a typical limitation a floating unit has when hoisting or lowering a riser string with a BOP in relation to wave height (Hs) and hook load.
Figure 2 shows the same limitation as in Figure 1, but with a RRP mounted.
Figure 3 shows an example of a RRP arranged on a drill floor.
Figure 4 shows a typical stiffness curve for the RRP.
Figures 5A-5C show an example of a functional setup of a RRP.
Figure 6 shows typical drill floor load variations with and without a RRP.
Figure 7 shows various possible embodiments according to the invention.
Figure 8 is a view of an embodiment of an RRP arranged on a drill floor.
Figure 9 is a view of an embodiment of an RRP arranged below a crown block.
Figure 10 is a view of an embodiment of an RRP arranged below a DDM.

Description of preferred embodiments

Throughout the description different terms such as 'riser' or 'riser string' is used. The skilled person will understand that the meaning of 'riser' and 'riser string' is the same, namely a string of tubular steel pipe extending from a floating unit downwardly towards a sea floor, either fixed to equipment on the sea floor or free-hanging in the water.

Figure 1 shows the allowable significant wave height for riser operations as a function of the spectral wave peak period. Two factors limit the allowable wave heights: Hook load capacity limit and max BOP displacement. The envelope shows the maximum allowable wave height as a function of wave period, considering the most critical of hook load capacity limit and BOP displacement limit.

Figure 2 shows the allowable significant wave height for riser operations as a function of the spectral wave peak period. The envelope shows the maximum allowable wave height as a function of wave period when a RRP according to the invention is installed. The allowable wave height between wave period 5 s and 7 s is significantly increased. As seen in the interval between 5 and 7 seconds it is possible to operate at much higher waves and still be below the 2 m heave range of the BOP and also below the max hook load limit.

Figure 3 is a detailed view of an embodiment of the invention. Figure 3 shows a RRP according to the invention arranged with a spider 7 on a floating platform or ship. A tubular, here shown as a riser string 13, is carried by the spider 7 and extends downwards into the water. The tubular may be a length of drill string or casing, and may for certain operations carry a piece of equipment, such as a BOP, for installation on the seafloor. The RRP is arranged as a part of a gimbal 14 to secure that the top of the riser string 13 is free to rotate about a horizontal axis. The gimbal 14 rests on the drill floor 2.

In this case the RRP is shown with a plurality of cylinders 11a and 11b connected to an accumulator 8. The cylinders 11a and 11b are pre-tensioned through a fluid pressure in accumulator 8 such that in the absence of a downwards force from the riser string 13, or with a force lower than the combined fluid force acting on the cylinder pistons (the “threshold force”), the cylinders will be in their mechanically limited end stroke positions (as shown in Figure 3) and the system will be rigid. This means that the top of the riser string 13 will follow the motion of the drill floor 2, i.e. the vessel. If the total downwards load force from the riser string 13 acting on the spider 7 exceeds the threshold force, the cylinders will be compressed.

Figure 4 illustrates the response of the RRP, shown as the displacement (or cylinder compression) distance u, to an increasing force F from the tubular. With a force applied to the device which is lower than the pre-compression, or threshold, force F_{th}, the device remains rigid, with the cylinders forced by the pre-compression pressure to the end stroke positions. When the force exceeds the threshold force, the device is compressed. (Here illustrated as a linear relationship between F and u, however this may not necessarily be the case.) The pressure in the accumulator can be regulated to change the threshold force, and thereby account for changes in the weight and length of the riser according to the relevant operational conditions.

This provides the advantage that when the riser load is below the threshold limit, the system is very stiff, and will be working as a conventional hard hang-off. When the riser load is above the threshold limit, the stiffness is reduced to a level such that it will alter the natural frequency of the system by in effect adding a spring element to the system dynamics. Thus, resonance can be prevented. Figures 5A-5C show an example of a detailed setup where the RRP comprises a plurality of cylinders and an accumulator 8. In this example, six cylinders 11 are connected to one accumulator 8, which accumulator 8 is partially filled with air and partially with oil (see Fig. 5A). The pressure in each cylinder 11 is set such that the force in the cylinders 11 combined give a threshold force that is 5 % above the maximum static load (i.e. the weight force) of the riser string 13 (with BOP connected). In this case the static load is 6700 kN, hence F_{th} is 7035 kN (6700 kN + 5%). Further details for this design example are: initial pressure 175 bar; piston diameter 292 mm; piston area 66966 mm^2; piston length 300 mm; accumulator diameter 1000 mm; oil height 200 mm; gas height 1000 mm; accumulator area 785398 mm^2; and accumulator volume 9425 l.

When the load from the riser string 13 on the spider 7 and gimbal 14 is below F_{th}, the RRP will be rigid. The spider and gimbal then act as they traditionally do; as a hard hang off. When the load from the riser string 13 is above F_{th}, the air in the accumulator 8 will be compressed and allow some movement of the riser string 13 in relation to the drill floor 2.

This effectively introduces a soft spring in the system (compared to the stiffness of the riser string alone) and makes the entire riser string 13 softer, increasing the natural period of the riser string from (in this case) 5.7 s to approximately 7 s. Thus, if the RRP is installed and activated at 7035 kN and the wave period is 5.7 seconds, the RRP will have changed the riser string natural period to 7 seconds and the system will not resonate. For other conditions, the RRP remains stiff, thus not affecting other operations. Advantageously, one thereby has the opportunity to “move” the resonance period of the riser string to a value different from the sea wave period.

The RRP could consist of a passive system with cylinders and an accumulator as described above, but is not limited by this as there may be other examples of passive systems. Other such systems may include a pre-tensioned Cellular buffer or a pre-tensioned spring, or any device with a non-linear stiffness which would produce a response similar to that shown in Figure 4.

