(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 806 100 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
26.11.2014 Bulletin 2014/48

(21) Application number: **13305675.4**

(22) Date of filing: **24.05.2013**

(51) Int Cl.:
E21B 47/10 *(2012.01)* ***E21B 49/00*** *(2006.01)*
E21B 21/00 *(2006.01)* ***E21B 21/08*** *(2006.01)*

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(71) Applicant: **Geoservices Equipements**
95700 Roissy en France (FR)

(72) Inventor: **Cadalen, Sébastien**
93300 Aubervilliers (FR)

(74) Representative: **Rzaniak, Martin**
Schlumberger
1, rue Henri Becquerel
B.P. 202
92142 Clamart (FR)

(54) **Method for monitoring the drilling of a well using a floating drilling rig and associated monitoring system**

(57) Method of monitoring the drilling of a well (13) using an installation (11) comprising a drilling rig (17) floating on the sea (24) the method comprising the steps of:
- obtaining an injection flow rate of a drilling fluid,
- measuring a flow of a drilling mud recovered from the well in a discharge pipe (25) connected to a diverter (23) of the slip-joint at a discharge measurement point (C),
- selecting a comparison point (C’) located between the diverter and the discharge measurement point,
- obtaining a slope value (0) representative of an angle of the discharge pipe with respect to a horizontal plane (P.
- modeling a flow of the drilling mud along the discharge pipe
- calculating a first flow rate of the drilling mud at the comparison point using the injection flow rate, and a second flow rate at the comparison point using the measured discharge flow rate, and
- performing a comparison between the first drilling mud flow rate and the second drilling mud flow rate to monitor the drilling.

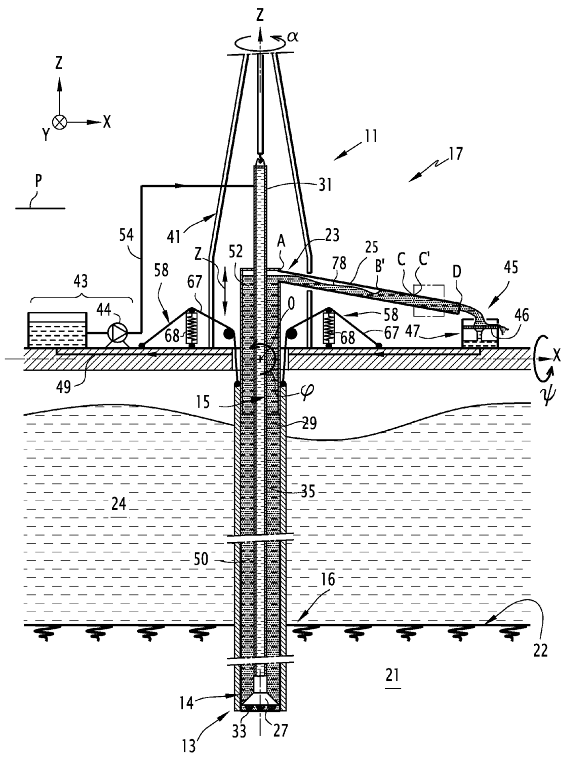

FIG.1

EP 2 806 100 A1

Description

[0001] The present disclosure relates to a method for monitoring the drilling of a well and to an associated drilling installation.

[0002] When drilling an oil well or a well for another effluent (in particular gas, vapor, water), it is known to inject a drilling fluid into the well and to recover a drilling mud generated by the mixing of the drilling fluid with components from the soil.

[0003] It is also known to periodically recover samples contained in the drilling mud emerging from the well, in view of their analysis to determine geological information on the nature of the formations which are drilled. Additionally, some analysis are carried out to determine the chemical and physical properties of the cuttings, for example the compositional and dimensional properties of the cuttings.

[0004] The above-mentioned analyses are carried out either in the vicinity of the well being drilled, for example in a specifically equipped cabin, or in a laboratory dedicated to the study of the cuttings, away from the drilling site.

[0005] The flow rate of the drilling mud exiting the well is monitored, e.g. in order to feed a model in which the depth in the well at which the samples have been extracted is determined. Knowing the drilling mud flow rate and the well and discharge pipe geometry, a depth may be attributed to each sample as a function of the time at which the sample was taken.

[0006] The drilling mud flow rate exiting the well is also a parameter in assessing the safety of the drilling operation.

[0007] There are known techniques for assessing the drilling mud flow rate in the discharge pipe, such as diverting the flow through a vibrant U shaped by-pass pipe and assessing the Coriolis force on the by-pass pipe, which leads the mass flow rate of the drilling mud.

[0008] Unfortunately, the floating drilling rig is subject to swell, which causes heave, sway, surge, pitch, roll, and yaw movements of the drilling rig. These movements generate fluctuations of the measured discharge flow rate that add to the changes in the flow rate of drilling mud exiting the well. The period of swell is for example around 15 seconds. This generates movements of the drilling rig having periods of around 15 seconds and sometimes longer.

[0009] A known technique in order to get rid of the fluctuations of the discharge flow rate that are due to the drilling rig movements is to calculate an average discharge flow rate over a given duration. Another known technique, more elaborate, consists in performing a frequency analysis of the measured discharge flow rate and keeping the lowest frequencies in order to calculate a corrected discharge flow rate that does not fluctuate as much as the measured discharge flow rate.

