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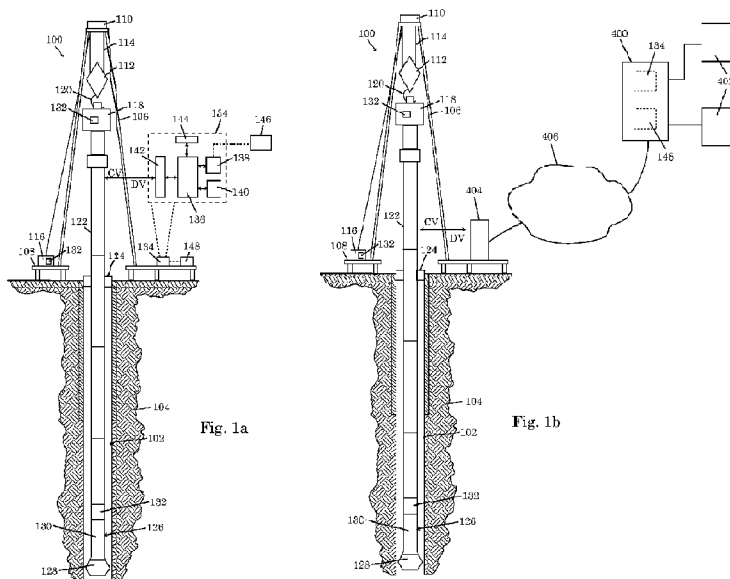
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(54) Title: APPARATUS AND METHOD FOR AUTOMATED DRILLING OF A BOREHOLE IN A SUBSURFACE FORMATION



(57) Abstract: Apparatus and method for automated drilling of a borehole in subsurface formations. In one embodiment, a method includes selecting at least one control variable. A drilling performance objective having a value that is influenced by drilling of the borehole using the at least one control variable is defined. A first interval of the borehole is drilled maintaining the at least one control variable at a first value. A second interval of the borehole is drilled maintaining the at least one control variable at a second value. A third interval of the borehole is drilled maintaining the at least one control variable at a third value. The third value is selected based on a comparison of the value of the drilling performance objective while drilling the first interval and the value of the drilling performance objective while drilling the second interval to a predetermined optimal value of the drilling performance objective.

AMENDED CLAIMS**received by the International Bureau on 11 February 2013 (11.02.2013)**

1. A method for automated drilling of a borehole in a subsurface formation, comprising:
 - selecting at least one control variable;
 - defining a drilling performance objective having a value that is influenced by drilling of the borehole using the at least one control variable;
 - drilling a first interval of the borehole maintaining the at least one control variable at a first value;
 - drilling a second interval of the borehole maintaining the at least one control variable at a second value;
 - selecting a third value for the at least one control variable by applying an offset value to one of the first and second values; wherein the selection of the one of the first and second values to which the offset is applied is based on a comparison of the value of the drilling performance objective while drilling the first interval and the value of the drilling performance objective while drilling the second interval to a predetermined value of the drilling performance objective; and
 - drilling a third interval of the borehole maintaining the at least one control variable at the third value.
2. The method of claim 1, further comprising selecting the second value by applying an offset value to the first value.
3. The method of claim 1, further comprising:
 - drilling more than three intervals of the borehole, and selecting, for each interval, a value of the at least one control variable by applying a near search offset value to the value of the at least one control variable applied for a previously drilled interval;
 - determining whether the value of the drilling performance objective has changed over the more than three intervals; and
 - selecting, responsive to the determining, the value of the at least one control variable by applying a far search offset value to the value of the at least

one control variable based on the drilling performance objective not having changed over the more than three intervals of the borehole; wherein the magnitude of the far search offset value is greater than the magnitude of the near search offset value.

4. The method of claim 1, further comprising selecting the third value by applying a first offset value to the second value based on the value of the drilling performance objective while drilling the second interval being nearer to the predetermined value of the drilling performance objective than the value of the drilling performance objective while drilling the first interval is to the predetermined value of the drilling performance objective.

5. The method of claim 4, further comprising selecting the third value by applying a second offset value to the first value based on the value of the drilling performance objective while drilling the first interval being nearer to the predetermined value of the drilling performance objective than the value of the drilling performance objective while drilling the second interval is to the predetermined value of the drilling performance objective.

6. The method of claim 5, wherein each of the first and second offset values comprises a magnitude and a direction, and the direction of the first offset value is different from the direction of the second offset value.

7. The method of claim 1, wherein the control variable comprises at least one of weight on bit, bit rotational speed, drill string rotational torque, rate of penetration and bit diameter.

8. The method of claim 1, wherein the drilling performance objective comprises at least one of mechanical specific energy of the drilling of the borehole and rate of penetration of drilling of the borehole.