In Figure 6, the dotted line shows a typical load variation on the drill floor from a riser string when its natural frequency coincides with the frequency of the heave motion of a drilling vessel, more specifically the load variation with and without a RRP. The continuous line shows the load variation with the RRP installed and activated. As is clear from the figure, the loads experienced at the drill floor (Y-axis) are significantly reduced when the RRP is installed and activated compared to when a RRP is not installed. When the frequency of the heave motion of the vessel starts to coincide with the natural frequency of the riser string, the amplitude increases for each wave. As above, the static load of the riser string is 6700 kN. The continuous line in the graph shows the load variation when the RRP is activated at a load 5 % above the static load, i.e. 6700 kN * 1.05 = 7035 kN. When the resonance-induced load reaches 7035 kN the RRP is activated and hence alters the natural frequency of the system preventing excessive resonance loads.

Figure 7 discloses additional embodiments of the invention, where several variants are shown. Figure 7 shows embodiments of the invention on a conventional drilling rig, with a derrick drilling machine (DDM) 1, drill floor 2, a crown block 3, a hoisting wire 4, a deadline drum 5, draw works 6, and a spider 7.

Locations RRP A- show possible applications of the device when the riser is hanging in a DDM, i.e. the RRP is arranged somewhere in the hoisting arrangement at locations RRP A1, RRP A2, RRP A3, RRP A4, or RRP A5, while location RRP B shows the riser string resting on the spider 7 / gimbal 14 at the drill floor 2 (as described above) or on a trolley. Location RRP A is here shown in five different possible positions, denoted RRP A1, RRP A2, RRP A3, RRP A4 and RRP A5, respectively. The RRP A arrangements can be used when the riser string 13 is connected to the DDM 1, while RRP B can be used when the riser is hung off at the drill floor 2. Figure 8 shows the latter arrangement, equivalent to that described above and shown in figures 3 and 5. Alternatively, the riser string 13 could in this same location of the RRP, i.e. RRP B, be resting on a trolley for trip saving. This is normally described as hard hang-off case. The riser string weight is going through the spider 7 in the RRP B and down on to the drill floor/trolley. This is the situation for example when the operation is waiting for a new riser to be connected to- or disconnected from the string. This could also be the situation when the operation needs a break due to harsh weather condition or for trip saving operations.

Figure 9 is a detailed view of an embodiment of the positioning RRP A1 according to the invention, arranged under the crown block 3 at the top of the derrick. In this example, preloaded cylinders 11a and 11b with accumulators 8 are used in the RRP. The cylinders 11a and 11b are preloaded to the threshold force such that the crown block 3 is lifted to the max cylinder extension upwards along the guide rails 9. In the static state, the compensator cylinders 11a and 11b will translate the entire hook load through the RRP. When the hook load exceeds the threshold force, the RRP will permit the crown block with DDM and riser string to move downwards with a necessary stiffness to alter the frequency of the riser string and modify its natural frequency period, and will be lifted upwards again some seconds later when the rig movement is giving less riser load.

Figure 10 illustrates a further embodiment where RRP A2 is used. In this example the RRP is mounted below the DDM 1 which is suspended in a DDM dolly 17, connected through elevator 15 and elevator links 16. In this example the RRP is exemplified with a preloaded spring. The RRP will remain fully extended until the riser load reaches the threshold force. When the load passes the threshold limit the riser load will start compressing the spring to a smaller extension such that it behaves, and give the same effect, as the cylinder and accumulator system described above. In the embodiment shown in Figure 10, the riser string 13 is hanging in the DDM 1 during hoisting and/or lowering. This can be used in a situation when one riser section is removed from- or a new section is added to the riser string. During this hoisting and lowering period, the RRP in position A2 prevents excessive loads on the hoisting system in case the riser string to come into natural frequency.

The threshold force and the pre-tension pressure can be varied according to the system design and operating conditions. This variation can be carried out based on the static load (i.e. the riser weight), external conditions (e.g. weather conditions), the specific design and type of riser or tubular used, or according to any load (e.g. a BOP unit) carried by the riser. For example, in the design example shown in figures 5A-5C it was found advantageous to adjust the pre-tension pressure such that when the wave period is below 6 seconds, the pressure is set such that F_{th} is 5% above the max static load and if the wave period is above 6 seconds, the pressure in the accumulator is set such that F_{th} is 30 % above of the static load.

This pressure setting can easily be regulated using known techniques. The wave period is also easy to measure using for instance a MRU (Motion Reference Unit). A simple dynamic simulation of the response of the riser to varying vessel heave motions or frequencies may assist in determining suitable settings for the threshold force.

The invention has been described in non-limiting embodiments. It is clear that the person skilled in the art may make a number of alterations and modifications to the described embodiments without diverging from the scope of the invention as defined in the attached claims.

Claims

1. Resonance prevention device for a tubular (13) suspended from a floating vessel,

   the device comprising a first element (7) adapted to carry the tubular (13) and a second element (14) adapted to be supported by the floating vessel, the first element (7) being connected with and carried by the second element (14) via at least one compression element (11),
   characterized in that
   the at least one compression element (11) is pre-tensioned in an end stroke position such that when subjected to a force from the tubular which is below a pre-defined threshold force, the at least one compression element (11) forms a rigid connection between the first element (7) and the second element (14), and when subject to a force higher than the threshold force the at least one compression element (11) forms a compressible connection between the first element (7) and the second element (14).

2. A resonance prevention device as defined in Claim 1, wherein the at least one compression element (11) comprises at least one cylinder (11a,11b) coupled to an accumulator (8).

3. A resonance prevention device as defined in Claim 2, whereby the pressure in the accumulator (8) is variable in order to adjust the pre-determined threshold force.

4. A resonance prevention device as defined in Claim 1-3, whereby the second element (14) is supported by a drill floor (2) of the floating vessel.

5. A resonance prevention device as defined in Claim 1-3, whereby the second element (14) is supported by a derrick drilling machine (1) on the floating vessel.

6. A resonance prevention device as defined in Claim 1-3, whereby the second element (14) is supported by a crown block (3) on the floating vessel.