[0010] However, these known techniques result in the fact that a sudden change in the flow rate of drilling mud exiting the well can be noticed in the corrected discharge flow rate after a certain time, which can be as long as 10 minutes. Such a delay or reaction time makes it less interesting, or even impossible, to use the corrected discharge flow rate for example as an early alert parameter of the well behavior. Typically, using the discharge flow rate as an alert parameter would require a reaction time below or equal to approximately 1 minute.

[0011] One aim of this embodiment is therefore to provide a method of monitoring the drilling of a well using a floating drilling rig subject to swell, in which the measured drilling mud discharge flow rate allows monitoring the drilling in a more efficient way, for example allowing the early detection of sudden changes in the flow of drilling mud exiting the well.

[0012] To this aim, it is proposes a method of monitoring the drilling of a well according to claim 1.

[0013] In other embodiments, the method comprises one or several of the features of claims 2 to 13, taken in isolation or any technical feasible combination.

[0014] The embodiment also relates to a system for monitoring the drilling a well according to claim 14.

[0015] The embodiment will be better understood upon reading the following description given solely by way of example and with reference to the appended drawings, in which:

- Figure 1 is a schematic view, taken in a vertical section, of a drilling installation according to one embodiment;
- Figure 2 is a schematic perspective view of a portion of the drilling installation shown in Figure 1, the portion including the discharge pipe.

[0016] In everything that follows, the terms "upstream" and "downstream" are understood with respect to the normal direction of circulation of a fluid in a pipe.

[0017] As illustrated in Figure 1, a drilling installation 11 comprises a rotary drilling tool 15 drilling a cavity 14 in a sea bed 22, a drilling rig 17 floating on the sea 24 and subject to swell, and a riser 50 extending between the sea bed 22and the drilling rig 17.

[0018] A well 13 delimiting the cavity 14 is formed in the substratum 21 by the rotary drilling tool 15. The well 13 defines a well head 16 on the sea bed 22.

[0019] The riser 50 is a pipe extending approximately along a vertical direction Oz between the well head 16 and the drilling rig 17.

[0020] The vertical direction Oz is for example used to define a heave movement z of the drilling rig 17 caused by the swell which is a translation along the vertical direction Oz. A yaw angle α is also defined as a rotation angle of the drilling rig 17 around the vertical direction Oz.

[0021] O is a reference point. For example O is defined by the average location of the inertial centre of the drilling rig 17 As a variant, O is defined by the average location of any other arbitrary point attached to the drilling rig 17.

[0022] In order to quantify the drilling rig movements caused by the swell, a roll direction Ox and a pitch direction Oy are also defined.

[0023] The pitch direction Oy is perpendicular to the vertical direction Oz. The pitch direction Oy is used to define a pitch angle φ of the drilling rig 17. The pitch direction Oy is also used to define a sway movement y of the drilling rig 17 which is a translation along the pitch direction Oy.

[0024] The roll direction Ox is perpendicular to the vertical direction Oz and to the pitch direction Oy. The roll direction Ox is used to define a roll angle ψ of the drilling rig 17. The roll direction Ox is also used to define surge movement x of the drilling rig 17 which is a translation along the roll direction Ox.

[0025] The Ox, Oy, Oz directions are fixed with respect to the sea bed 22.

[0026] The drilling tool 15 comprises a drilling head 27, a drill string 29 and a liquid injection head 31.

[0027] The drilling head 27 comprises means 33 for drilling through the rocks and/or sediments of the substratum 21, the drilling operation producing solid drilling residues or "cuttings". The drilling head 27 is mounted on the lower portion of the drill string 29 and is positioned at the bottom of the well 13.

[0028] The drill string 29 comprises a set of hollow drilling pipes. These pipes delimit an internal space 35 which makes it possible to bring a drilling fluid from the drilling rig to the drilling head 27. To this end, the liquid injection head 31 is screwed onto the upper portion of the drill string 29.

[0029] The drilling fluid is in particular a drilling mud, in particular a water-based or oilbased drilling mud.

[0030] The drilling rig 17 comprises a slip-joint 52 engaged vertically in the riser 50, an injection pipe 54 hydraulically connected to the liquid injection head 31 for injecting the drilling fluid, and a discharge pipe 25 hydraulically connected to a diverter 23 of the slip-joint 54 for recovering the drilling mud, the discharge pipe 25 having a discharge flow meter 56 for measuring a flow of the drilling mud and obtaining a measured discharge flow rate.

[0031] The drilling rig 17 comprises means 41 for supporting the drilling tool 15 and driving it in rotation, means 43 for injecting the drilling liquid, and a shale shaker 45, for receiving and treating the drilling mud emerging from the well.

[0032] The drilling rig 17 comprises means 58 for attaching the drilling rig 17 to the riser 50.

[0033] As shown in figure 2, the drilling rig 17 comprises a heave sensor 60, a sway sensor 60a, and a surge sensor 60b, all of them located in the vicinity of the diverter 23.

[0034] The drilling rig 17 also comprises a yaw sensor 61, a roll sensor 62, and a pitch sensor 64, all of them located in the vicinity of the discharge pipe 25.