9. An apparatus for automated drilling of a borehole in a subsurface formation, comprising:

a drill sting for drilling the borehole, the drill sting controlled by a set of control variables;

sensors for measuring a plurality of drilling variables during drilling of the borehole;

a drilling performance optimizer configured to:

evaluate, based on at least one of the drilling variables, a drilling performance objective having a value that is influenced by drilling of the borehole using the set of control variables; and

select an operative set of values for the set of control variables based on the value of the drilling performance objective by applying an offset value to one of a first and second set of values for the set of control variables applied to drill intervals of the borehole; wherein the one of the first and second set of values is selected based on the value of the drilling performance objective produced while applying each of the first and second set of values that is closest to a predetermined value of the drilling performance objective.

10. The apparatus of claim 9, wherein the drilling performance optimizer is configured to:

compare to the predetermined value of the drilling performance objective a first value of the drilling performance objective that is determined while drilling a first interval of the borehole using a first set of values of the set of control variables; and

compare to the predetermined value of the drilling performance objective a second value of the drilling performance objective that is determined while drilling a second interval of the borehole using a second set of values of the set of control variables; and

select the operative set of values based on the comparisons.

11. The apparatus of claim 9, wherein the offset value comprises magnitude and direction; and the drilling performance optimizer is configured to select the direction of the offset value based on which of the first and second set of values for the set of

control variables is applied to produce the value of the drilling performance objective closest to the predetermined value of the drilling performance objective.

12. The apparatus of claim 11, wherein the drilling performance optimizer is configured to:

apply an offset having a same direction as that of a last applied offset based on the second set of values being applied to produce the value of the drilling performance objective closest to the predetermined value of the drilling performance objective; and

apply an offset having a different direction from that of a last applied offset based on the first set of values being applied to produce the value of the drilling performance objective closest to the predetermined optimum value of the drilling performance objective.

13. The apparatus of claim 11, wherein the drilling performance optimizer is configured to:

select the second set of values based on the first set of values; and

apply the second set of values during a last drilling interval and apply the first set of values during a penultimate drilling interval.

14. The apparatus of claim 9, wherein the drilling performance optimizer is configured to:

monitor the value of the drilling performance objective over drilling of more than three successive intervals of the borehole;

apply different sets of values for the set of control variables to each interval;

adjust each of the different sets of values by applying a near search offset;

determine whether the value of the drilling performance objective has changed over the more than three successive intervals; and

generate a far search set of values for the set of control variables by applying a far search offset value based on the drilling performance objective not having changed over the more than three successive intervals of the borehole;

wherein a magnitude of the far search offset value is greater than a magnitude of the near search offset value.

15. The apparatus of claim 9, wherein the set of control variables comprise at least one of weight on bit, bit rotational speed, drill string rotational torque, rate of penetration and bit diameter; and the drilling performance objective comprises at least one of mechanical specific energy of the drilling of the borehole and rate of penetration of drilling of the borehole.

16. A non-transitory computer-readable medium encoded with computer-executable instructions for automated drilling of a borehole in a subsurface formation, when executed the computer-executable instructions cause a processor to:

control drilling of a first interval of the borehole using a set of control variables populated with a set of first values;

determine a first value of a drilling performance objective corresponding to drilling of the first interval of the borehole;

control drilling of a second interval of the borehole using the set of control variables populated with a set of second values;

determine a second value of the drilling performance objective corresponding to drilling of the second interval of the borehole;

generate a set of third values for the set of control variables by applying an offset value to one of the set of first values and the set of second values; wherein selection the one of the set of first values and the set of second values to which the offset is applied is based on which of the first value of the drilling performance objective and the second value of the drilling performance objective is nearest to a predetermined value of the drilling performance objective; and

control drilling of a third interval of the borehole using the set of control variables populated with the set of third values.

17. The computer-readable medium of claim 16, encoded with instructions that cause a processor to generate the set of second values by applying an offset value to the set of first values.

18. The computer-readable medium of claim 16, encoded with instructions that cause a processor to:

control drilling of each of more than three successive intervals of the borehole using the set of control variables populated with a different set of values for each interval;

generate each different set of values by applying a near search offset value to a previously used set of values;

determine whether the value of the drilling performance objective has changed over the more than three successive intervals;

generate a far search set of values for the set of control variables by applying a far search offset value to a previously used set of values based on the drilling performance objective not having changed over the more than three intervals of the borehole; and

control drilling on an interval of the borehole using the set of control variables populated with the far search set of values;

wherein a magnitude of the far search offset value is greater than a magnitude of the near search offset value.

19. The computer readable medium of claim 16, wherein the offset value comprises a magnitude and a direction.

20. The computer readable medium of claim 16, encoded with instructions that cause a processor to:

apply an offset value comprising a first direction based on the set of first values being selected; and

apply an offset value comprising a second direction based on the set of second values being selected.

21. The computer readable medium of claim 20, wherein the second direction is the same as a direction of an offset value applied to the set of first values to produce the set of second values.

22. The computer-readable medium of claim 16, encoded with instructions that cause a processor to:

select at least one control variable of the set of control variables from a group consisting of weight on bit, bit rotational speed, drill string rotational torque, rate of penetration and bit diameter; and
select the drilling performance objective from a group consisting of mechanical specific energy of the drilling of the borehole and rate of penetration of drilling of the borehole.