

A method and a system for controlling movements of a free-hanging tubular

Field of the invention

5 The invention concerns a method, an apparatus, and a system for controlling movements of a free-hanging tubular suspended via a connector element by at least one compensator member which is connected to a buoyant vessel. The invention is particularly suitable for controlling riser movements during a soft hangoff procedure.

10 Background of the invention

As subsea oil and gas fields at great water depths are being developed, the facilities used in drilling and production of hydrocarbons will increasingly be floating structures such as drilling ships, semi-submersible platforms and drilling rigs, etc. These floating structures move under the influence of waves, winds and currents. This means that the pipes which
15 link the floating structure with the subsea wells must be sufficiently flexible and strong to be able to move with the platform on the surface. As the movements and wave forces are greatest at the surface, the pipe is also exposed to the greatest bending stresses in this area.

20 The riser is a key component when drilling in deep waters, and a major concern for the drilling operator is the ability to efficiently run and retrieve the riser, and to operate it safely in deep and ultra-deep waters (e.g. 1000 - 3000 metres). Severe weather conditions often develop rapidly, leaving only little time to secure and pull the riser.

25 Whenever a floating drilling unit experiences severe weather, it must at some point disconnect the riser from the seabed and suspend the riser from the floating rig. The disconnection from the seabed is normally done because the rig's vertical heave motion is too large for the tensioner system stroke capacity or because of the excessive load variations this would cause on the wellhead or the riser.

30 In the traditional "hard hangoff" procedure, the riser (disconnected from the seabed) is suspended from the rig, while the telescopic joint between the riser and the rig has been collapsed and locked, and the tensioners released. Thus, in a hard hangoff, vessel (rig) motions are transferred directly to the riser and may induce severe loads. The hard hangoff procedure is not applicable for deeper waters, as the riser length becomes considerable (e.g. 1000 metres or more) and the riser is subjected to
35 high compressive loads which may cause buckling.

5 In a “soft hangoff” procedure – which particularly applicable for deep waters – the tensioners and telescopic joint remain active with the tensioners supporting the free-hanging riser weight from the telescopic joint. The telescopic joint and tensioners absorb vertical rig movements, significantly reducing load variations on the riser system.

10 The result of a riser-seabed disconnect is normally to have the tensioner cylinders at a fully extended or retracted position (retracted for a direct acting tensioner, extended for a wire-line tensioner) At this point the riser, supported by the tensioner system, will have to move together with the rig as the tensioner cylinders are in an endstroke position. The riser will have a fairly large mass, with buoyancy elements. This means that it will not have the ability to fall down in the water as quickly as the rig does. This phenomenon is more applicable as the water depths and riser lengths increase. When the rig heaves downwards with the sea, the riser mass will have to be pushed down in the sea with the result of shallow water buckling of the riser.

15 In a typical soft hangoff procedure, the tensioner cylinders are normally stroked to a mid-stroke position and the free-hanging riser is allowed to be supported by the tensioners in a passive and somewhat uncontrolled manner. The riser has a large mass/wet weight ratio and can easily buckle when subjected by the large compression loads caused by the riser upper end having to follow the rig motion. Thus, a major concern during a soft hangoff procedure is to avoid overloading the riser caused by large downwards acceleration that could buckle the upper section of it. Another concern is to prevent the tensioner cylinders from hitting endstroke.

20 The present applicant has devised and embodied this invention to overcome these shortcomings and to obtain further advantages.

Summary of the invention

The invention is set forth and characterised in the main claim, while the dependent claims describe other characteristics of the invention.

30 It is therefore provided 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, said tubular extending into a body of water below the vessel, characterised by first sensing means for sensing dynamic and/or spatial parameters of the compensator member and thus that of the vessel;
35 second sensing means for sensing dynamic and/or spatial parameters of the connector element, and thus that of an upper region of the tubular; data processing means for processing data supplied by said first and second sensing means and

determining one or more parameters regarding the movement between the vessel and the upper region of the tubular; and adjusting means for controlling at least the stiffness and dampening of the compensator member; whereby the axial loads which are transferred between the compensator and the tubular may be controlled.

- 5 In one embodiment, the first sensing means comprises motion sensing means for sensing movements of the compensator member and thus that of the vessel. In one embodiment, the second sensing means comprises position indicator means for sensing the position of the connector element, and thus that of an upper region of the tubular, with respect to the compensator member.
- 10 In one embodiment, the one or more parameters regarding the movement between the vessel and the upper region of the tubular comprises acceleration.