[0035] By "in the vicinity of an element" it is meant that the sensor is located at a distance from the element of less than 5 m, and moves together with the element. Preferably, the sensor is located on the element.

[0036] The drilling rig 17 also comprises a calculator 66 connected to the heave sensor 60, the sway sensor 60a, the surge sensor 60b, the yaw sensor 61, the pitch sensor 62 and the roll sensor 64.

[0037] The injection means 43 are hydraulically connected to the injection head 31 via the injection pipe 54 in order to introduce and circulate the drilling fluid in the inner space 35 of the drill string 29.

[0038] The injections means 43 and the liquid injection head 31 form an assembly for injecting the drilling fluid into the well 13.

[0039] The injections means 43 includes a pump 44 adapted to provide an injection flow rate of the drilling fluid.

[0040] The shale shaker 45 collects the recovered drilling mud charged with cuttings coming from the discharge pipe 25. The shale shaker 45 is equipped with sieves 46 to allow the separation of the solid drilling residues or cuttings, from the recovered drilling mud. The shale shaker 45 also comprises a mud tank 47 located under the sieves 46 to store the recovered drilling mud deprived of cuttings.

[0041] A recirculation duct 49 connects the mud tank 47 to the injection means 43 to recirculate the mud collected in the mud tank 47 to the injection means 43.

[0042] In a known manner, the attaching means 58 comprises cables 67 having an extremity fixed on the drilling rig 17 and an opposite extremity fixed on the top of the riser 50, and riser tensioners 68 for maintaining a tension in the cables 67.

[0043] The slip-joint 52 is movable along the vertical direction Oz. The slip-joint 52 closes the well 13 in the vertical direction Oz upwards.

[0044] A lower part of the slip-joint 52 slides approximately vertically within the top of the riser 50 in order to cope with the heave movement z of the drilling rig 17.

[0045] The diverter 23 is for example located at the top of the slip-joint 52. The diverter 23 defines an inlet of the discharge pipe 25 corresponding to a point A of the discharge pipe 25.

[0046] The discharge pipe 25 for example has a circular section. The discharge pipe 25 comprises a first part 70 extending along a longitudinal direction L between point A and a point B, a second part 72 extending between the point

B and a discharge measurement point C, and a third part 74 extending between the point C and a point D.

[0047] The second part 72 has the shape of a by-pass in the example and includes the discharge flow meter 56 which is located just downstream of point C.

[0048] The point D is located at a downstream outlet of the discharge pipe 25.

[0049] An intermediate point B' of the discharge pipe 25 is defined by the fact that, along a first portion 76 of discharge pipe extending from the point A to the point B', the drilling mud flow has a free surface 78, whereas the drilling mud has no free surface in a second portion 80 of the discharge pipe 25 extending from the point B' to the point C. The drilling mud completely fills the discharge pipe 25 in the second portion 80.

[0050] The discharge flow meter 56 is adapted to generate a measured discharge flow rate. The discharge flow meter 56 is for example a Coriolis flow meter.

[0051] The heave sensor 60 is adapted to generate a heave value versus time that is representative of the heave movement $\underline{z}$, for example representative of the position of the diverter 23 along the vertical direction $\underline{Oz}$. The heave sensor 60 is for example an accelerometer.

[0052] The pitch sensor 62 and the roll sensor 64 are respectively adapted to generate a pitch value and a roll value representative of the pitch angle φ and the roll angle ψ. The pitch sensor 62 and the roll sensor 64 are for example Inclinometers.

[0053] The sway and surge sensors 60a, 60b are respectively adapted to generate a surge value and a sway value respectively representative of the sway movement $\underline{x}$ and the surge movement $\underline{y}$. The surge sensor 60a and the sway sensor 60b are for example accelerometers.

[0054] The yaw sensor 61 is adapted to generate a yaw value representative of the yaw angle α. The yaw sensor 61 is for example a gyroscope.

[0055] The calculator 66 is adapted to model the flow of the drilling mud in the discharge pipe 25 at least between the diverter 23 (point A) and the discharge flow meter 56 (point C) using a mathematical model.

[0056] The calculator 66 comprises a unit 90 in order to obtain a slope value θ of the first part 70 of the discharge pipe 25 using the pitch value and the roll value, a first calculation unit 92 for calculating a first flow rate of the drilling mud at a comparison point C' using the injection flow rate, and a second calculation unit 94 for calculating a second flow rate of the drilling mud at the comparison point C' using the measured discharge flow rate.

[0057] The calculator 66 is adapted to determine the location of the intermediate point B'.

[0058] The calculator 66 also comprises a comparator 96 for performing a comparison between the first drilling mud flow rate and the second drilling mud flow rate, and for generating a comparison result intended to be used to monitor the drilling.

[0059] The slope value θ is representative of an angle made by the longitudinal direction D of the discharge pipe 25 with respect to a horizontal plane P.

[0060] The first calculation unit 92 is adapted to use the flow of the drilling mud modeled along the discharge pipe to determine the location of the intermediate point B' and to calculate the drilling mud first flow rate.

[0061] According to a particular embodiment, the comparison point C' is the discharge measurement point C. The first drilling mud flow rate is then calculated at point C. In this particular embodiment, the drilling mud second flow rate is equal to the measured discharge flow rate.

