Title: DRILLING CONTROL METHOD AND SYSTEM

Abstract: Method and system for drilling control comprising a plurality of controllers adapted to control performance process parameters, on the basis of driller controls from a driller that provides this as instructions to said controllers, wherein the system further comprises sensors and means for obtaining process values, such as downhole pressure, temperature and torque, wherein the system is adapted to, continuously and/or repeatedly, calculate safeguard envelopes for performance process parameters on the basis of process values and drilling process models and that it is adapted to restrain said controllers from applying performance process parameters outside said safeguard envelopes as a result of driller instructions, and a method and system for automatically triggering a remedying action in case of an evolving or existing critical situation, comprising calculation of process parameter boundaries which represent a critical condition for the well by using calibrated drilling process models, comprising (i) triggering an emergency action if a parameter exceeds said boundaries, said emergency action being intended to minimize the effect of said critical situation, (ii) then further analyzing the well in order to determine which remedying action to then be applied, the remedying action being intended to remedy the cause of said effect; (iii) if said remedying action is not capable of remedying the cause of said effect, then applying predetermined safe process parameters or shutting down.

Diagram: Fig. 2

NEW COMPONENTS

DIAPHRAGM FACTORY CONDITIONS

CONFIGURATION

CALIBRATION DATA/INFORMATION

MACHIQUE CONTROL

PERMEABILITY

DEVIATIONS

MANUAL DISPOSITIONS

DRILLING
The present invention relates to drilling of hydrocarbon wells. In particular, the invention relates to a method and a drilling control system for providing risk reduction and improved efficiency of a drilling process.

**Background**

When drilling a hydrocarbon well, such as a subsea well, it is known to operate the drilling equipment through a computerized drilling system. The drilling operator controls the various parameters of the process using control devices such as joysticks, throttles or switches. The control devices are connected to equipment controls, such as a controller for the rotary table.

When drilling such a well, one wishes to drill the well as efficiently as possible, with regards to time, cost and safety, while at the same time avoiding doing any damage to the formation being drilled, which may contain producible gas and oil reservoirs. To achieve this one must adapt the drilling process to drilling of the well in question. This has been the case for the history of drilling of oil and gas wells.

Systems are known which monitor drilling control parameters in order to prevent damage to the drilling equipment, for instance to the drill bit or tubular (drill string, casing or liner). Such control parameters can include drill string velocity, drill string torque, drill string RPM, hook load, WOB, pump flow rate, and choke opening and choke pump flow rate. They may automatically generate an alarm if a critical situation is detected.

The challenges in controlling the drilling process are not new, but drilling of oil and gas wells is becoming more and more of a challenge. Known reservoirs are being depleted, leading to problems with both formation stability and narrowing pressure windows. Expanding areas of exploration and production, including increasing activities in arctic and deep sea/deep reservoir areas, are generating new demands on safety and accuracy of drilling process control.

Patent publication US 7,172,037 (Baker Huges Inc.) describes a system for optimizing a drilling process by providing optimized parameters to the driller or
drilling control system. Patent publication US 6,662,110 also regards a system for optimization of a drilling process as well as for protection of well drilling systems.

Patent publication US 6,968,909 (Schlumberger) describes a downhole drilling system that is based on running scripts for various drilling steps and drilling conditions. For instance, a tripping script is run for tripping of the drill string. Thus, with this system, the drilling is performed on "autopilot", for as long as the system recognizes what is taking place ("diagnostic" (316) and "manual control" (320) in Fig. 3). This automated system collects downhole and surface measurements to continually update drilling process models and to calculate optimised drilling parameters as well as operating limits. In addition, it contains automated analysis of the drilling conditions, which can result in running of a remedying script if an undesired condition is detected.

It is, however, desirable to perform drilling operations manually, in the sense of controlling the drilling equipment, such as the top drive / the rotary table, mud pumps, and the winch drive (drawworks) with suitable interface means, such as a joystick, without the risk of damaging the well due to human error. The present invention provides a novel solution to this task.

Furthermore, current systems for optimisation of drilling parameters work independently, individually controlling one parameter or a set of parameters to enable optimisation with respect to a particular mechanism. Full optimisation with respect to individual mechanisms may be detrimental to other process mechanisms. As an example, fully optimised rate of penetration with respect to specific mechanical energy, through adjustment of WOB and RPM may lead to cuttings build-up issues if the pump rate is not adjusted accordingly, which is further constrained by the existing formation geopressures. Intelligent coordination between different input to optimisation and given constraints is desirable to ensure that the overall process is optimal.
The invention
A new methodology has been developed to fulfill the requirements described above. The overall objective of this method is to maintain the functioning of the drilling machinery within safeguards accounting for both the machine limitations but also the wellbore limits. In addition, automatic triggering of corrective actions can assist in maintaining the well integrity in case of abnormal situations.