The compensator member preferably comprises a hydraulic cylinder connected via a first fluid line to an accumulator, and a first valve means for controlling the flow in said first fluid line, and a first pressure sensing means for sensing the pressure of
15 said hydraulic fluid. Preferably, at least one pressure vessel is fluidly connected to the accumulator via a second fluid line and regulator means, and further comprising a second pressure sensing means, whereby the pressure exerted on the hydraulic fluid in the accumulator by a pressurised gas in the pressure vessel may be controlled.

- 20 In one embodiment, a heat exchanger, with a cooling circuit, is thermally connected to the first fluid line, whereby hydraulic fluid in the first fluid line may be cooled in heat exchange with a cooling fluid.

It is also provided a system for controlling movements of a free-hanging tubular, wherein a plurality of apparatuses according to the invention are connected to the
25 tubular via respective compensator members arranged in a symmetrical pattern around the tubular, and further comprising a common data processing means and a common user interface, whereby the movements of the free-hanging tubular may be controlled by a selective manipulation of the individual apparatuses.

- It is also provided a method of controlling movements of a free-hanging tubular
30 suspended via a connector element by at least one compensator member which is connected to a buoyant vessel, said tubular extending into a body of water below the vessel, characterised by collecting motion data for the vessel; collecting motion data for the upper region of the tubular with respect to the compensator member; processing said motion data for the vessel and said motion data for the upper region
35 of the tubular and determining one or more parameters regarding the movement between the vessel and the upper region of the tubular and, based on such data, controlling at least the stiffness and dampening of the compensator member;

whereby the axial loads which are transferred between the compensator and the tubular may be controlled.

In one embodiment, the collecting of motion data for the vessel comprises sensing movements of the vessel. In one embodiment, the collecting motion data for the upper region of the tubular comprises sensing the position of an upper part of the tubular with respect to the compensator member.

In one embodiment, the method further comprises the sensing of a first pressure in a hydraulic cylinder connected between the tubular and the vessel, said hydraulic cylinder being connected via a first fluid line to an accumulator, and the sensing of a second pressure in the accumulator exerted by at least one pressure vessel fluidly connected to the accumulator via a second fluid line and regulator means.

The reduction of air volume is a trade-off with the functioning of a soft hangoff function. For the best possible soft hangoff function, the air volume should be infinite. With an infinite air volume and frictionless tensioner system the riser would in theory be standing still in the water. If the system is not tuned correctly, the result may be a rig and riser in opposing motion. The result of this would be that the tensioner cylinders are using a lot of their stroke capacity. If the relative motion between the riser and the rig is too large the cylinders will hit endstroke for each wave top and bottom. If the air volume is reduced, the riser motion will increase. This is not favourable for the riser as a high vertical acceleration may lead to buckling in the upper part of the riser.

By setting up the system correctly with the possibilities given by the tensioner system, it will synchronise the rig and riser movements and create a dampening effect to the riser. This is done by finding the correct combination of:

- Air pressure;
- Air volume;
- Choking of oil flow to create a dampening effect. This can be done as a fixed choking or it may be varied over time based on known parameters, such as:
 - Variations in system pressure
 - Cylinder position
 - Cylinder speed
 - Accelerations
 - Or other parameters based on measured data

The control system may be set up to self adjust or it can be a fixed solution for all combinations of heave and riser configurations.

With the invention, it is possible to monitor and control the movements of a free-hanging riser, with respect to a moving rig. The motion of the riser may be accurately measured,

and it is no longer necessary to rely on merely visual observations, from a moving (heaving and rolling) platform, of the riser top movements.

With the compensator system and method according to the invention, the compensator cylinders may be kept at mid-stroke position as a flexible element
5 between the rig and the riser, whereby riser motion is substantially reduced and riser buckling is prevented.