7. A resonance prevention device as defined in any preceding claim, whereby the pre-defined threshold force is set at a value between 5% and 30% above the static weight force of the tubular (13).

8. A resonance prevention device as defined in any preceding claim, whereby the pre-defined threshold force is set at a value between 5% and 10% above the static weight force of the tubular (13).

9. A resonance prevention device as defined in any preceding claim, whereby the pre-defined threshold force is set based on at least one of the factors: (i) a weight of the tubular (13), (ii) a length of the tubular (13), (iii) a weight of a load suspended by the tubular (13), and (iv) a wave period for waves acting on the floating vessel.

10. Hoisting arrangement in a derrick on a floating offshore unit, the hoisting arrangement suspending a tubular (13) supporting a load, wherein the hoisting arrangement comprises cables, draw works (6), a drilling machine (1) and a travelling block (12), **characterized in that** at least one resonance prevention device according to any preceding claim is arranged along the hoisting arrangement, the at least one resonance prevention device being adapted to prevent resonance in the tubular (13), thereby minimizing the load in the tubular (13) and supporting structure.

11. An arrangement on a drill floor (2) on a floating unit, the arrangement suspending a tubular (13) supporting a heavy load, **characterized in that** the arrangement comprises at least one resonance prevention device according to any preceding claim, the at least one resonance prevention device being adapted to prevent resonance in the tubular (13), thereby minimizing the load in the tubular (13) and supporting structure.

Patentkrav

1. Resonanshindringsinnretning for et rør (13) som henger fra et flytende fartøy,

   der innretningen omfatter et første element (7) tilpasset til å bære røret (13) og et andre element (14) tilpasset til å støttes av det flytende fartøyet, der det første element (7) er forbundet med og bæres av det andre elementet (14) via minst to kompresjonselementer (11),

   karakterisert ved at

   det minst ene kompresjonselementet (11) er forspent i en endeslagposisjon, slik at når det utsettes for en kraft fra røret som er under en forhåndsdefinert terskelkraft, danner det minst ene kompresjonselementet (11) en stiv forbindelse mellom det første elementet (7) og det andre elementet (14), og når det utsettes for en kraft som er høyere enn terskelkraften danner det minst ene kompresjonselementet (11) en komprimerbar forbindelse mellom det første elementet (7) og det andre elementet (14).

2. Resonanshindringsinnretning som definert i krav 1, hvori det minst ene kompresjonselementet (11) omfatter minst én sylinder (11a, 11b) koblet til en akkumulator (8).

3. Resonanshindringsinnretning som definert i 2, hvorved trykket i akkumulatoren (8) er variabelt for å justere den forhåndsbestemte terskelkraften.

4. Resonanshindringsinnretning som definert i krav 1-3, hvorved det andre elementet (14) støttes av et boregulv (2) til det flytende fartøyet.

5. Resonanshindringsinnretning som definert i krav 1-3, hvorved det andre elementet (14) støttes av en boretårnboremaskin (1) på det flytende fartøyet.

6. Resonanshindringsinnretning som definert i krav 1-3, hvorved det andre elementet (14) støttes av en kronblokk (3) på det flytende fartøyet.

7. Resonanshindringsinnretning som definert i et hvilket som helst foregående krav, hvorved den forhåndsbestemte terskelkraften settes til en verdi på mellom 5 % og 30 % over rørets (13) statiske vektkraft.

8. Resonanshindringsinnretning som definert i et hvilket som helst foregående krav, hvorved den forhåndsbestemte terskelkraften settes til en verdi mellom 5 % og 10 % over rørets (13) statiske vektkraft.

9. Resonanshindringsinnretning som definert i et hvilket som helst foregående krav, hvorved den forhåndsbestemte terskelkraften fastsettes basert på minst én av faktorene: (i) en vekt til røret (13), (ii) en lengde til røret (13), (iii) en vekt til en last hengt opp av røret (13) og (iv) en bølgeperiode for bølger som virker på det flytende fartøyet.

10. Heiseanordning i et boretårn på en flytende offshore enhet, der heiseanordningen henger opp et rør (13) som støtter en last, hvori heiseanordningen omfatter kabler, trekkeblokker (6), en boremaskin (1) og en løpeblokk (12), **karakterisert ved at** minst én resonanshindringsinnretning ifølge et hvilket som helst foregående krav er anordnet langs heiseinnretningen, der den minst ene resonanshindringsinnretningen er tilpasset til å hindre resonans i røret (13) og derved minimere belastningen i røret (13) å støtte strukturen.

11. Anordning på et boregulv (2) på en flytende enhet, der anordningen henger opp et rør (13) som støtter en tung last, **karakterisert ved at** anordningen omfatter minst én resonanshindringsinnretning ifølge et hvilket som helst foregående krav, der den minst ene resonanshindringsinnretningen er tilpasset til å hindre resonans i røret (13) og derved minimere belastningen i røret (13) og støtte strukturen.