[0062] The mathematical model uses the slope value θ. The mathematical model advantageously uses a first derivative of the heave value versus time. The mathematical model advantageously uses both a first derivative of the heave value versus time and a second derivative of the heave value versus time. The mathematical model advantageously uses the second derivative of both surge and sway versus time.

[0063] The mathematical model advantageously comprises a first set of equations and a second set of equations.

[0064] For example the first set of equations includes equations known as the "shallow water equations". The first set of equations is intended to be used for modeling the flow of the drilling mud in the first portion 76.

[0065] For example the second set of equations includes an equation representative of a balance between gravity and pressure loss in the drilling mud in the second portion 80.

[0066] The second set of equations is intended to be used for modeling the flow of the drilling mud in the second portion 80.

[0067] The mathematical model will be further described below.

[0068] A method of drilling a well will now be described. The method advantageously involves using the installation 11 described above.

[0069] The drilling fluid is injected by the injection means 43 in the injection pipe 54. The pump 44 allows obtaining an injection flow rate of the drilling fluid into the well 13.

[0070] The drilling fluid flows via the drill string 29 into the well 13. Then the drilling mud flows upwards via the riser 50 and the slip-joint 52 outside of the drill string 29. The drilling mud exits the slip-joint 52 via the diverter 23.

[0071] The drilling mud is recovered in the discharge pipe 25. The drilling mud exits the discharge pipe 25 at the point D in order to be treated in the shale shaker 45. The treatment of the drilling mud generates a mud that is advantageously recycled via the recirculation duct 49 to the injection means 43.

[0072] The flow of the drilling mud is measured, advantageously on a continuous basis, at the discharge measurement point C using the flow meter 56 in order to obtain the measured discharge flow rate versus time.

[0073] For example the comparison point C' is chosen to be at the discharge measurement point C. The second drilling mud flow rate is set as equal to the measured discharge flow rate.

[0074] The heave movement of the drilling rig 17 versus time is measured at the point A by the heave sensor 60 in order to obtain the heave value,

[0075] The slope value θ is obtained as follows. A parameter representative of the pitch angle φ is measured by the pitch sensor 62 in order to obtain the pitch value versus time, and a parameter representative of the roll angle ψ is measured by the roll sensor 64 in order to obtain the roll value versus time. The slope value is calculated by the unit 90 using the pitch value and the roll value.

[0076] According to particular embodiments (not represented) wherein the first part 70 of the discharge pipe 25 is not straight, a plurality of slope values along the first part 70 are calculated.

[0077] The flow of the drilling mud along the discharge pipe 25 between the diverter 23 and the discharge measurement point C is then modeled by the calculator 66 using the mathematical model.

[0078] For example the "shallow water equations" of the first set of equations are as follows:

$$\frac{\partial a}{\partial t} + \frac{\partial (au)}{\partial s} = \dot{m}$$

(1: mass conservation)

$$\frac{\partial (au)}{\partial t} + \frac{\partial}{\partial s}(\beta a u^2 + g\,\zeta) = g' a - P_w c_w \frac{1}{2} u^2$$

(2: momentum conservation)

[0079] With:

- s : the curvilinear coordinate associated to the flow line
- a: cross section occupied by the drilling mud in the discharge pipe 25,
- u: average velocity of the drilling mud in the discharge pipe 25,
- $\dot{m}$ mass source term
- β: the Boussinesq momentum coefficient,
- ζ: the pressure expressed in total dynamic head,
- P_w: wetted perimeter of the discharge pipe 25,
- c_w: Fanning friction factor
- g': effective gravity.

[0080] The slope value θ is used to calculate the effective gravity g' in the momentum conservation equation. For example:

$$g' = (\vec{g} + \vec{a}) \cdot \vec{e}_s$$

With g the gravity vector, $\vec{a} = (\ddot{x}, \ddot{y}, \ddot{z})$ the acceleration vector, and $\vec{e}_s$ the unit vector associated to the flow line slope

$\ddot{x}$ is the surge acceleration

$\ddot{y}$ is the sway acceleration

$\ddot{z}$ is the heave acceleration

[0081] The first derivative of the heave value versus time is used as a boundary condition providing the flow of the drilling mud entering the discharge pipe 25 at point A. It is for example assumed that the flow rate of drilling mud that would exit the diverter in case the slip-joint 52 did not move vertically is equal to the injection flow rate.

[0082] The "shallow water equations" are also described for example in:

[1] F. Alcrudo, P. Garcia-Navarro, and J.-M. Saviron. Flux difference splitting for 1 D open channel flow equations.

International Journal for Numerical Methods in Fluids, vol. 14, pp. 1008-1018, 1992.
[2] E. Aldrighetti. Computational hydraulic techniques for the Saint Venant Equations in arbitrarily shaped geometry. PhD thesis, Universita degli Studi di Trento, 2007.

[0083] The above "shallow water equations" are advantageously solved by the first calculation unit 92 using the finite-volume method.

[0084] By solving the shallow water equations, the first calculation unit 92 provides the flow of the drilling mud as well as a height h of drilling mud along the first portion 76. h is obtained with a knowing the geometry of the cross-section of the discharge pipe 25. The term "a.u" is the flow of drilling mud.