The goal of this methodology is not to completely automate part or the whole of the drilling process, but to apply continuously updated envelopes of protection. Therefore the operator has the freedom to operate the drilling machinery as he wishes, while he is given assistance in maintaining the drilling conditions within safe boundaries. This methodology is solely used by the drilling machinery operators.

The methodology provides direct machine control but can also provide early problem detection during the drilling process, so that the operator can decide on corrective actions, or alternatively trigger automatic actions in case of emergency to take advantage of the rapidity of computer controlled machine steering.

When determining preferable drilling control parameters today, such as ROP, WOB, applied drillstring torque and drilling fluid circulation rate, one takes into account such properties as the dimensions of the well, formation properties (e.g. stresses, geopressures, geothermal), the drillstring (e.g. bit type, material properties of string elements) and the drilling fluid (e.g. density, rheology). For updating of optimal parameters, analysis of well behaviour during drilling of the well may be performed, where available data from sensors on the rig and downhole are applied, possibly together with results from active testing of the well. From such analysis permissible operational windows and process constraints may also be determined. Such analysis is normally performed independently of the drilling operation on the rig.

Process constraints comprise machine limits, material limits and wellbore/formation limits. Machine limits (e.g. maximum power of draw works engines) and material limits (e.g. maximum torque on drill string elements) are
provided by the suppliers of the drilling machinery. Wellbore and formation limits may be determined by analysis of historical data from offset wells and survey data, and by active testing of the well (e.g. Leak Off Test/Formation Integrity Test to determine upper pressure bound). Such active tests are performed by the drilling crew on the rig.

Since all decision making is done by the operator based on availability of information, there will always be a time delay before any action is taken when undesired symptoms are observed. During this delay there is a great risk of the observed problem escalating and becoming more severe (e.g. pressure build-up).

Unexpected behaviour occurring during drilling operations is today detected by the drilling crew with the aid of alarms. It is the drilling crew’s task to interpret behaviour and take appropriate mediating measures. The reaction taken depends on the experience of the crew, and various procedures may be used for the same type of incident. This is one of the major challenges of today’s drilling process. The full know-how of the organisation is not applied, and inappropriate mediating actions may cause loss of time, loss of production, and possibly loss of the well. Thus, as will appear from the description below, an advantageous embodiment of the invention comprises means for rapid remedial action.

According to a first aspect of the invention there is provided a method of drilling an oil or gas well, wherein performance process control parameters are controlled through machine controllers, wherein a driller drills a well by controlling said process control parameters through said machine controllers with driller instructions, and wherein process values are provided, for instance measured, and continuously or repeatedly input to a safeguard calculation unit. According to the invention the method comprises the following steps:

(a) with the safeguard calculation unit, continuously or repeatedly calculate safeguard limits for process control parameters, derived from process limits, such that at least some of said safeguard limits constitute boundary values of performance process parameter-related safeguard envelopes;
(b) restricting controller output to remain within said safeguard envelopes, as said controllers are adapted to keep said controller output within said safeguard envelopes, thereby preventing driller instructions to result in performance process parameters exceeding said safeguard envelopes;

The said safeguard calculation unit comprises continuously calibrated drilling process models, which enable calculation of safeguards limits for said performance process control parameters, the calculation being based on for instance wellbore pressure limits and mechanical tubular limits as constraints, as well as current process values. The said safeguard calculations are performed by iterative calculations until the safeguard limits converge, for instance with respect to (or align with) the wellbore pressure limits and mechanical tubular limits.

In the simplest application, step (c) involves using an iterative zero point solver applying forward calculations of the hydraulics model for calculating acceleration, deceleration and velocity limits for pipe movement (with geopressures applied as constraints.