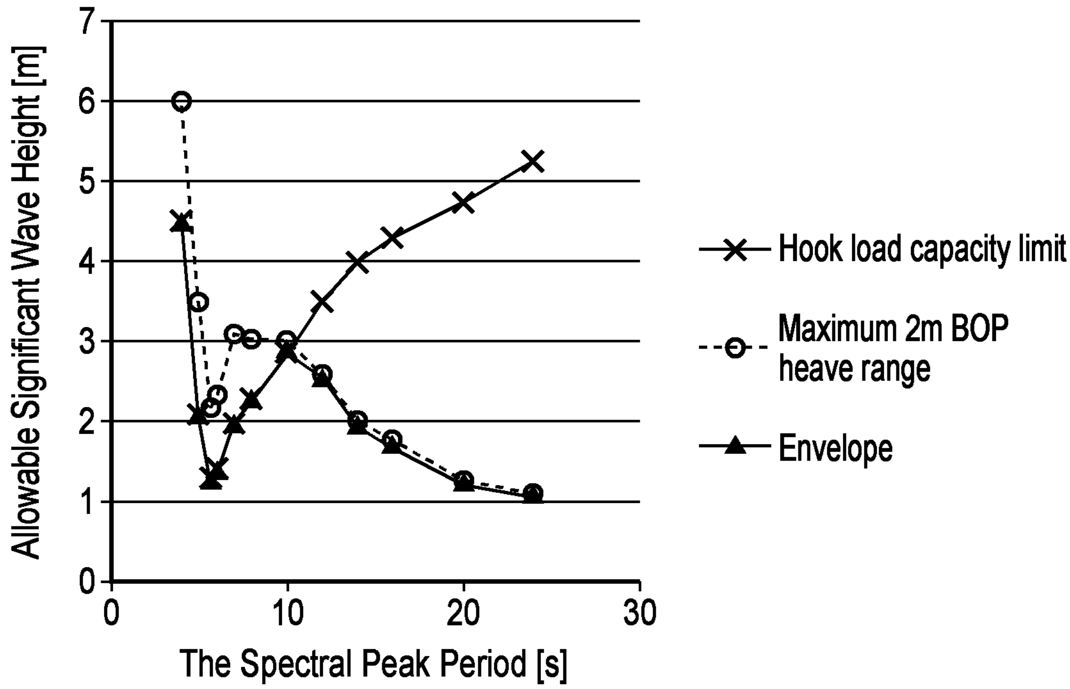

Allowable Significant Wave Height [m]
0
1
2
3
4
5
6
7
0
10
20
30
The Spectral Peak Period [s]
Hook load capacity limit
Maximum 2m BOP heave range
Envelope

FIG. 1

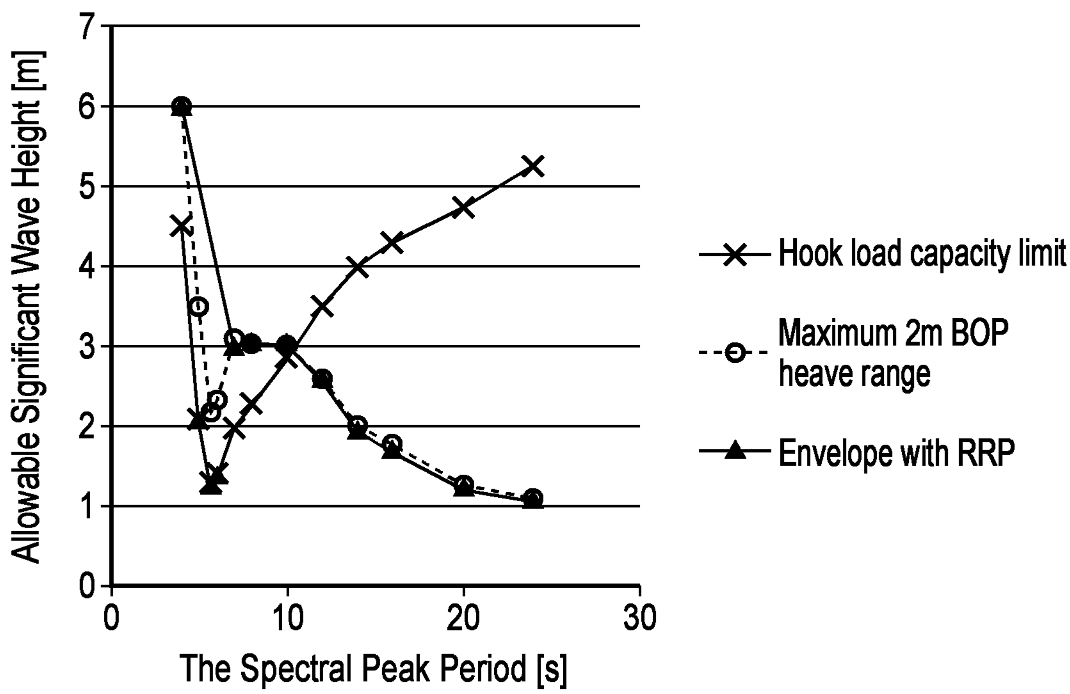

Allowable Significant Wave Height [m]
0
1
2
3
4
5
6
7
0
10
20
30
The Spectral Peak Period [s]
Hook load capacity limit
Maximum 2m BOP heave range
Envelope with RRP