[0085] Knowing the height h along the first part 70, the location of the intermediate point B' in the discharge pipe 25 is obtained. A flow rate q_{out} of the drilling mud at the intermediate point B' is obtained.

[0086] For example the second set of equations consists of the following equations:

$$\frac{\partial V}{\partial t} = q_{out} - q_c \qquad (3)$$

$$q_c = f(\Delta P) \qquad (4)$$

$$\Delta P = \rho g H \text{ and } H = \frac{V}{a}\sin\theta \qquad (5)$$

[0087] Which leads to:

$$\frac{\partial V}{\partial t} = q_{out} - f\left(\rho g \frac{V}{a}\sin\theta\right) \qquad \text{(6: pressure loss - gravity balance)}$$

[0088] With:

V: volume of the drilling mud in the second portion 80 of the discharge pipe 25 (between point B' and point C),
q_{out}: the drilling mud flow rate at point B',
q_c: flow rate in the Coriolis flow meter 56,
ΔP: pressure loss ΔP in the flow meter 56,
f: function providing the drilling mud flow rate q_c in the flow meter 56 versus the pressure loss ΔP,
ρ: density of the drilling mud,
H: height difference between point B' and point C,

[0089] The above equation is advantageously solved by the first calculation unit 92 using the finite-difference method.

[0090] The first calculation unit 92 solves equation (6) and then calculates the flow q_c of the drilling mud at point C using equations (4) and (5), that is to say the drilling mud first flow rate.

[0091] As explained above, the drilling mud second flow rate is equal to the measured discharge flow rate in this example. The second calculation unit 94, in this example, just sets the drilling mud second flow rate as equal to the measured discharge flow rate.

[0092] The comparator 96 compares the drilling mud first flow rate and the drilling mud second flow rate and generates the comparison result. For example, the comparison result is the absolute value of the difference between the drilling mud first flow rate and the drilling mud second flow rate.

[0093] If the comparison result is larger than a predetermined threshold, then an alert is for example generated. The alert is used to monitor the drilling.

[0094] Thanks to the above described features, the method of drilling the well 13 and the installation 11 allow obtaining a first drilling mud flow rate that is calculated using the mathematical model in order to include a calculated impact of the swell on the drilling mud flow in the discharge pipe 25. The first drilling mud flow rate can be directly compared with the measured discharge flow rate, without performing a frequency analysis or an average that would introduce a reaction time of more than 1 minute.

[0095] As a consequence, the method of drilling the well 13 and the installation 11 allow monitoring the drilling in a more efficient way, enabling an early detection of sudden changes in the flow of drilling mud exiting the well 13.

[0096] As a variant (no represented), the comparison point C' is set to be in the vicinity of the diverter, for example at the same location as the point A.

[0097] In another variant (not represented), the first drilling mud flow rate is advantageously calculated using the injection flow rate and a well mathematical model representative of the drilling mud generation process in the well 13.

[0098] The well mathematical model is adapted for calculating a flow rate of drilling mud that would exit the slip-joint 52 under the assumption that the slip-joint 52 does not move vertically. The impact of the heave movement of the drilling rig 17 on the flow of drilling mud entering the discharge pipe 25 is taken into account by using the first derivative of the heave value versus time.

Claims

1. Method of monitoring the drilling of a well (13) using an installation (11) comprising a drilling rig (17) floating on the sea (24) and subject to swell, a riser (50) extending between the sea bed (22) and the drilling rig (17) and connected to a well head (16), a slip-joint (52) attached to the drilling rig (17) and sliding vertically with respect to the riser (50), and a drilling tool (15) having an injection head (31), the swell causing a heave movement, a pitch movement and a roll movement of the drilling rig (17), the method comprising the steps of:

- obtaining an injection flow rate of a drilling fluid into the well (13) injected through an injection pipe (54) connected to the injection head (31), and
- measuring a flow of a drilling mud recovered from the well (13) in a discharge pipe (25) connected to a diverter (23) of the slip-joint (52) at a discharge measurement point (C) of the discharge pipe (25) in order to obtain a measured discharge flow rate, **characterized in that** it also comprises the steps of:
- selecting a comparison point (C') in the discharge pipe (25) located between the diverter (23) and the discharge measurement point (C),
- obtaining a slope value (θ) representative of an angle made by a longitudinal direction (L) of the discharge pipe (25) with respect to a horizontal plane (P), and measuring a parameter representative of the heave movement ($\underline{z}$) of the drilling rig (17) versus time at a heave measurement point in order to obtain a heave value,
- modeling a flow of the drilling mud along the discharge pipe (25) between the diverter (23) and the discharge measurement point (C) using a mathematical model, the mathematical model using the slope value (θ) and one or several derivatives of the heave value versus time,
- calculating a first flow rate of the drilling mud at the comparison point (C') using the injection flow rate,
- calculating a second flow rate of the drilling mud at the comparison point (C') using the measured discharge flow rate, the step of calculating the first drilling mud flow rate and/or the step of calculating the second drilling mud flow rate using the flow of the drilling mud modeled along the discharge pipe (25), and
- performing a comparison between the first drilling mud flow rate and the second drilling mud flow rate in order to generate a comparison result, and using the comparison result in order to monitor the drilling.