In a preferred embodiment, the method according to the first aspect of the invention is characterized in that values and/or parameters are provided by application of one or more of the following systems:

i) a drilling machinery data acquisition system, which is an integrated part of a machine control system and which is adapted to provide control system values, such as for instance standpipe pressure, active volume, block velocity, block position, hook load, bit depth, ROP, RPM, pipe torque, drilling fluid pit temperature, and drilling fluid pit density;

ii) a mud logging system, which may consist of manual or automatic fluid sampling and analysis providing such measurements as drilling fluid rheology, composition, temperature and density; and

iii) a downhole measurement data acquisition system, comprising downhole sensor tools for providing downhole measurements, such as downhole pressure, downhole temperature and survey measurements.
The rate and quality of these measurements can differ depending on the type of sensor and the mode of transmission of the measurements. Therefore there is a need to integrate the different sources, apply necessary corrections and quality control procedures before making use of the measurements in further calculations.

In another preferred embodiment of the method according to the first aspect of the invention, it comprises storing and communicating data, wherein provided data is stored in a data repository, such as a database, and at least some of said data is being quality controlled, and wherein at least some of said data is being used for calibration of said drilling process models for application in safeguarding and diagnostics. For ease of communication such a data repository may apply open standards of data communication such as OPC or WITSML. The data repository may also store set-points defining behaviour of machine controllers.

The method may also involve applying automated data quality control through filtering applications, such as FIR / MR filtering and automatic high pass coefficient distribution analysis, allowing for smoothing and detection of outliers (or invalid measurements).

Furthermore, the method can be characterized in that calibration of drilling process models of the drilling process (e.g. drill-string mechanic, drilling fluid hydraulic, heat transfer and rock mechanic) are used to calculate the envelope of protection to maneuver the drilling machinery. Some inputs used by such models are uncertain or not well known. It is therefore necessary to estimate those parameters using real-time measurements within a calibration process. The objective is to achieve a global calibration of the physical models for the remaining of the drilling operation. At start, the parameters requiring calibration are uncertain and therefore the quality of the results predicted by the physical models is at its lowest. With time, acquired measurements help reducing the uncertainty on the physical parameters being calibrated and therefore the accuracy of the calculations made with the physical models increases.
In another embodiment of the method according to said first aspect, the method involves calibrating drilling process models, wherein for the calibration of hydraulics models, fluid flow friction factor calibration is performed by using unscented Kalman filtering or steady state model with zero point solver, wherein measured standpipe pressure and downhole pressure are applied for calibration.

It is also possible to calibrate the drilling process models in such way that for the calibration of torque and drag model, drill string sliding/rotating friction is estimated by using back calculation with a zero point solver, applying measured hook load and torque for model tuning.

The method may also comprise continuously applying tubing/drill string velocity safeguards during running and pulling of a tubular, wherein

i) iterative calculation of drill string velocity, acceleration and/or deceleration limits is performed by forward calculations using calibrated hydraulics model from current process values, bounds given by pressure limits (PP or FP) in open hole section, and zero point solver; and wherein

ii) drill string velocity acceleration and/or deceleration limits are enforced through machine controllers.

Also, the method according to the first aspect of the invention may involve performing continuous application of tubular mechanical safeguards during movement of such, such as maximum overpull / setdown weight and rotating torque, wherein

i) bounds are given by elastic limits constraints and direct calculation of limits is performed using current configuration of wellbore trajectory and tubular length; and wherein

ii) tubular mechanical limits are enforced through machine controllers.

In an additional embodiment, the method comprises the steps of

i) continuously or repeatedly predicting future process values on the basis of at least drilling process models and past or current process values;

ii) in that future, comparing predicted process values with current process values, as measured or otherwise provided; and then
iii) if current process values deviate outside predetermined allowed deviation values, input remedying instructions to said controllers in order to provide remedying performance process parameter from said controllers.

According to a second aspect of the present invention, there is provided a drilling control system comprising a plurality of controllers adapted to control performance process parameters, on the basis of driller controls from a driller that provides this as instructions to said controllers, wherein the system further comprises sensors and means for obtaining process values, such as downhole pressure, temperature and torque. The system is adapted to, continuously and/or repeatedly, calculate safeguard envelopes for performance process parameters on the basis of process values and drilling process models and that it is adapted to restrain said controllers from applying performance process parameters outside said safeguard envelopes as a result of driller instructions.

Preferably, the system according to the second aspect of the present invention is characterized in that
i) machine controller algorithms for application of derived safeguards are implemented directly in the machine controllers;
ii) the behaviour of these machine controller algorithms is uniquely defined through setpoints or curves;
ii) calculated setpoints or curves defining safeguards, are communicated to the machine controllers from the safeguard calculation units through a central data repository;
iv) the commands given by the operator are constantly compared to the continuously updated envelopes of protection of the drilling machinery. If these commands are within the safeguards they are used directly to control the drilling machines. However, if the commands are outside the acceptable limits of both the well and the capability of the drilling machinery, the safest condition is applied.

