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A Real-Time Riser Management System For DP Drilling Vessels

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Abstract: Offset of a dynamically positioned drilling vessel from the setpoint location above the wellhead affects a number of operational parameters which influence the point at which a disconnect should be initiated. Factors establishing disconnect limits, among others, include bottom flex joint angle, top riser angle, slip joint strokeout, riser tensioner strokeout, and riser/moonpool contact. For each of these parameters, the vessel x,y positions at which the physical disconnect limit is reached are variable over the course of a drilling operation. Furthermore, in an emergency situation, the speed at which the vessel is moving and the time it takes for execution of the disconnect sequence bears directly on the point in time when the disconnect should be initiated.

Conventionally the bottom flex joint angle has been used as the determining disconnect parameter. With increasing water depth, either the surface slip joint strokeout or riser tensioner strokeout will become the physical limit. Depending on a particular rig's configuration, the existing weather conditions and/or drilling conditions, other equipment parameters may constitute the limiting factor.

This paper discusses a real-time riser management system which continuously monitors vessel, drilling, and riser parameters and processes this information in combination with vessel and riser mathematical models to present drilling personnel with information detailing the existing riser configuration and disconnect margins, and the margin remaining before a disconnect has to be initiated.

1.0 Introduction

Offset of a dynamically positioned drilling vessel from the setpoint location above the wellhead affects a number of operational parameters which influence the point at which a disconnect should be initiated. Factors establishing disconnect limits, among others, include bottom flex joint angle, top riser angle, slip joint strokeout, riser tensioner strokeout, and riser/moonpool contact. For each of these parameters, the vessel x,y positions at which the physical disconnect limit is reached (the limit envelope) are variable over the course of a drilling operation. Both the size and position of the limit envelopes are influenced by such factors as riser tension, mud weight, ocean currents, tidal and vessel draft changes, and vessel position, attitude, and wave induced motions. Furthermore, in an emergency situation, the speed at which the vessel is moving and the time it takes for execution of the disconnect sequence bears directly on the point in time when the disconnect should be initiated.

Conventionally the bottom flex joint angle has been used as the determining disconnect parameter. With increasing water depth, either the surface slip joint strokeout or riser tensioner strokeout will become the physical limit. Depending on a particular rig's configuration, the existing weather conditions and/or drilling conditions, other equipment parameters may constitute the limiting factor.

To accurately determine actual disconnect limits and safety margins, to provide information for operational riser management through adjustment of top tension and vessel position, and to provide the maximum time to deal with an emergency situation, it is essential to monitor, analyze, display and utilize disconnect information in real-time. This is what the SmartDisconnect and SmartRiser systems are designed to achieve.

Use of the these systems can improve operational economy by:

- reducing the probability of costly riser disconnect
- reducing the time spent with drilling suspended because of excessive riser angle
- enhancement of riser coupling fatigue life by facilitating lower stress levels
- reduction of keyseating inside the riser.

2.0 System Overview

The SmartDisconnect system (SDs) and SmartRiser system (SRs) are real-time computer systems designed to continuously monitor vessel, drilling, and riser parameters, process the measured parameters in combination with vessel and riser mathematical models, and present the processed information in such a way that ***drilling personnel can clearly understand the <u>existing</u> riser conditions and disconnect margins*** and ***the <u>margin remaining</u> (both distance and time) before a disconnect has to be initiated***. The systems provide information to allow positioning of the vessel to provide ***the greatest safety margin*** with respect to existing disconnect limits (i.e., the position providing the greatest allowable elapsed time for vessel movement before reaching the disconnect limit). Both systems utilize measurements from normal drilling system equipment and vessel instrumentation to monitor disconnect related parameters. The disconnect limit envelopes determined from the processing of the disconnect parameters are illustrated in Figure 2-1.

The SmartRiser system provides additional riser instrumentation and augmented riser mathematical models to determine the ***3-D riser profile*** and provide information for ***control of riser shape*** through adjustments in top tension and vessel position. This allows real-time riser management with information presented to facilitate positioning the vessel at the location which

- ***minimizes the curvature in the riser***
- ***minimizes the peak stress in the riser***.