2. Method according to claim 1, **characterized in that**:

- the comparison point (C') is located at the discharge measurement point (C), and
- the second drilling mud flow rate is equal to the measured discharge flow rate.

3. Method according to claim 1 or 2, **characterized in that** the step of obtaining a parameter representative of a slope of the discharge pipe includes the substeps of:

- measuring a parameter (φ) representative of the pitch movement at a pitch measurement point, and a parameter (ψ) representative of the roll movement at a roll measurement point, in order to obtain a pitch value and a roll value, and
- calculating the slope value (θ) using the pitch value and the roll value.

4. Method according to claim 3, **characterized in that** the pitch measurement point and the roll measurement point are located in the vicinity of the discharge pipe (25), preferably on the discharge pipe.

5. Method according to any of claims 1 or 4, **characterized in that** the heave measurement point (A) is located in the vicinity of diverter (23), preferably on the diverter (23).

6. Method according to any of claims 1 to 5, **characterized in that** the mathematical model includes shallow water equations.

7. Method according to any of claims 1 to 6, **characterized in that** a first derivative of the heave value versus time is used as a boundary condition of the mathematical model.

8. Method according to any of claims 1 to 7, **characterized in that** it comprises the step of measuring a parameter representative of a sway movement (y) of the drilling rig (17) versus time in order to obtain a sway value, and measuring a parameter representative of a surge movement (x) of the drilling rig (17) versus time in order to obtain a surge value, and **in that**
a second derivative of the heave value versus time, a second derivative of the sway value versus time, and a second derivative of the surge value versus time are used by the mathematical in order to calculate an effective gravity term.

9. Method according to any of claims 1 to 8, **characterized in that** the slope value (θ) is used to calculate a source term in a momentum conservation equation of the mathematical model.

10. Method according to any of claims 1 to 9, **characterized in that** the step of modeling a flow of the drilling mud along the discharge pipe (25) comprises the substep of calculating a height (h) of drilling mud along the discharge pipe (25) between the diverter (23) and the discharge measurement point (C) in order to determine an intermediate point (B') of the discharge pipe (25), the discharge pipe (25) being partially filled with the drilling mud between the diverter (23) and the intermediate point (B'), and the discharge pipe (25) being fully filled with the drilling mud between the intermediate point (B') and the discharge measurement point (C).

11. Method according to claim 10, **characterized in that** the mathematical model has a first set of equations used for a first portion (76) of the discharge pipe (25) extending between the diverter (23) and the intermediate point (B'), and a second set of equations used for a second portion (80) of the discharge pipe (25) extending between the intermediate point (B') and the discharge measurement point (C).

12. Method according to claim 11, **characterized in that**:

- the first set of equations of the mathematical model includes shallow water equations, and
- the second set of equations of the mathematical model comprises an equation representative of a balance between gravity and pressure loss in the drilling mud.

13. Method according to claim 12, **characterized in that** the step of modeling a flow of the drilling mud along the discharge pipe (25) comprises the substep of solving the first set of equations of the mathematical model using the finite-volume method, and the substep of solving the second set of equations of the mathematical model using the finite-difference method.

14. System for monitoring the drilling of a well (13) in an installation (11) the installation, comprising:

- a drilling rig (17) intended to float on the sea (24) and to be subject to swell, the swell causing a heave movement, a pitch movement, a roll movement, a surge movement, a sway movement, and a yaw movement of the drilling rig (17),
- a riser (50) intended to extend between the sea bed (22) and the drilling rig (17) and to be connected to a well head (16),
- a slip-joint (52) attached to the drilling rig (17) and sliding vertically with respect to the riser (50),
- a drilling tool (15) having an injection head (31),
- an injection pipe (54) connected to the injection head (31), and means (43) for injecting a drilling fluid into the well (13) through the injection pipe (54),
- a discharge pipe (25) connected to a diverter (23) of the slip-joint (52) for recovering a drilling mud from the well (13),

the system comprising:
- means (44) for obtaining an injection flow rate of the drilling fluid in the injection pipe (54),
- a discharge flow meter (56) for measuring a flow of the drilling mud at a discharge measurement point (C) of

the discharge pipe (25) and obtaining a measured discharge flow rate,
characterized in that the system also comprises:
- a unit (90) to obtain a slope value (θ) representative of an angle made by a longitudinal direction (L) of the discharge pipe (25) with respect to a horizontal plane (P), and a sensor (60) for measuring a parameter representative of the heave movement (z) of the drilling rig (17) versus time at a heave measurement point and obtaining a heave value,
- a calculator (66) using a mathematical model for modeling a flow of the drilling mud along the discharge pipe (25) at least between the diverter (23) and the discharge measurement point (C), the mathematical model using the slope value (θ) and one or several derivatives of the heave value versus time,
- a first calculation unit (92) for calculating a first flow rate of the drilling mud at a comparison point (C') selected in the discharge pipe (25) between the diverter (23) and the discharge measurement point (C), the first calculation unit (92) using the injection flow rate,
- a second calculation unit (94) for calculating a second flow rate of the drilling mud at the comparison point (C') using the measured discharge flow rate, the first calculation unit (92) and/or the second calculation unit (94) using the flow of the drilling mud modeled along the discharge pipe (25), and
- a comparator (96) for performing a comparison between the first drilling mud flow rate and the second drilling mud flow rate, and for generating a comparison result intended to be used to monitor the drilling.