According to a third aspect of the present invention, there is provided a method for automatically triggering a remedying action in case of an evolving or existing critical situation, comprising calculation of process parameter boundaries which
represent a critical condition for the well by using calibrated drilling process models. The method comprises

(i) triggering an emergency action if a parameter exceeds said boundaries, said emergency action being intended to minimize the effect of said critical situation,

(ii) then further analyzing the well in order to determine which remedying action to then be applied, the remedying action being intended to remedy the cause of said effect;

(iii) if said remedying action is not capable of remedying the cause of said effect, then applying predetermined safe process parameters or shutting down.

In an embodiment of the third aspect of the present invention, the method is applied for detection of packoff / bridging, wherein

(a) limits for detecting indication of packoff or bridging are detected by
   • rapid buildup of pump pressure;
   • steady increase / erratic torque behaviour;
wherein detection is achieved by comparing predicted values, by using models, to actual behaviour;

(b) limits for triggering automated action with respect to pump pressure and torque behaviour are calculated as a function of fluid flowrate, pipe torque and RPM;

(c) immediate automatic action comprises a predefined %-wise reduction of flowrate;

(d) if packoff is diagnosed due to continuously increasing pump pressure / torque or sustained erratic torque, automatic shutdown of pumps is performed;

(e) if bridging is diagnosed by resulting stabilised torque variations / pump pressure, then flowrate is automatically increased to maximum allowable flowrate as a function of bridge, as defined by remediating algorithms with calculated input parameters.

According to a fourth aspect of the present invention, there is provided a system for calculation of the acceptable threshold conditions before determining that the
well has entered a critical situation. The system is adapted to apply the calibrated drilling process models in said calculation, wherein, in case a parameter is exceeding the continuously updated conditions for a critical situation, an automatic action is triggered automatically to minimize the effect of the critical situation. This automatic action can adapt itself as a function of the response of the well to the automatic action. Preferably, this system is further characterized in that

i) machine controller algorithms for automatic triggering of remediating action are implemented directly in the machine controllers;

ii) machine controller algorithms for dynamic remediating action are implemented directly in the machine controllers;

iii) calculated setpoints / curves / surfaces defining triggering and dynamic remediating action are communicated to the machine controllers from the calculations through a central data repository;

iv) the measured process values are continuously compared with the triggering limits, and wherein, if triggering limits are exceeded then remediating action is automatically triggered;

v) after triggering, further remediating control is performed dynamically as a function of response, as defined by the setpoints / curves / surfaces defining appropriate dynamic remediating action.

According to the present invention, one may also imagine using the same methods and systems for calculating a window of efficiency. That is, using the same methodology for keeping the process within a preferred operational window. Thus, one may use the same set-up for the window of efficiency as is used for said safeguard limits or safeguard windows.

The term performance process parameter defines a parameter or value which can be controlled or changed by the driller by appropriate instructions to or control of the drilling equipment. Such parameters can include values for WOB (weight on bit), drillpipe, RPM (rotations per minute), and drilling fluid flowrate.

A driller should be conceived as a person who manually controls the drilling process by giving driller instructions with suitable interface means, such as
joysticks, throttles or switches. Hence, driller instructions are instructions for performance process parameters.

Furthermore, a controller is a device that controls engines or other actuators, such as the engine for the rotary table/top drive, drawworks or the pump for the mud flow. A controller can thus control an engine on the basis of driller instructions, however while being operated by software or software-corresponding hardware, such as a logic electrical circuit.

Process values are various characteristics related to the drilling and the drilled well, such as ROP (rate of penetration), temperatures, pressure, cuttings concentration, and drill string torque.

Control system values are values that are directly generated in the surface drilling control system (DCS) through the DCS instrumentation (as opposed to measured values downhole).

The safeguards' limits are limits within which performance parameters are to be kept.

Drilling process models are models used to simulate a drilling process. Some of the most important models are hydraulics model (pressure, density, multiphase flow), temperature model, mechanics model (torque and drag, string/pipe forces, torque). Furthermore, there are earth models, comprising formation layering model, formation stresses/geopressures model, and geothermal models. In addition there are wellbore models, comprising wellbore stability model and trajectory model.