FIG. 2

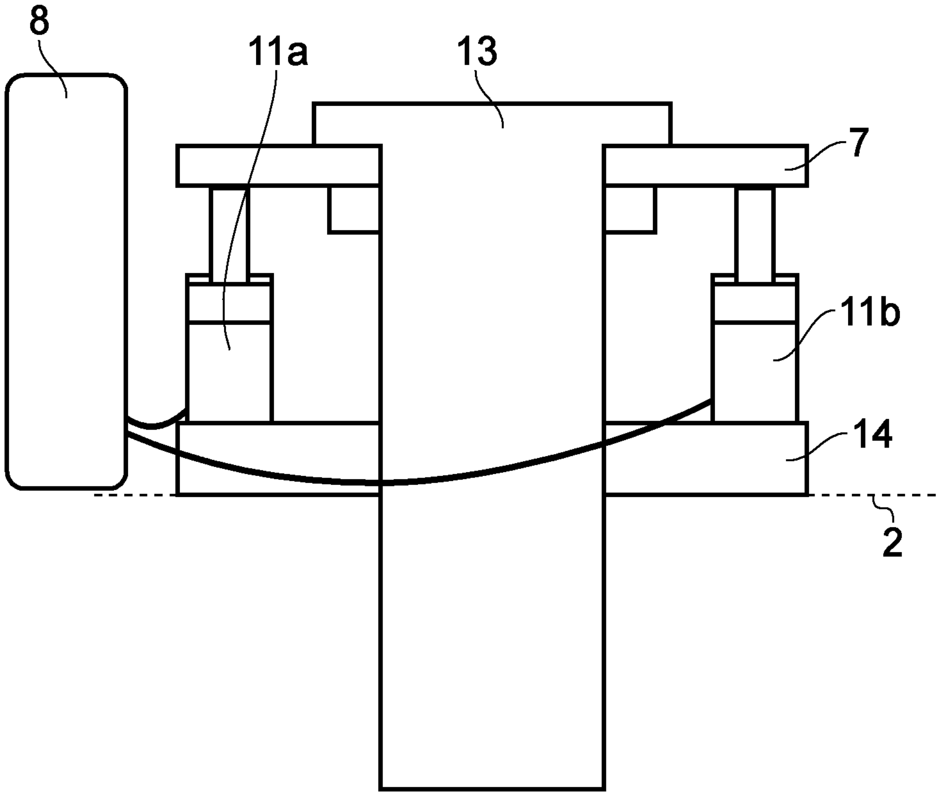


FIG. 3

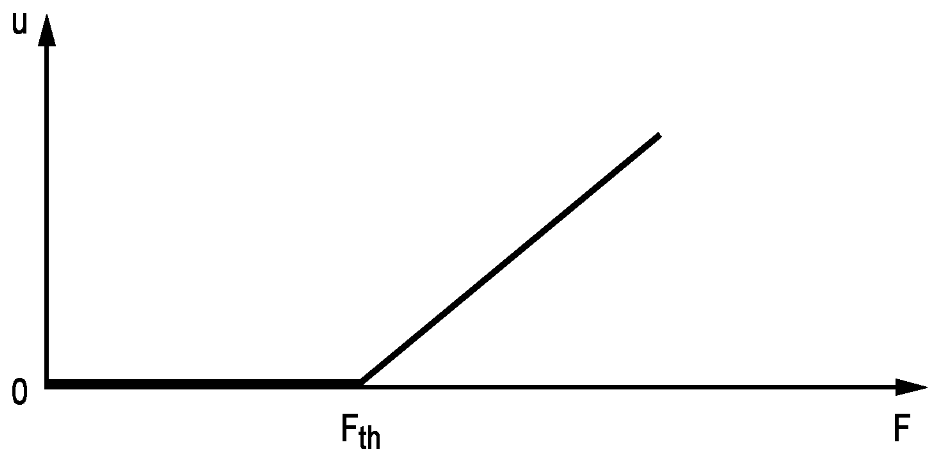


FIG. 4

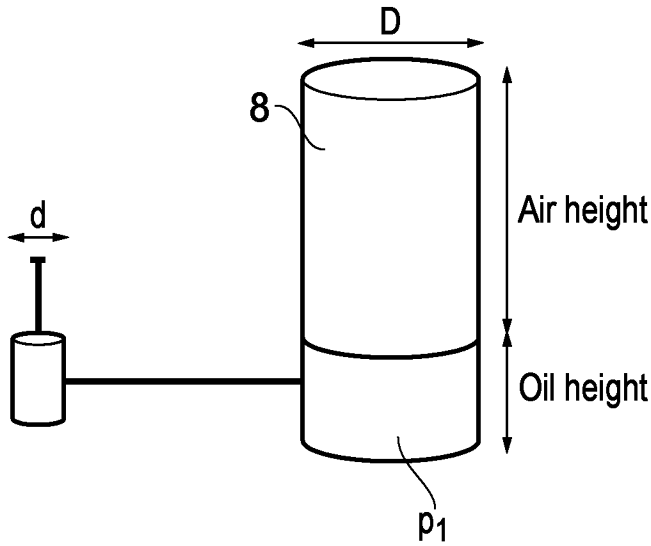


FIG. 5A

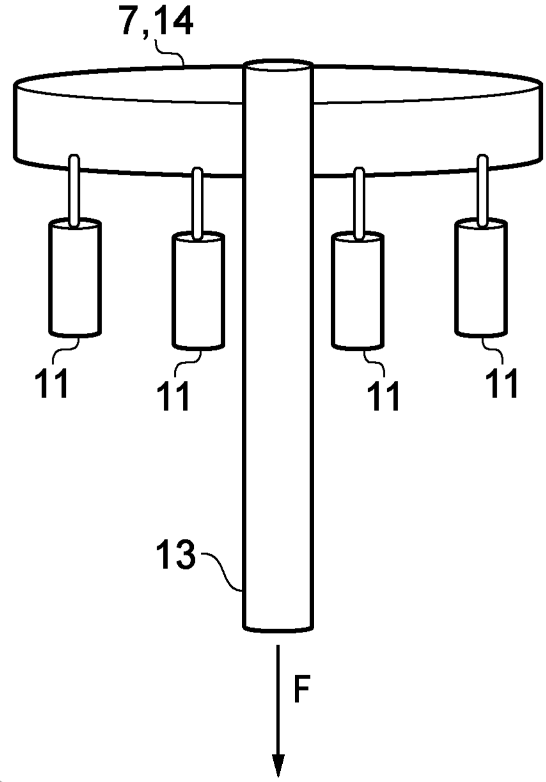