The SmartRiser system can also

- determine the ***required riser space out*** prior to landing the stack
- maintain a ***database of cumulative riser stress***,

and estimate the ***riser profile*** for

- the ***LMRP disconnected*** and suspended at the bottom of the riser
- the ***stack unlatched*** and suspended at the bottom of the riser.

Operator data entry provides for system setup for the drill site, setting of red/yellow alarm limits for each disconnect parameter, and ongoing adjustment to account for changing conditions during drilling (variations in riser tension, mud weight, etc.).

Display and alarming of disconnect and riser data are at the system main console and at remote display terminals which can be located on the drill floor, DP room, BOP control room, toolpusher's office, and bridge.

3.0 Disconnect Parameters and Instrumentation

To a large extent the instrumentation necessary for monitoring disconnect parameters is included in other vessel and drilling equipment systems. For parameters that are not measured by rig systems, instrumentation is supplied as part of the SDs/SRs. Table 3-1 lists the SDs/SRs disconnect parameters and the rig systems in which they are likely to be found.

3.1 SRs Riser Instrumentation

For drilling locations where the current velocity profile may not be well known or the current may be time varying, the riser shape cannot be accurately determined with only top and bottom riser angle measurements. In this situation additional riser instrumentation providing tilt measurements at selected positions along the riser is required to adequately characterize the 3-D riser profile.

Table 3-1 SDs/SRs Parameters

Parameter	**Vessel System**
Vessel position - DGPS	DP system
Acoustic	DP system
Vessel heading	Vessel gyrocompass
Vessel pitch/roll	DPS vertical reference sensor(s)
Wind velocity	DPS anemometer(s)
Propulsion commands	DPS or propulsion controllers
Propulsion states	DPS or propulsion controllers
Riser top angle	BOP mux system
Flexjoint angle	BOP mux system
Slipjoint position	Drilling equipment
Riser tensioner position	Drilling equipment

The instrumented riser is illustrated in Figure 3-1. The underwater sensor packages measure riser tilt and 3-axis accelerations at points along the riser. The data is transmitted to the surface through the BOP MUX cables using inductively coupled modems. No special SRs cables are required.

4.0 Data Processing and System Functionality

The measured parameters, along with operator entered data, are processed in conjunction with vessel and riser mathematical models to:

- estimate the vessel position and velocity
- estimate the 3-D riser profile
- determine the existing disconnect limit envelopes and disconnect margins
- calculate the estimated time to reach the disconnect limit

and provide information for operational riser management by drilling personnel through adjustment of vessel position and top tension.

4.1 Vessel and Riser Estimators

The vessel and riser estimators determine the vessel position and velocity, and 3-D riser profile. This is done through the use of vessel and riser mathematical models which model dynamic (low frequency) vessel displacement and resultant riser shape in response to forces acting on the vessel and riser.

4.1.1 Smart Disconnect Estimator Configuration

The SmartDisconnect system estimator configuration is shown in Figure 4-1. The vessel equations of motion implemented in the vessel estimator model the relationship between environmental (wind, wave, current) and propulsion forces and vessel heading and horizontal displacement. The riser catenary equations implemented in the riser estimator relate the catenary shape and slipjoint slipout to top of riser (vessel) position, riser tension, and hydrodynamic (current and vessel velocity) and gravitational (riser weight, buoyancy, mud weight) forces.

4.1.2 Smart Riser Estimator Configuration

The SmartRiser system estimator configuration is shown in Figure 4-2. In the SRs configuration, the riser estimator is augmented to process the additional riser tilt measurements. The augmented riser estimator provides an estimate of the 3-D riser profile **<u>and</u> corresponding force profile** (i.e., the force profile necessary to produce the estimated riser shape). With the force profile along the riser determined (i.e., the current profile), **the SRs can estimate the expected riser profile for varying conditions of mud weight, top tension, and vessel position**. Riser bending moments and stress can be calculated from the riser profile.