**Example of embodiment**

In order to give a more thorough understanding of the various features of the present invention, a detailed description of an example embodiment is given in the following with reference to the drawings, in which

Fig. 1 is an illustration of a prior art system for drilling process control;
Fig. 2 is a schematic illustration of a set-up according to the present invention; Fig. 3 is a schematic diagram illustrating the flow of information in a system according to the one shown in Fig. 2; Fig. 4 is a schematic diagram illustrating an example of tripping / reaming control; Fig. 5 is a schematic diagram illustrating tripping/reaming without safeguarding; Fig. 6 is a schematic diagram illustrating an automatic stuck pipe action; and Fig. 7 is a flow chart for manual pack-off or bridging prevention.

Fig. 1 illustrates a known set-up for a drilling process. For drilling of oil and gas wells, such a drilling control system (DCS) can be used on the drilling rig. A DCS of the prior art may consist of sensors for measuring drilling parameters, computer controlled drilling machinery with computer aided machine control, and a human operator interface. The objective of such a system is to aid the driller (or operator) in controlling drilling process parameters, such as velocity of the drill string when running in and out of the borehole, or wellbore fluid flowrate, through application of software control algorithms embedded in the machine control.

In addition to the manual control of parameters performed by the operator or driller in Fig. 1, there may be manually tunable parameters in the MACHINE CONTROL, such as constant WOB or ROP settings which may be automatically enforced by the system through application of process control during drilling operations, though application of machine control algorithms. However, there can also be automated dynamic control of control parameters. To avoid damage to the drilling machinery, limits with regards to machinery operational parameters may be automatically enforced through drilling control system algorithms. Such parameters would be set through "system configuration" in Fig. 1.

Furthermore, the "runtime support-unit" in Fig. 1 provides analysis of measured data, providing feedback to the driller for process control optimization, e.g. values for WOB and pipe revolution frequency to achieve optimal drilling rate of penetration (ROP), or maximum allowable pump-rate given the existing well pressure boundaries and mud properties. To provide update of necessary information for such analysis, "manual measurements" may be performed, such
as measurements of mud properties performed by the mud engineer on the rig. Input from support personnel is also communicated to the driller.

In order for the machine control algorithms to function properly, initial configuration of process properties, such as drillpipe section lengths, and setting of control parameters, such as ROP or WOB are performed with the "system configuration"-unit prior to drilling operations. Such settings may of course also be updated during operations, based on analysis of process behavior, provided by runtime support.

Having described some essential features of a prior art set-up, reference is now made to Fig. 2, illustrating an embodiment of the present invention. Before going into detailed examples (further below), an overview of the main features and possibilities is given.

The main principle of this set-up is to use physical models of the drilling process to update continuously acceptable safeguards and conditions for triggering emergency procedures.

The system can be decomposed in the following steps:

1. Acquire data and perform a quality assurance (QA) of the measurements
2. Calibrate the physical models
3. Calculate the safeguards and critical conditions for abnormal situations
4. Steer the drilling machinery within an envelope of protection
5. Warn the operator of downhole condition deterioration
6. Trigger automatic actions in case an unexpected event has been recognized.

Preferably, the data for such a system is provided by three different systems:

- A drilling machinery data acquisition system
- A mud logging unit
- A downhole measurement data acquisition system
The rate and quality of these measurements can differ depending on the type of sensor and the mode of transmission of the measurements. Therefore the different sources are integrated and necessary corrections are performed, as well as quality control procedures, before making use of the measurement in further calculations.

The various physical models of the drilling process (such as drill-string mechanic, drilling fluid hydraulic, heat transfer and rock mechanic) are used to calculate the envelope of protection to maneuver the drilling machinery. Some inputs used by such models are uncertain or not well known. It is therefore necessary to estimate those parameters using real-time measurements within a calibration process. The objective is to achieve a global calibration of the physical models for the remaining of the drilling operation. At start, the parameters requiring calibration are uncertain and therefore the quality of the results predicted by the physical models is at its lowest. With time, acquired measurements help reducing the uncertainty on the physical parameters being calibrated and therefore the accuracy of the calculations made with the physical models is increasing.

Using the calibrated physical models, calculation of envelopes of protection of the drilling machinery in function of the different type of drilling operations (tripping, reaming, drilling, circulation, etc) is performed. Preferably, one also calculates the maximum acceptable conditions before considering that the well has entered a critical situation.