FIG. 5C

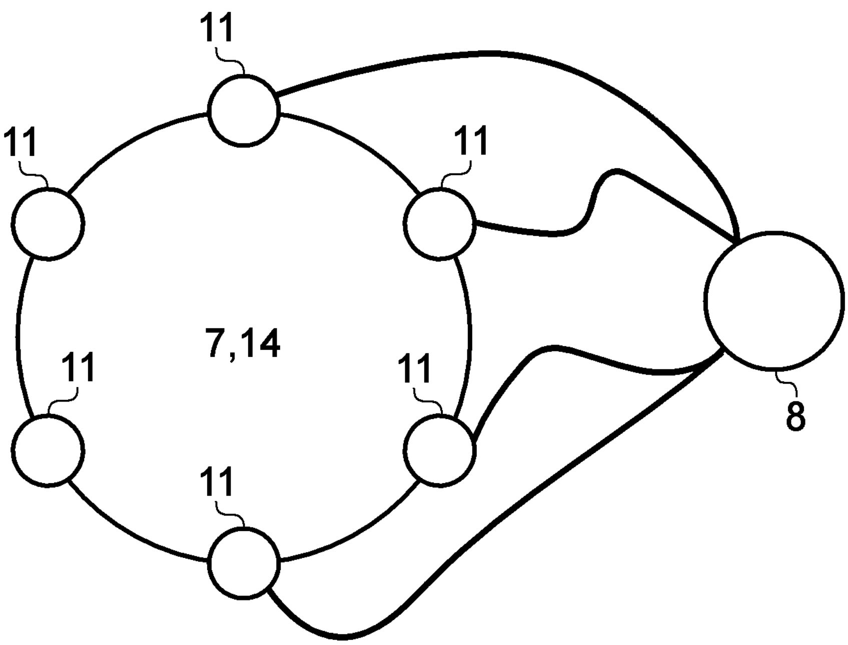


FIG. 5B

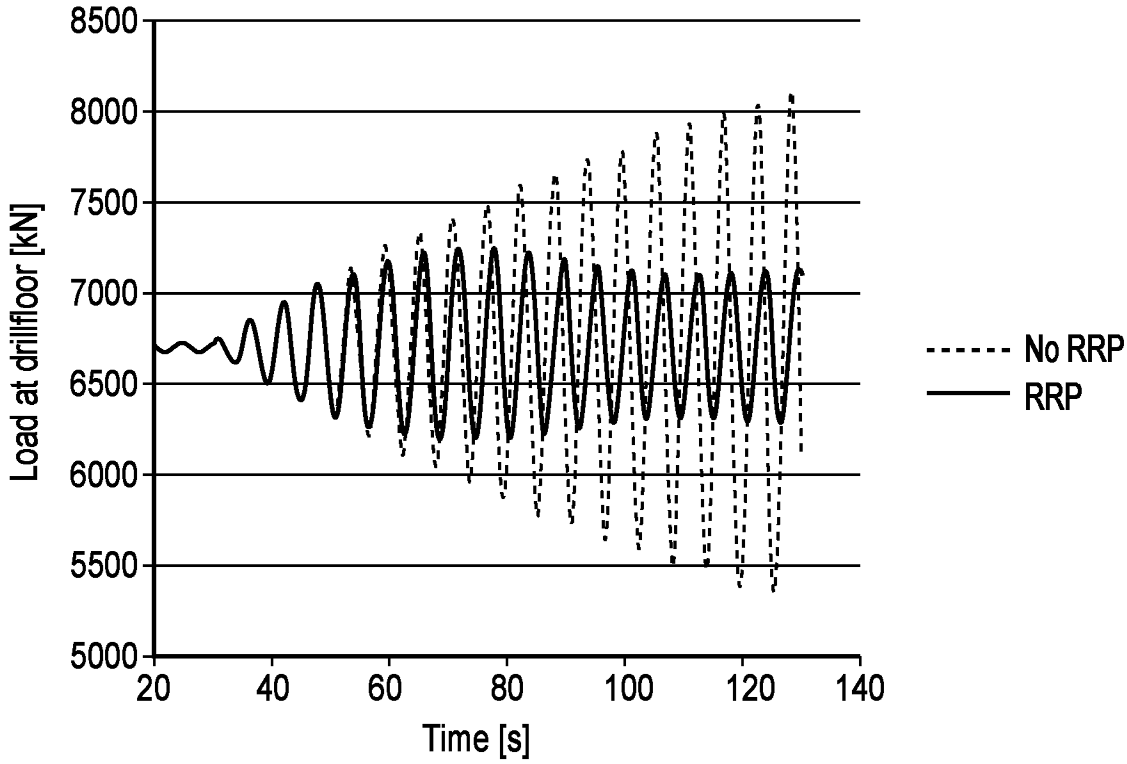

8500
8000
7500
7000
6500
6000
5500
5000
Load at drillfloor [kN]
20
40
60
80
100
120
140
Time [s]
No RRP
RRP