Brief description of the drawings

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

Figure 1 is a schematic illustration of a free-hanging riser suspended from a floating rig via compensators;

Figure 2 is a schematic illustration of a number of compensation systems
15 according to the invention, connected to a riser via a tensioner ring;

Figure 3 is a block diagram illustrating the compensation system and method of the invention;

Figure 4 is an illustration of a direct acting tensioning system, with which the invention may be carried out; and

20 Figure 5 is a schematic illustration of a wireline tensioning system, with which the invention may be carried out.

Detailed description of a preferential embodiment

Figure 1 shows a drilling rig 2, floating in water and generally being subjected to water waves W, water currents and wind loads. A free-hanging riser 4 is suspended
25 by the rig 2 via compensators 7. In the illustrated embodiment, riser tensioners are used as compensators. A telescopic joint 5 allows relative movement between the riser and the rig. The movements (e.g. heave) of the rig is illustrated by the double arrow denoted H, while the riser dynamics is illustrated by a double arrow denoted R. Figure 1 thus illustrates a soft hangoff mode for the riser.
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The compensation apparatus 1 which controls the stiffness and response of each respective compensator 7 will now be described with reference to figure 3.

The compensator 7 comprises a housing which is connected to the rig 2, and a piston 24a with a piston rod 24b which is connected to the riser 4 (schematically illustrated), as with a conventional tensioner cylinder. An accumulator 26 supplies hydraulic fluid 14 to the compensator 7 via a hydraulic line 35, controlled via a valve 25, which preferably is a proportionally controlled shut-off valve. Pressure in the hydraulic system is monitored by a first pressure transmitter 27.

A gas (normally air) is fed into the accumulator 26 via supply lines 31 which are connected to pressure vessels 33a-d. In figure 3, a total of four pressure vessels, controlled via respective valves 29, feed pressurised air into the accumulator 26. Pressure in the gas (air) system is monitored by a second pressure transmitter 28. Additional air may be fed into the system from a reservoir 32, and surplus air may be vented off via the valve-controlled air outlet 30, as and when required. The pressure in the vessels 33a-d is normally and ideally constant, but addition or depletion of air may be necessitated because of e.g. temperature variations in the air system.

The compensation apparatus 1 further comprises a Motion Reference Unit (MRU) 36 which is connected to the compensator housing and thus senses the movement of the compensator 7. The MRU may comprise an accelerometer or an inertial system, which per se is known in the art. A position indicator 21, which is mounted on the rig, monitors the movement of the compensator cylinder rod 24b (and hence the riser top). The position indicator 21 may be an optical indicator, an electromagnetic sensing device, or any other position indicator which is known in the art.

The compensation apparatus 1 further comprises a central processing unit (CPU) 22 which collects and processes data and controls the system. Data lines between the CPU 22 and the various components are indicated by dotted lines in figure 3. Control input data to the CPU is provided via a user interface 37 (a terminal or similar), and pertinent data (e.g. rig and riser dynamics) may also be presented via the user interface.

In operation, rig motions are calculated by the CPU 22, based on e.g. position data from the position indicator 21 and motion data from the MRU 36. The acceleration is calculated by the CPU based on data from the MRU that basically indicates the motion of the cylinder tube plus or minus the motion measured by the position indicator 21. By adding these two motions together, the motion at the top of the riser is calculated.

The user interface 37 may display e.g. acceleration of the riser top and the maximum/minimum stroke of the compensator cylinder 24b.

By using the collected data, the CPU may (by itself, or assisted by input via the user interface) provide control signals to the system (e.g. valves 25, 29) and thereby

adjust parameters to achieve the best possible result/combination of acceleration and stroke within the limitations given by the rig motion. Examples of controllable system parameters are pressure, stiffness, and dampening.