4.2 SRs Accelerometer Processing

The SRs riser instrumentation accelerometer measurements can be processed to provide information on the **amplitude and frequency of the vortex induced vibrations** (x,y accelerations). When the LMRP/stack is not connected to the bottom, the z-axis accelerations can be processed to determine the vessel heave induced LMRP/stack/riser motions and the related dynamic riser stretch and stress.

4.3 Disconnect Limit Calculations

The disconnect limit calculations utilize the measured data and the vessel/riser estimators to determine the following disconnect limit information.

- the disconnect limit envelopes associated with each parameter
- the estimated time to reach the disconnect limit for drift-off and drive-off conditions
- disconnect margins and alarm conditions

How these items are determined is discussed below.

4.3.1 Disconnect Limit Envelopes

The disconnect limit envelopes represent, for each disconnect parameter, the locii of vessel x,y positions at which the disconnect alarm limits are reached (both red/yellow envelopes based on the operator-entered limit values). An illustration of disconnect limit envelopes is provided in Figure 2-1. These envelopes are determined through use of the riser estimator by moving the x,y vessel position radially outward from the present vessel position (setting vessel velocity to zero and holding the force profile constant) until the limit is reached. This is done in 10° azimuth increments, thus defining each limit envelope as a rosette made up of the end points of 36 limit vectors pointing radially outward from the present vessel position.

The limits for each of the disconnect parameters are determined as follows.

Flex joint angle: The flex joint angle limit is determined directly from the estimated riser profile as the set of vessel x,y positions where the flex joint angle is equal to the flex joint angle red/yellow limits.

Top riser angle: In the same fashion, the top riser angle limit is determined directly from the estimated riser profile as the set of vessel x,y positions where the top riser angle is equal to the top riser angle red/yellow limits.

Riser contact with the lower edge of the moonpool: This limit is determined as the top riser angle which would result in riser contact with the lower edge of the moonpool. The calculations are based on the moonpool and riser/slip joint dimensions and geometry, and the vessel list, trim, average heading, and short period pitch, roll, and yaw amplitudes. The limit is determined as the set of x,y positions where the [top angle + short period motion amplitude + red/yellow limit margin] would result in moonpool contact.

Slip joint/riser tensioner strokeout: This limit is determined as the vessel position where slip joint strokeout would result in the dynamic slip joint and/or riser tensioner stroke reaching the red/yellow stroke margin limit. The calculations are based on the present slip joint and riser tensioner center positions, heave motion amplitudes, and the slip joint to riser tensioner stroke relationship. The limit is determined as the vessel position where the [slip joint/tensioner center position + motion amplitude + strokeout + red/yellow limit margin] would result in the either the slip joint or tensioner reaching the maximum physical strokeout limit.

4.3.2 Time to Reach Disconnect Limit

The estimated time to reach the disconnect limit is determined by running the vessel/riser estimator forward in time from the present vessel location to produce the predicted vessel trajectory and corresponding riser profile time history. The estimator is run until the red disconnect limit is reached.

For the drift-off scenario the propulsion commands (input to vessel estimator) are set to zero. For the drive-off scenario the propulsion commands are held constant at their currently commanded state.

The yellow/red time margins are then calculated as [estimated time to reach disconnect limit - automatic disconnect time - yellow/red time pad].

4.3.3 Disconnect Margins and Alarm Calculations

The yellow/red disconnect limit margin for each of the disconnect parameters is determined by the shortest of the 36 yellow/red limit vectors for the parameter (i.e., the point on the envelope nearest the vessel).

The overall yellow and red limit envelopes are determined by the set of the shortest (yellow/red) vectors at each of the 36 directions over all disconnect parameters.

A yellow/red alarm condition exists when the length of the corresponding limit vector becomes zero.

A yellow/red time to disconnect alarm exists when the time margin before reaching the estimated disconnect time limit reaches zero.