The commands given by the operator are constantly compared to the continuously updated envelopes of protection of the drilling machinery. If this command is within the safeguards it is used directly to control the drilling machines. However, if the command is outside the acceptable limits of both the well and the capability of the drilling machinery, the safest condition is applied. Thus, the driller is indeed controlling the machinery manually (i.e. through appropriate interface means), but the well and machinery are protected from overloading.
During the drilling process, the evolution of drilling parameters is continuously monitored and compared with predictions made by the calibrated physical models. Discrepancies between the measurements and the forecasts may be indication of downhole condition deterioration. Forward simulations made with the current conditions are used to check if the current section can be drilled safely. If it is still possible to drill to end of the section, warnings are raised to signal the operator of the potential problem. But if it will not be possible to reach the end of the section, an alarm is generated to inform the operator that corrective actions need to be run in order to cure the problem. In this way, the system takes advantage of the experience and the analytic capabilities of the driller in such a challenging situation, while still keeping the equipment and the well safe from damage.

In case a parameter is exceeding the continuously updated conditions for an unexpected situation, an automatic action is triggered automatically to minimize the effect of, and possibly remedy the critical situation. This automatic action can adapt itself as a function of the response of the well to the procedure.

Fig. 3 is a schematic diagram illustrating the flow of information in a system according to the one shown in Fig. 2.

Having described the main features of the embodiment shown in Fig. 2 in a general manner, reference is now made to Fig. 4, and a more tangible example of use will be given.

Fig. 4 illustrates the use of a tripping safeguarding unit which calculates maximum acceleration, velocity and deceleration of the drill string. The safeguarding ensures that the downhole pressure window is not exceeded as a result of pipe movement. With application of models in safeguarding, downhole pressure is known with high accuracy at all times, ensuring good control. If the driller (i.e. the driller signal) remains within the safeguard envelope, the left hand side of the diagram of Fig. 4 will apply. The driller then freely instructs the machinery within the safeguard envelope. However, should the driller give
instructions that extend beyond machine limits, the machine limits will be applied and restrict the driller's instructions (see lower left box of Fig. 4).

On the other hand, if the driller moves outside the safeguard envelope, his control signal is limited to the safeguard limit. Also, if this safeguard limit is outside machine limits, the machine limit is applied.

Fig. 5 illustrates an embodiment without safeguarding. In this embodiment only the drilling machinery is protected by the system. In this embodiment the driller must himself ensure that the downhole pressure is within the available operating window, while performing a tripping operation. Thus, if the driller remains within the machine limits, his signal will be applied directly. If he moves outside the machine limits, the limits will be applied instead of his signal.

Fig. 6 shows the set-up for an automatic mediating action on detection of pack-off or bridging. If indication of possible pack-off/bridging is measured, the driller is alerted and the flowrate (Q) is reduced to a reduced (emergency) flowrate (Qem). The Qem can for instance be 80% of the maximum circulation rate. T and Tmax are the torque and the maximum torque of the drill string, respectively. Tmax is calculated on the basis of mechanical models, and depends on the position of the drill string, its characteristics, hole configuration, circulation rate, etc. In case of bridging (right hand side of Fig. 6), the flow rate is reduced to safe flowrate (Qs).

If the situation stabilizes the driller is alerted and the automated control procedure is finished. If not, the pumps are stopped (left hand side of Fig. 6). Also, in case of pack-off (left hand side), the pumps are stopped and the driller is alerted, see Fig. 6. Also in case of pack-off, the drilling is interrupted and the pumps are stopped. In Fig. 6, the abbreviations have the following meanings:

Qem - Emergency flowrate (e.g. 80%)
Tmax - Maximum torque (calculated based on makeup / yield)
SPPem - emergency standpipe pressure (standpipe pressure with emergency flowrate)
Qs(SPPem) - Safe flowrate (which is a function of extent of bridge (narrowing of annulus) which is derived from emergency standpipe pressure SPPem using hydraulics model)

SPPs - Safe standpipe pressure (calculated using hydraulics model - function of extent of bridge derived from emergency standpipe pressure)

SPPmeasured - measured standpipe pressure

Fig. 7 illustrates a flow chart for manual pack-off or bridging prevention.

With the present invention several advantages are obtained. For instance, by the application of calibrated models, continuously updated operational parameter windows are available. The parameter windows are updated faster than what is possible with remote support, and also much more accurate than planned limits, since the updated limits are based on real values, not foreseen or predicted values.

The possibility to drill directly, i.e. to control the machinery directly through interface means such as joysticks and switches, with the safeguarding function to account for excessive drilling instructions, makes it possible to take advantage of human knowledge and experience while still not risking damage to the equipment or formation.