- 5 The compensation apparatus pressure should be adjusted to the wet weight of the riser. The weight of the system is measured by the first pressure transmitter 27 (closest to the cylinder in the piping system) The pressure sensed by the first pressure transmitter 27 will, in combination with the measured rod position and system stiffness, be used to set the system pressure, i.e. by controlling the pressure vessels. As the compensation cylinder is constant motion, it may take some time and iterations for the CPU to find the balance. As described above, the system pressure is adjusted by venting off air, if pressure is to be reduced, or adding air into the system by opening from the standby pressure vessel 32 if air is to be added. System pressure may also have to be adjusted over time due to temperature changes in the gas.
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- 15 The compensation apparatus stiffness can be adjusted by controlling the number of open pressure vessels 33a-d, i.e. by controlling the air volume of the system. If it is desired to increase the compensator stiffness (i.e. the spring constant), the number of open pressure vessels is reduced, ultimately reducing the amount of stroke on the compensator cylinder. Another consequence of increasing the stiffness is that the overall riser motion will increase. This means that the outer boundaries for selecting the number of pressure vessels to be open, is in one end cylinder movement and the other end riser acceleration. Each pressure vessel is equipped with an isolation valve 29 and can only have the function of fully open or fully closed.
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- 25 The compensation apparatus stiffness can be adjusted by selecting the number of open air pressure vessels per cylinder 7. This can be done in increments of 1, from no (zero) bottles open to all (four) bottles open. With all bottles open the system is soft and the riser will move less relative to the rig, but this could cause the cylinders to bottom out of stroke if the weather is too severe. With fewer bottles open, the stiffness increases and the riser will follow the rig movements more.
- 30 Referring now to figures 2, 4 and 5, the dynamics of a riser is preferably compensated by a compensator system, comprising a plurality of compensation apparatuses 1 as described above. Figure 2 schematically illustrates one such compensator system, where six compensator apparatuses 1 with respective compensator cylinders 7 are arranged around the riser in a symmetrical pattern, all being connected to a riser tensioner ring 8 which supports the riser 4. The mechanical and hydraulic systems for each compensator cylinder 7 are as described above, but are preferably controlled by a common CPU 22' and a common user interface 37'. The dotted lines in figure 2 indicate data transmission lines. In such system, the number of pressure vessels 33 within each apparatus 1 may vary. For
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example, in the configuration where one compensator 7 is controlled by four pressure vessels 33a-d (figure 3), the stiffness and dampening may be controlled in increments of 1/4. With the configuration illustrated in figure 2, increments of 1/24 are possible if each apparatus 1 comprises four pressure vessels. The compensators
5 in the different compensator apparatuses may be controlled independently of one another. In practical operations, however, the compensators are operated with a certain symmetry about the riser axis.

Figure 4 is an illustration of a direct acting tensioner system, with which the invention may be utilised. A number of tensioner cylinders, which in the system
10 according to the invention function as compensator cylinders 7 are suspended from a frame 23 which is supported by the drill floor 9. Each cylinder rod 24b free end is connected to a tensioner ring 8 which in turn is connected to the riser 4. Each compensator cylinder 7 is connected to a system of pressure vessels 33 and other components as described above with reference to figure 3.

Figure 5 is an illustration of a wireline tensioning system, with which the invention may be utilised. A number of tensioner cylinders, which in the system according to the invention function as compensator cylinders 7 are at one end connected to a drill floor 9 and each cylinder rod 24b free end is connected to sheaves which operate a plurality of wires 10, running through idler sheaves 11 and to the top end of the
20 riser 4, in a manner which is known per se. Each cylinder rod 24b free end is connected to a tensioner ring 8 which in turn is connected to the riser 4. Each compensator cylinder 7 is connected to a system of pressure vessels 33 and other components as described above with reference to figure 3.

Thus, each compensation apparatus 1 may have a plurality of pressure vessels, e.g.
25 anything from two to eight pressure vessels per compensator cylinder 7. The number of pressure vessels open for each individual cylinder 7 will not have to be the same throughout the system. By this combination, one could effectively adjust the system stiffness in smaller fractions of the total system pressure volume.

System dampening can be adjusted on the proportionally controlled shut-off valve
30 25, arranged in the oil stream between the compensator cylinder 7 and the oil accumulator 26 (see figure 3). The dampening effect will help in avoiding resonance frequencies and force the riser to follow the rig motion. If these two motions are not synchronized, the effect would be excessive stroke of the compensator cylinders. Increased dampening will increase riser acceleration, while
35 reduced dampening may lead to resonance or synchronization error. The choking of the proportionally controlled shut-off valve 25 does not have to be set at a constant ratio, it may have to be actively adjusted over each heave period to either acceleration, speed, cylinder position, cylinder direction or a combination of these.

Thus, choking of the oil flow may be effected as a fixed choking or may be performed over time based on known parameters.

5 Choking the proportionally controlled shut-off valve will thus increase the dampening effect otherwise only generated by the natural flow restriction and seal friction. It can be done by either setting the valve to a fixed position or it can be an active control to this with a variable choking relative to either stroke or speed (or a combination) or it could vary with retracting and extending.

10 If the proportionally controlled shut-off valve 25 is set at a constant ratio (fixed position), it should be set to a dampening effect which is less than the relief pressure of the valve 25, as a relief valve (not shown) otherwise could re-open the shut-off valve 25.

15 Choking the proportionally controlled shut-off valve 25 will generate heat, as the valve takes energy from the relative movements between the rig and riser. The hydraulic line 35 is therefore advantageously and optionally provided with a heat exchanger 15 (see figure 3) which serves to cool the hydraulic fluid 14. The heat which is transferred from the hydraulic fluid and into the cooling medium may be dissipated by heat exchange with seawater or (preferably) with utility systems on the rig.