The position of greatest vessel disconnect safety margin is determined from the overall limit margin envelope as the point midway between the end points of the two limit vectors on the axis containing the shortest limit vector.

4.4 SRs Riser Management

In addition to all the functionality provided by the SDs, the SRs provides information allowing for better riser management over the course of the drilling operation.

With the 3-D riser profile and 3-D force profile along the riser (i.e., the current profile) determined, the SRs can estimate the expected riser profile for varying conditions of mud weight, top tension, and vessel position. Riser bending moments and stress are calculated from the riser profile. The SRs provides information allowing for better operational riser management over the course of the drilling operation.

The system can determine the ***required riser space out*** prior to landing the stack.

During drilling, the SRs provides information on

- the ***vessel position*** which minimizes the maximum tilt angle along the riser
- the ***vessel position*** which minimizes the maximum stress in the riser
- the ***vessel position*** and required (minimum) ***top tension*** so that the maximum tilt angle at any position along the riser is less than a specified value.

It can also estimate the ***riser profile*** for

- the ***LMRP disconnected*** and suspended at the bottom of the riser
- the ***stack unlatched*** and suspended at the bottom of the riser.

With the SmartRiser system, a ***database of cumulative riser stress*** can be maintained for the riser system.

5.0 System Architecture

The SDs and SRs hardware architecture is shown in Figure 5-1. The architecture is designed for flexibility, providing the capability for multiple serial channels, digital and analog I/O, and multiple display terminals. This allows the hardware to be easily configured to accommodate a client's particular vessel. The system can also be expanded to provide duplex redundancy if so desired.

Data display and alarming is provided at the main data processing computer and at the remote terminals. The user interface provides both graphical and alpha-numeric presentation of disconnect information. Data displays can be customized to meet clients' operational requirements. Both visual and audio alarms are provided at each user interface location. The alarms are configured based on the location of the terminal and client preference.

6.0 Discussion of Disconnect Parameters

This section provides additional information related to disconnect parameters which further illustrates the importance of monitoring, analyzing, and presenting disconnect information in real-time.

Figure 6-1 shows an example set of disconnect limit envelopes and discusses the factors which govern the size and position of the envelopes. The important point here is that the envelopes (both size and position) are affected by a number of different factors which are continually changing. Thus, real-time monitoring and analysis is required to be able to assess the disconnect limit conditions, determine the available margin, and present information to allow positioning the vessel such that the margin is maximized.

Figure 6-2 shows the relationship between slip joint strokeout and vessel offset. The relationship is non-linear, with the amount of strokeout per unit of vessel displacement (slope of the curve) increasing as the vessel is further from the wellhead. This means that in a drift-off/drive-off situation, the rate of extension increases as the vessel moves further off location.

Figure 6-3 presents curves illustrating the relationship between riser angle and slip joint strokeout and the vessel offset necessary, as a function of depth, to cause the angle/strokeouts. The curves shown are for a riser angle of 5° and strokeouts of 16, 20, and 24 feet. These curves provide the following information.

They illustrate the riser angle being the limiting factor in shallow water while tensioner strokeout becomes the limiting factor as depth increases. For the data values plotted (i.e., 5° riser angle and 16, 20 and 24 foot strokes) the crossover points occur at depths of 4000, 5000, and 6000 feet respectively. Note that the slope of the line for a 10° riser angle is twice as steep as the 5° angle, and that for a 10° angle the cross-over points would occur between depths of 1000 and 2000 feet.

The difference in offsets for the different strokeouts illustrate how the available vessel position displacement margin (i.e., position displacement before strokeout is reached) is affected by tidal changes and vessel heave. For example, at 5000' depth, the difference in offset between 16 and 24 foot strokeouts is 100 feet. This means that a tidal change of ±4 feet can increase/decrease the allowable vessel displacement by ±50 feet. Also, it illustrates that a heave of ±4 feet would decrease the allowable offset by 50 feet.

REFERENCES

Earl Robinson, Drilling Fundamentals - DP Operations - Drilling with Riser, MTS Dynamic Positioning Conference, 1997.