Due to the more accurately calculated parameter windows, tripping or reaming operations can be performed faster, thereby saving valuable time and hence costs.

Also, the demands on the driller to detect emerging critical situations and react accordingly is reduced, since the system will monitor such conditions automatically.


Claims

1. Method of imposing safeguard during drilling of a well, such as an oil and/or gas well, by the use of a drill rig having at least a speed controlled pipe string hoist, wherein performance process control parameters are controlled through machine controllers, wherein a driller drills a well by controlling said process control parameters through said machine controllers with driller instructions, and wherein process values are provided, for instance measured, and continuously or repeatedly input to a safeguard calculation unit, where the safeguard calculation unit, continuously or repeatedly calculate safeguard limits for process control parameters, derived from process limits, such that at least some of said safeguard limits constitute boundary values of performance process parameter-related safeguard envelopes, characterized in restricting controller output to remain within said safeguard envelopes, as said controllers are adapted to keep said controller output within said safeguard envelopes, thereby preventing driller instructions to result in performance process parameters beyond said safeguard envelopes;

wherein said safeguard calculation unit comprises continuously calibrated drilling process models, which enable calculation of safeguards limits for said performance process control parameters, the calculation being based on at least one of the following limits - wellbore pressure limits - wellbore stability limits, - mechanical tubing limits, as constraints, as well as current process values, and wherein said safeguard calculations are performed by
iterative calculations until the safeguard limits converge.

2. Method according to claim 1, characterized in that values and/or parameters are provided by application of one or more of the following systems:

i) a drilling machineries data acquisition system, which is an integrated part of a machine control system and which is adapted to provide control system values

ii) a mud logging system; and

iii) a downhole measurement data acquisition system, comprising downhole sensor tools for providing downhole measurements, such as downhole pressure, downhole temperature and survey measurements.

3. Method according to any one the preceding claims, characterized in calibrating drilling process models, wherein for the calibration of hydraulics models, fluid flow friction factor calibration is performed by using unscented Kalman filtering or steady state model with zero point solver, wherein measured standpipe pressure and downhole pressure are applied for calibration.

4. Method according to any one the preceding claims, characterized in calibrating drilling process models, wherein for the calibration of torque and drag model, tubular (drill string / casing / liner) sliding/rotating friction is estimated by using back calculation with a zero point solver, applying measured hook load and torque for model tuning.

5. Method according to claim 1, characterized in continuously applying tubular velocity safeguards during running and pulling of a tubular, wherein

i) iterative calculation of tubular velocity limits is
performed by forward calculations using calibrated hydraulics model from current process values, bounds given by pressure limits (PP or FP) in open hole section, and zero point solver; and wherein

ii) tubular velocity limits are enforced through machine controllers.

6. Method according to claim 1, characterized in performing continuous application of tubular mechanical safeguards during reaming and reciprocation, such as maximum overpull / setdown weight and rotating torque, wherein

i) bounds are given by elastic limits constraints and direct calculation of limits is performed using current configuration of wellbore trajectory and tubular length; and wherein

ii) tubing mechanical limits are enforced through machine controllers.

7. Method according to any one of the preceding claims, characterized in,

i) continuously or repeatedly predicting future process values on the basis of at least drilling process models and past or current process values;

ii) in that future, comparing predicted process values with current process values, as measured or otherwise provided; and then

ii) if current process values deviate outside predetermined allowed deviation values, input remedying instructions to said controllers in order to provide remedying performance process parameter from said controllers.

8. Drilling control system comprising a plurality of controllers adapted to control performance process parameters, on the basis of driller controls from a
driller that provides this as instructions to said controllers, wherein the system further comprises sensors and means for obtaining process values, such as downhole pressure, temperature and torque, characterized in that it is adapted to, continuously and/or repeatedly, calculate safeguard envelopes for performance process parameters on the basis of process values and drilling process models and that it is adapted to restrain said controllers from applying performance process parameters outside said safeguard envelopes as a result of driller instructions.

9. Method for automatically triggering a remedying action in case of an evolving or existing critical situation, comprising calculation of process parameter boundaries which represent a critical condition for the well by using calibrated drilling process models, characterized in

(i) triggering an emergency action if a parameter exceeds said boundaries, said emergency action being intended to minimize the effect of said critical situation,

(ii) then further analyzing the well in order to determine which remedying action to then be applied, the remedying action being intended to remedy the cause of said effect;

(iii) if said remedying action is not capable of remedying the cause of said effect, then applying predetermined safe process parameters or shutting down.