20 Adjusting the air pressure, air volume and oil flow, thus prevents the cylinders from hitting endstroke, prevents riser buckling and avoids resonance between riser and rig

CLAIMS

1. An apparatus (1) for controlling movements of a free-hanging tubular (4) in a soft hang-off mode suspended via at least a connector element (8) by at least one compensator member (7) which is connected to a buoyant vessel (2), said tubular extending into a body of water below the vessel, **characterised by**
- first sensing means (36) for sensing dynamic and/or spatial parameters of the compensator member and thus that of the vessel (2);
 - second sensing means (21) for sensing dynamic and/or spatial parameters of the connector element (8), and thus that of an upper region of the tubular;
 - data processing means (22) for processing data supplied by said first and second sensing means (36, 21) and determining one or more parameters regarding the movement between the vessel and the upper region of the tubular; and
 - adjusting means (24a,b, 25, 26, 29, 33a-d) for controlling at least the stiffness and dampening of the compensator member (7);
- whereby the axial loads which are transferred between the compensator and the tubular may be controlled.
2. The apparatus of claim 1, wherein the first sensing means (36) comprises motion sensing means (36) for sensing movements of the compensator member and thus that of the vessel (2).
3. The apparatus of claim 1 of claim 2, wherein the second sensing means (21) comprises position indicator means (21) for sensing the position of the connector element (8), and thus that of an upper region of the tubular, with respect to the compensator member.
4. The apparatus of any one of the preceding claims, wherein said one or more parameters regarding the movement between the vessel and the upper region of the tubular comprises acceleration.
5. The apparatus of any one of the preceding claims, wherein the compensator member comprises a hydraulic cylinder (7) connected via a first fluid line (35) to an accumulator (26), and a first valve means (25) for controlling the flow in said first fluid line, and a first pressure sensing means (27) for sensing the pressure of said hydraulic fluid.
6. The apparatus of claim 5, further comprising at least one pressure vessel (33a-d) fluidly connected to the accumulator (26) via a second fluid line (31) and regulator means (29), and further comprising a second pressure sensing means (28),

whereby the pressure exerted on the hydraulic fluid in the accumulator by a pressurised gas in the pressure vessel may be controlled.

7. The apparatus of any one of the preceding claims, further comprising a heat exchanger (15), with a cooling circuit (16), thermally connected to the first fluid
5 line (35), whereby hydraulic fluid in the first fluid line may be cooled in heat exchange with a cooling fluid.

8. A system for controlling movements of a free-hanging tubular (4) in a soft hang-off mode, wherein a plurality of apparatuses (1) according to any one of
10 claims 1 – 7 are connected to the tubular (4) via respective compensator members (7) arranged in a symmetrical pattern around the tubular, and further comprising a common data processing means (22') and a common user interface (37'), whereby the movements of the free-hanging tubular may be controlled by a selective manipulation of the individual apparatuses (1).

9. A method of controlling movements of a free-hanging tubular (4) in a soft
15 hang-off mode suspended via a connector element (8) by at least one compensator member (7) which is connected to a buoyant vessel (2), said tubular extending into a body of water below the vessel, **characterised by** collecting motion data for the vessel (2); collecting motion data for the upper region of the tubular with respect to the compensator member; processing said motion data
20 for the vessel and said motion data for the upper region of the tubular and determining one or more parameters regarding the movement between the vessel and the upper region of the tubular and, based on such data, controlling at least the stiffness and dampening of the compensator member; whereby the axial loads which are transferred between the compensator and the tubular may be controlled.

25 10. The method of claim 9, wherein the collecting of motion data for the vessel comprises sensing movements of the vessel (2).

11. The method of claim 9 or claim 10, wherein the collecting motion data for the upper region of the tubular comprises sensing the position of an upper part of the tubular with respect to the compensator member.

30 12. The method of claim 11, further comprising the sensing of a first pressure in a hydraulic cylinder (7) connected between the tubular (4) and the vessel (2), said hydraulic cylinder being connected via a first fluid line (35) to an accumulator (26), and the sensing of a second pressure in the accumulator exerted by at least one pressure vessel (33a-d) fluidly connected to the accumulator (26) via a second fluid
35 line (31) and regulator means (29).