FIG. 6

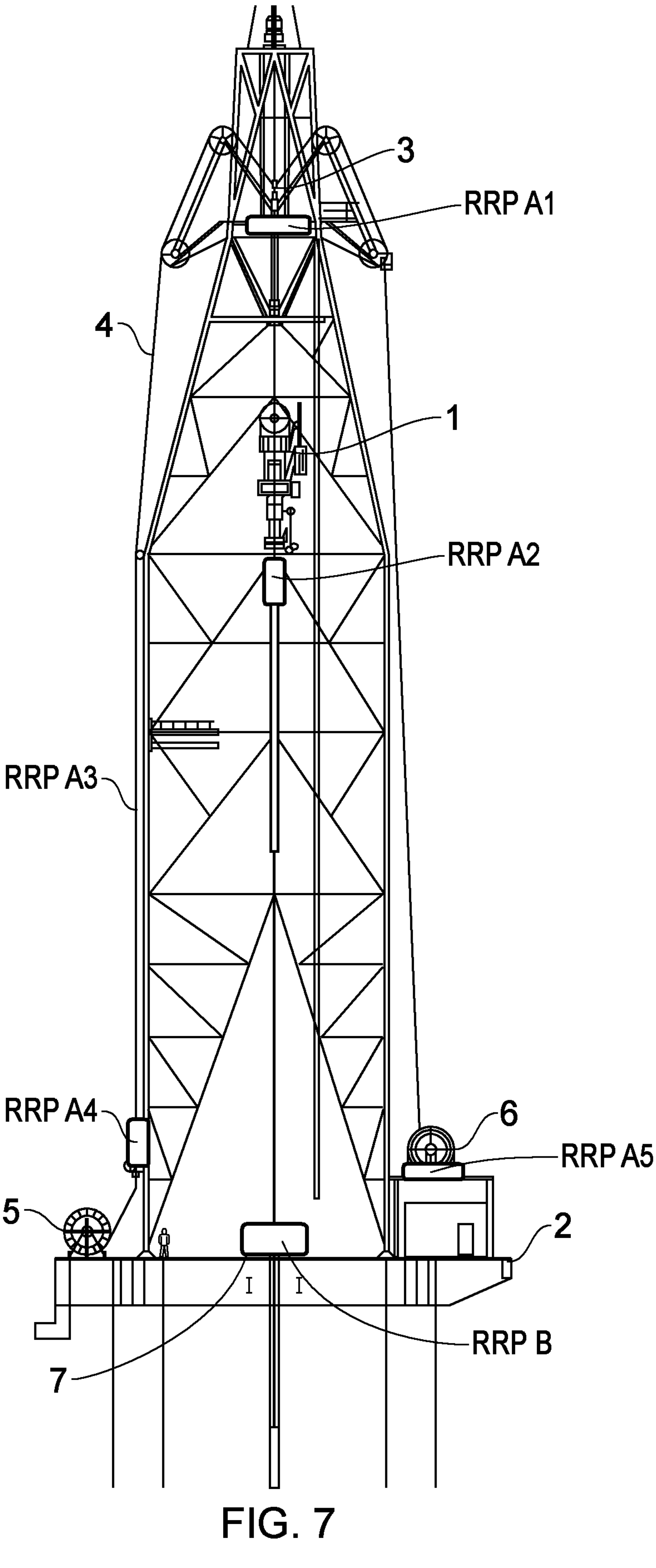


FIG. 7

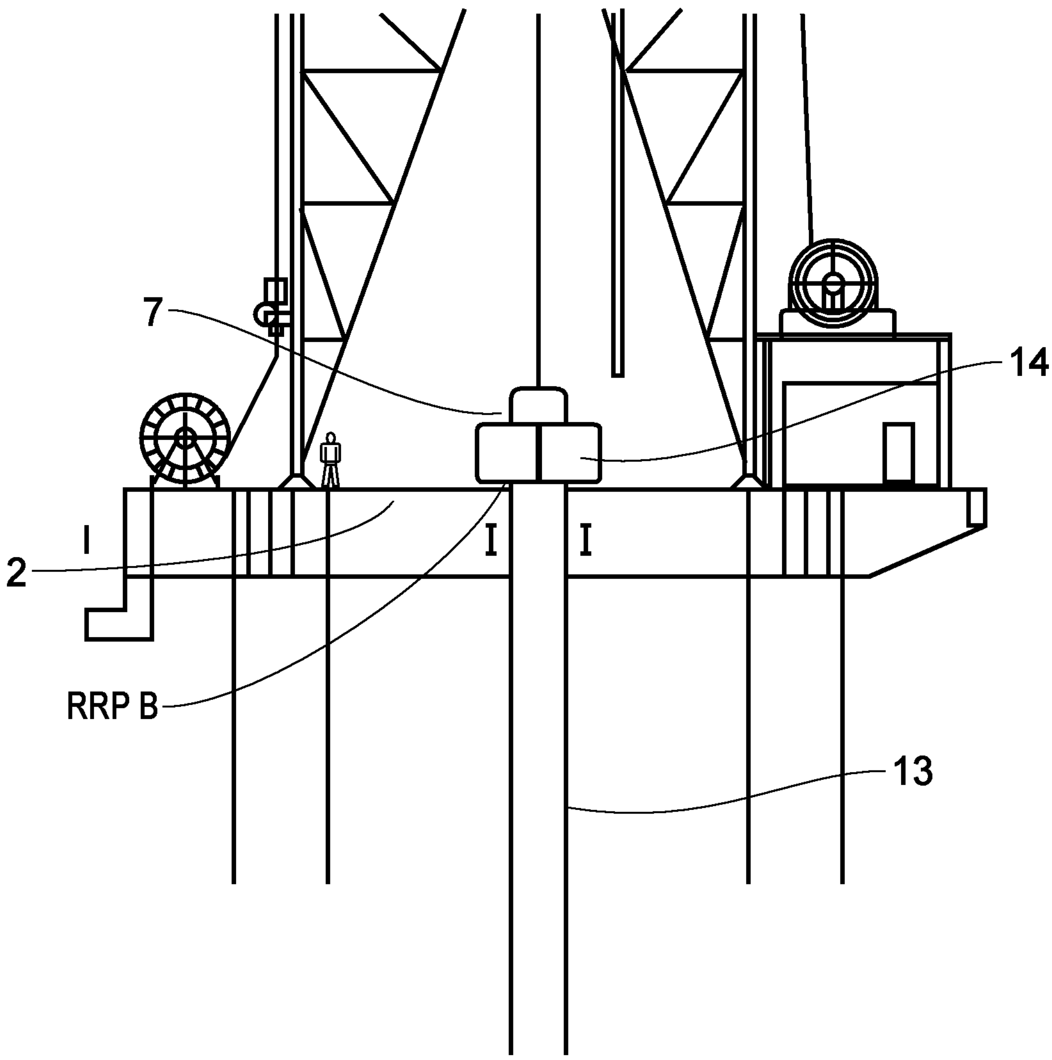