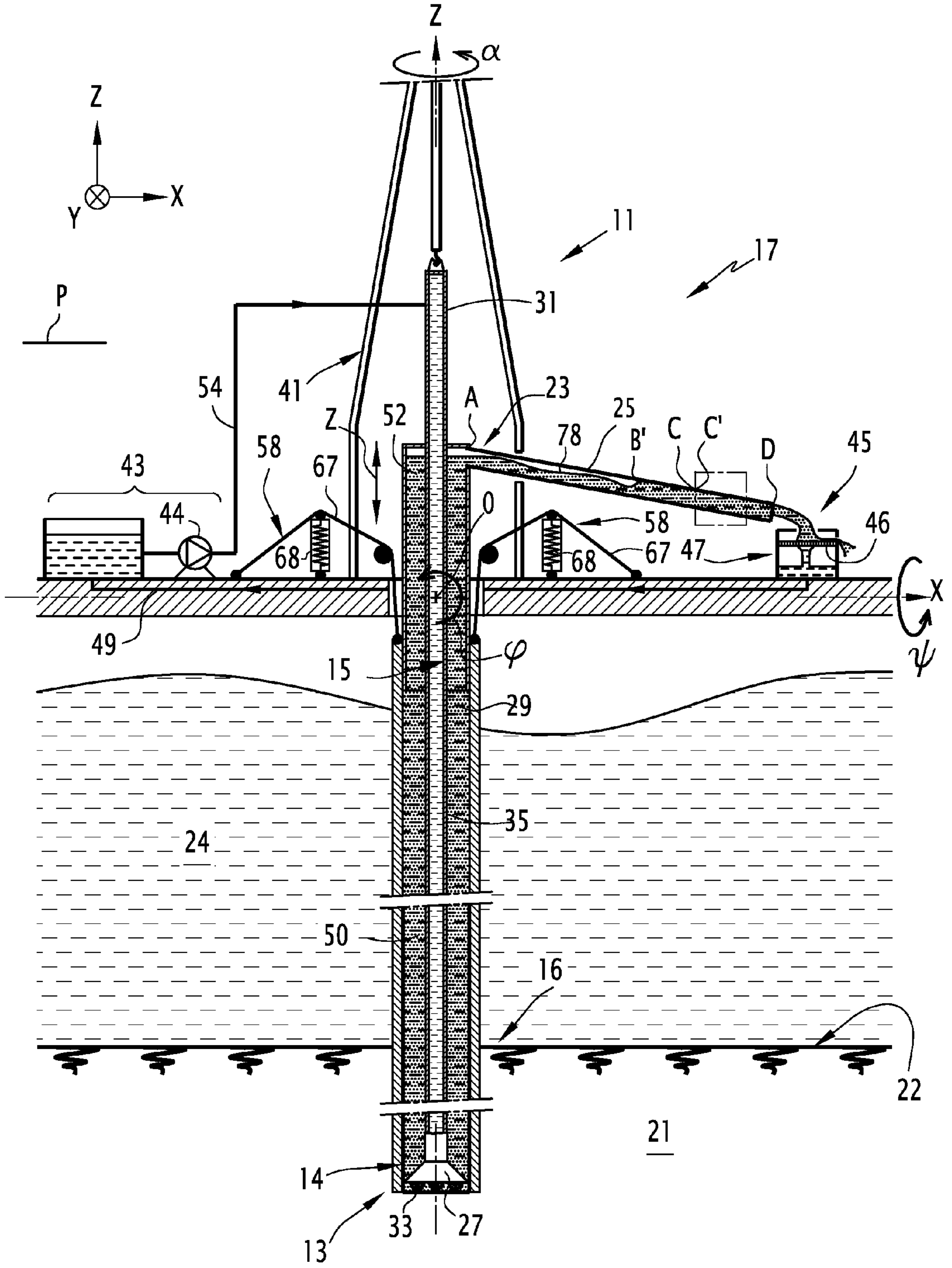
Z
α
Z
Y
X
11
17
P
31
54
41
23
A
25
52
Z
78
B'
C
C'
D
45
43
58
67
44
0
58
46
68
68
67
47
X
49
φ
ψ
15
29
35
24
50
16
22
21
14
33
27
13