10. Method according to claim 9 for application of automatic remediating action on detection of packoff / bridging, characterized in that

(a) limits for detecting indication of packoff or bridging are detected by
• rapid buildup of pump pressure;
• steady increase / erratic torque behaviour;
wherein detection is achieved by comparing predicted values, by using models, to actual behaviour;

(b) limits for triggering automated action with respect to pump pressure and torque behaviour are calculated as a function of fluid flowrate, pipe torque and rpm;

(c) immediate automatic action comprises a predefined %-wise reduction of flowrate;

(d) if packoff is diagnosed due to continuously increasing pump pressure / torque or sustained erratic torque, automatic shutdown of pumps is performed;

(e) if bridging is diagnosed by resulting stabilised torque variations / pump pressure, then flowrate is automatically increased to maximum allowable flowrate as a function of bridge, as defined by remediating algorithms with calculated input parameters.

11. System for calculation of the acceptable threshold conditions before determining that the well has entered a critical situation, adapted to apply the calibrated drilling process models in said calculation, wherein, in case a parameter is exceeding the continuously updated conditions for a critical situation, an automatic action is triggered automatically to minimize the effect of the critical situation, characterized in that this automatic action can adapt itself as a function of the response of the well to the automatic action, and wherein

  i) machine controller algorithms for automatic triggering of remediating action are implemented directly in the machine controllers;
  ii) machine controller algorithms for dynamic remediating action are implemented directly in the machine controllers;
iii) calculated setpoints /curves / surfaces defining
triggering and dynamic remediating action are
communicated to the machine controllers from the
calculations through a central database;

iv) the measured process values are continuously compared
with the triggering limits, and wherein, if triggering
limits are exceeded then remediating action is
automatically triggered;

v) after triggering, further remediating control is
performed dynamically as a function of response, as
defined by the setpoints/curves/surfaces defining
appropriate dynamic remediating action.
Fig. 1
(prior art)
Fig. 2
Fig. 3

Fig. 4
Drillers signal applied directly

Inside machine limits

Control

Pipe velocity

Driller

Exceed machine limits

Machine limits applied

Fig. 5

Indication of possible packoff/bridging
- Exceed torque variation
- Exceed pressure/pressure buildup

Continued Pressure/torque increase
OR T = Tmax

Packoff

Alert driller and reduce Flowrate to Q = Qm

Pressure/torque Stabilised
AND T < Tmax

Reduce to safe flowrate
Q = Qs(SPPem)

Pressure OK?
SPPs(SPPem) > SPPmeasured
AND T < Tmax

No

Bridging

Yes

Automatic control procedure finished
Alert Driller

Fig. 6
Driller observes prolonged indication of packoff/bridge tendencies: Pressure increasing Torque buildup/erratic torque

Driller halts drilling; reduces flowrate

Continued indication

Further reduction of flowrate; Work pipe to clean hole

Situation stabilises

Unsuccessful

Symptoms gone

Attempt to reestablish circulation

Successful

Proceed drilling

Fig. 7
INTERNATIONAL SEARCH REPORT

International application No. PCT/NO2010/000081

A. CLASSIFICATION OF SUBJECT MATTER
E21B 44/00 (2006.01), E21B 41/00 (2006.01)
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NO, DK, FI, SE: Classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPODOC, WPI, FULL TEXT DATABASES, PATGRANSK

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>Li, G. et al. An Iterative Ensemble Kalman Filter for Data Assimilation. SPE Annual Technical Conference and Exhibition, 11-14 November 2007, Anaheim, California, USA, SPE 109808 Page 1 lines 1-13</td>
<td>8</td>
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</tbody>
</table>

Further documents are listed in the continuation of Box C. See patent family annex.

Date of the actual completion of the international search: 28/05/2010

Date of mailing of the international search report: 01/06/2010

Authorized officer: Bjørn Inge Kalland

Telephone No.: +47 2238 7400 (direct)

Form PCT/ISA/210 (second sheet) (July 2009)
<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
</table>
INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO2010/000081

Box No. II  Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. [ ] Claims Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III  Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. Claims: 1-8
Method and system for drilling control wherein the system is adapted to restrain process controllers from applying performance process parameters outside calculated safeguard envelopes as a result of driller instructions.

2. Claims: 9-11
Method and system for automatically triggering a remedying action in case of an evolving or existing critical situation.

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet (2)) (My 2009)