FIG. 8

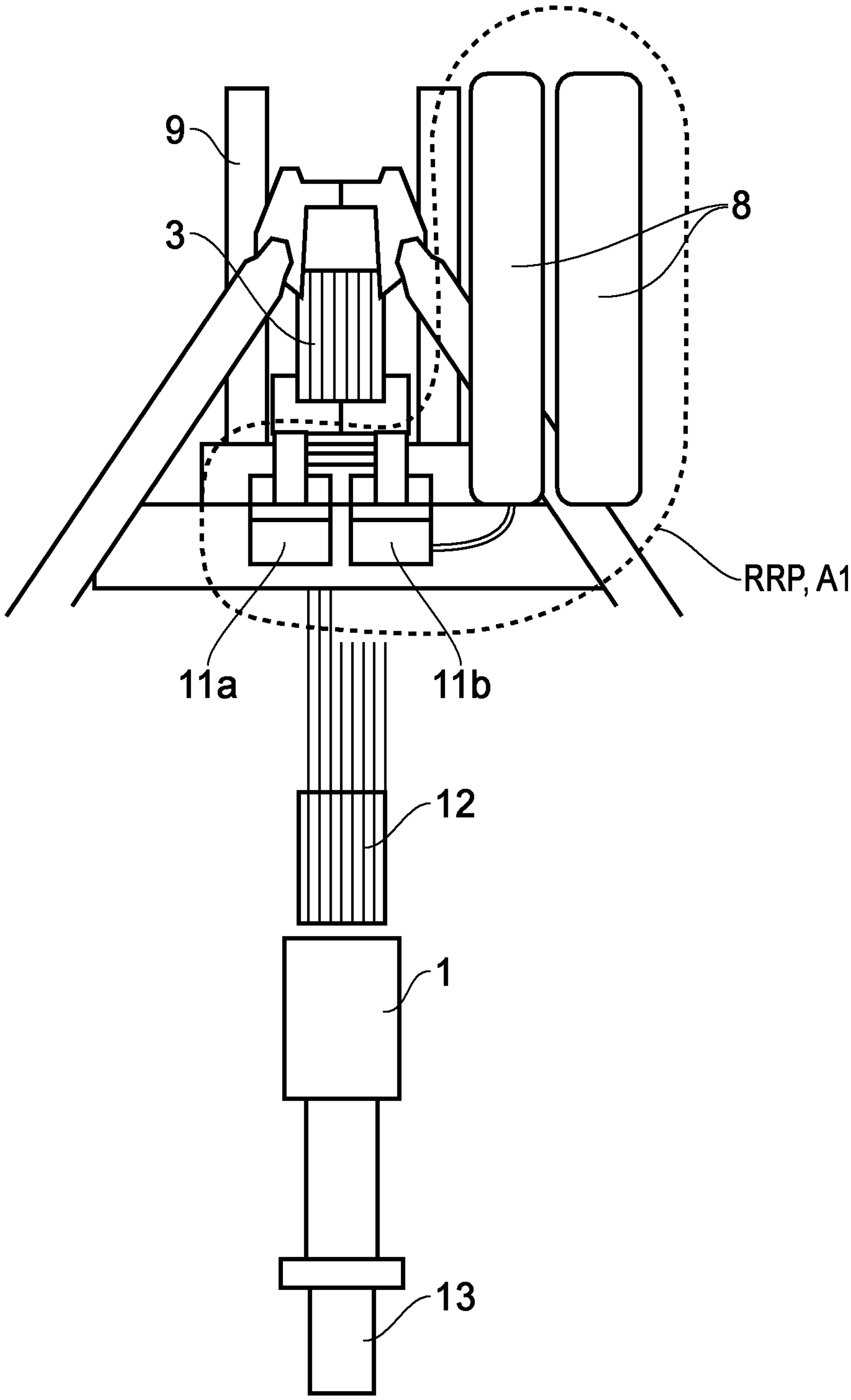


FIG. 9

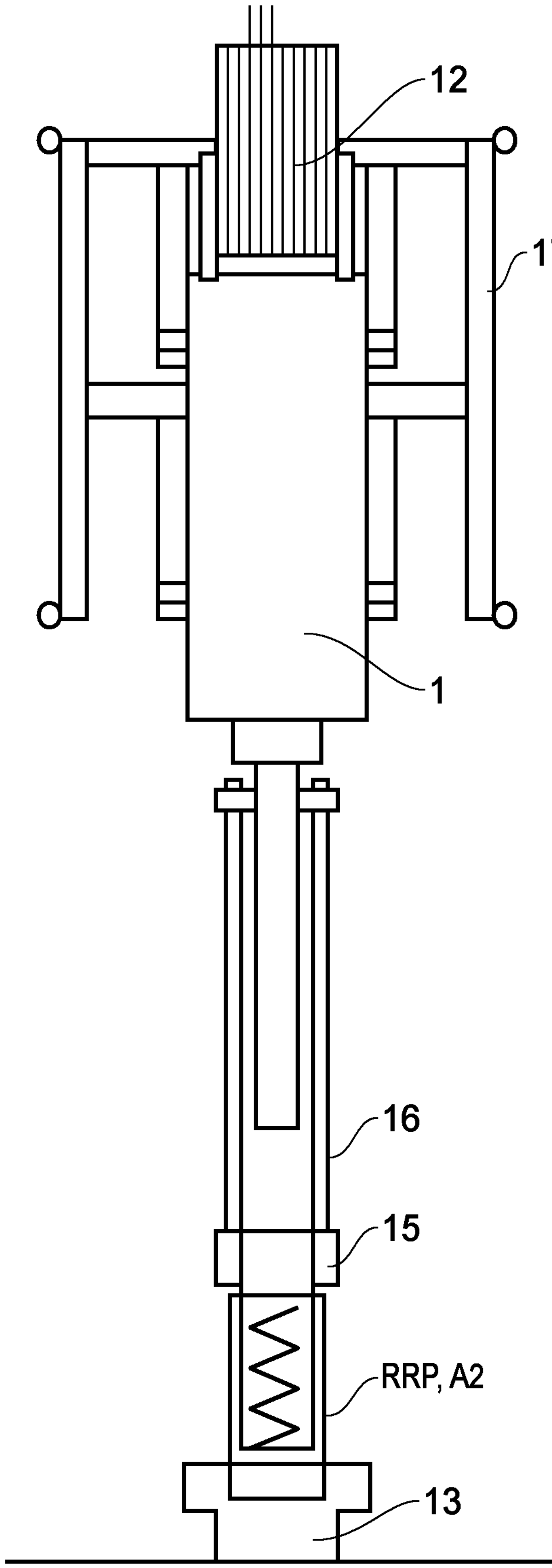


FIG. 10