FIG.1

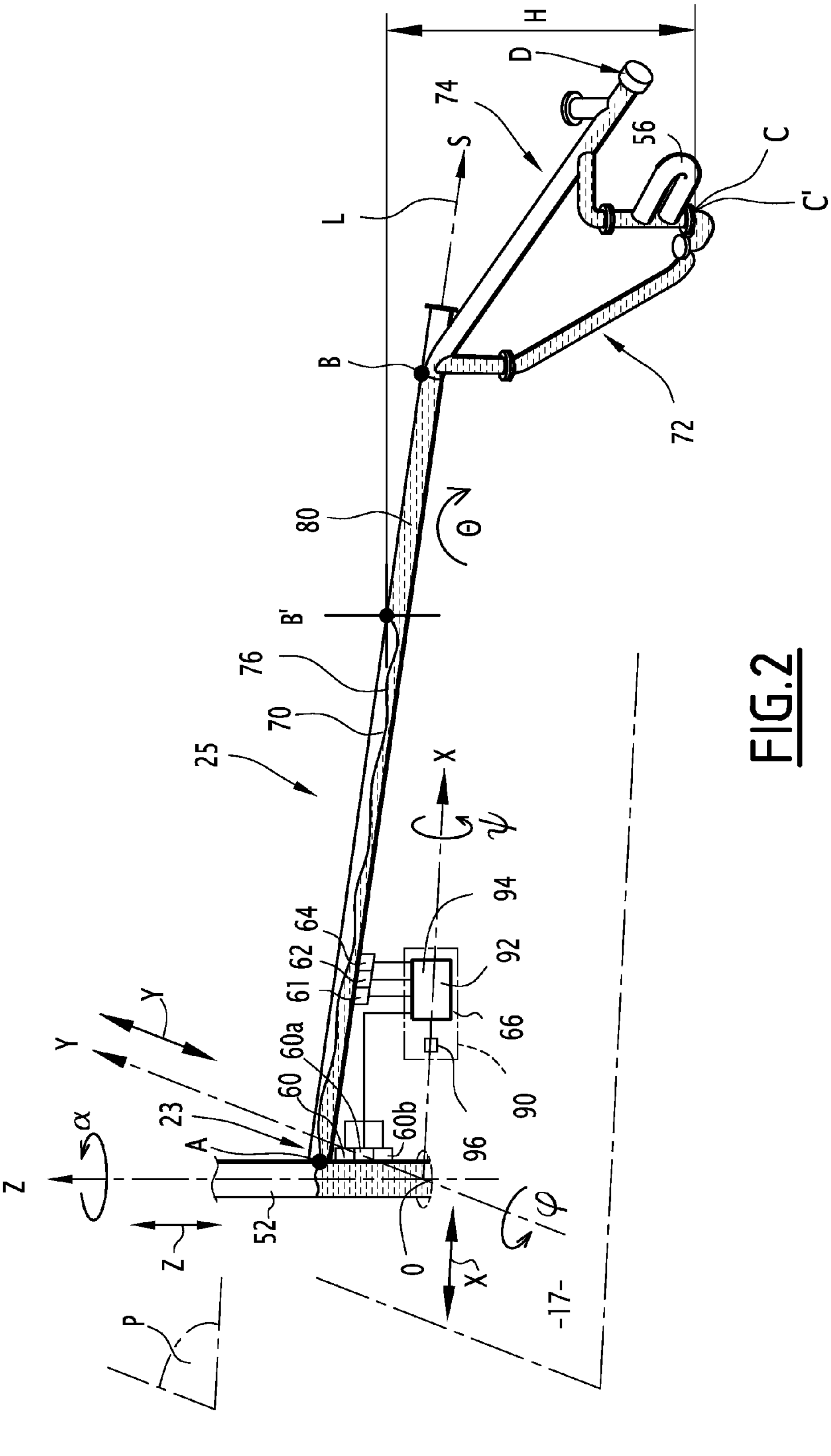
Z
α
Y
23
A
60
60a
60b
61
62
64
94
92
66
90
96
0
X
ψ
φ
52
P
-17-
25
70
76
B'
80
Θ
B
72
L
S
74
D
H
56
C
C'

FIG.2

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 13 30 5675

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 4 282 939 A (MAUS L DONALD ET AL) 11 August 1981 (1981-08-11) * the whole document * -----	1-14	INV. E21B47/10 E21B49/00 E21B21/00 E21B21/08
A	EP 0 498 128 A1 (SCHLUMBERGER SERVICES PETROL [FR] SEDCO FOREX TECH INC [PA]; SCHLUMBER) 12 August 1992 (1992-08-12) * the whole document * -----	1-14	
A	US 3 910 110 A (JEFFERIES ROBERT KENNEDY ET AL) 7 October 1975 (1975-10-07) * the whole document * -----	1-14	

TECHNICAL FIELDS SEARCHED (IPC)

E21B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	7 October 2013	Manolache, Iustin

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
....
& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 13 30 5675

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

07-10-2013

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4282939 A	11-08-1981	NONE	
EP 0498128 A1	12-08-1992	CA 2060736 A1	08-08-1992
		DE 69107606 D1	30-03-1995
		EP 0498128 A1	12-08-1992
		NO 920486 A	10-08-1992
		US 5205165 A	27-04-1993
US 3910110 A	07-10-1975	GB 1453203 A	20-10-1976
		NL 7412994 A	08-04-1975
		US 3910110 A	07-10-1975

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Non-patent literature cited in the description

- **F. ALCRUDO ; P. GARCIA-NAVARRO ; J.-M. SAVIRON.** Flux difference splitting for 1 D open channel flow equations. *International Journal for Numerical Methods in Fluids,* 1992, vol. 14, 1008-1018 **[0082]**
- **E. ALDRIGHETTI.** Computational hydraulic techniques for the Saint Venant Equations in arbitrarily shaped geometry. *PhD thesis,* 2007 **[0082]**