DYNAMIC POSITIONING CONFERENCE
September 18-19, 2001

HIGH TECH SESSION

Using the Drilling Riser as Position Reference

Morten Høklie, *SeaFlex*

Nils Albert Jenssen, *Kongsberg Simrad*

Per Osen, *Seaflex*

Ivano Ciatti, *Saipem*

Abstract

This paper presents a system where response measurements of the drilling riser are used to derive position estimates suitable for DP-operations by use of the Kalman filtering technique. By combining vessel position and riser inclinations a dynamic mathematical model of the riser is tuned automatically by estimating a current profile. After initial tuning, the model is able to estimate the vessel position based on riser inclination measurements only.

The Riser Position Reference (RPR) system prototype is presently under test onboard the drill ship "*Saipem 10000*" offshore West Africa. Some of the results from the initial sea trials are presented herein. The RPR has been installed in combination with an existing Riser Management System (RMS), which includes a position optimizing function for drilling operations.

Introduction

A quite limited number of different position reference systems are suitable for dynamic positioning (DP) of deep water drilling vessels. Presently, only satellite systems and hydro acoustic systems are adequate for such operations. There is a need for new types of position reference systems based on different technologies that both satisfy the formal requirements to redundant position references for DP class 2 and 3 operations, as well as the general need to enhance safety of deep water drilling operations.

The objective of the work presented herein has been to develop an independent DP position reference system, the Riser Position Reference (RPR), by utilisation of the instrumented drilling riser. Through on-line measurements and analysis of the relevant riser responses (top and bottom riser inclinations), the system provides vessel position and velocity, as required by the DP system.

To some extent the riser can be compared with a taut wire. There is a relation between the length of the riser, its inclination and deflection and the vessel offset relative to the wellhead. In deep water, this relation is particularly complex, as the riser may have large deflections and the riser responses will be highly dependent on the current profile, wave forces and vessel motions. The measured riser responses will reflect the dynamic behaviour of both vessel and riser. The low frequency vessel motions (i.e. motion components apart from the high frequency wave motion) in the horizontal plane will be the primary unknowns that shall be derived.

In the RPR mathematical models of vessel and riser dynamics are combined with an extended Kalman filter (EKF), to estimate the actual position of the vessel relative to the wellhead.

The RPR development has been a joint effort between Kongsberg Simrad and SeaFlex and supported by Saipem, Statoil and Norsk Hydro.

Vessel and Riser Systems

The new deepwater drill ship "*Saipem 10000*" was used as basis for the initial simulations to test the RPR algorithm and is presently being used for full scale testing of the RPR prototype.

“*Saipem 10000*”

Some vessel particulars are:

Hull:	228 m x 42 m (748 ft x 138 ft)
Displacement:	96,455 t
Thrusters:	6 azimuth thrusters 4,000 kW each
DP System:	Kongsberg Simrad SDP-32, DP Class 3
Riser:	21” ABB Vetco Gray 3,000 m (10,000 ft) w.d.

The RPR system is implemented as an extension to the Riser Management System (RMS) supplied by Kongsberg Simrad and SeaFlex already installed onboard the “*Saipem 10000*”. The RMS is integrated with the SDP system. One of the main features of the RMS is to provide the DP operator with an advice on the optimum vessel position in order to minimize the flex joint angles.

Through the integration with the SDP system, the RMS and RPR is continuously supplied with required real-time data:

- Vessel position and motions
- BOP stack and lower riser inclinations
- Tensioner pull and stroke measurements
- Upper riser inclinations

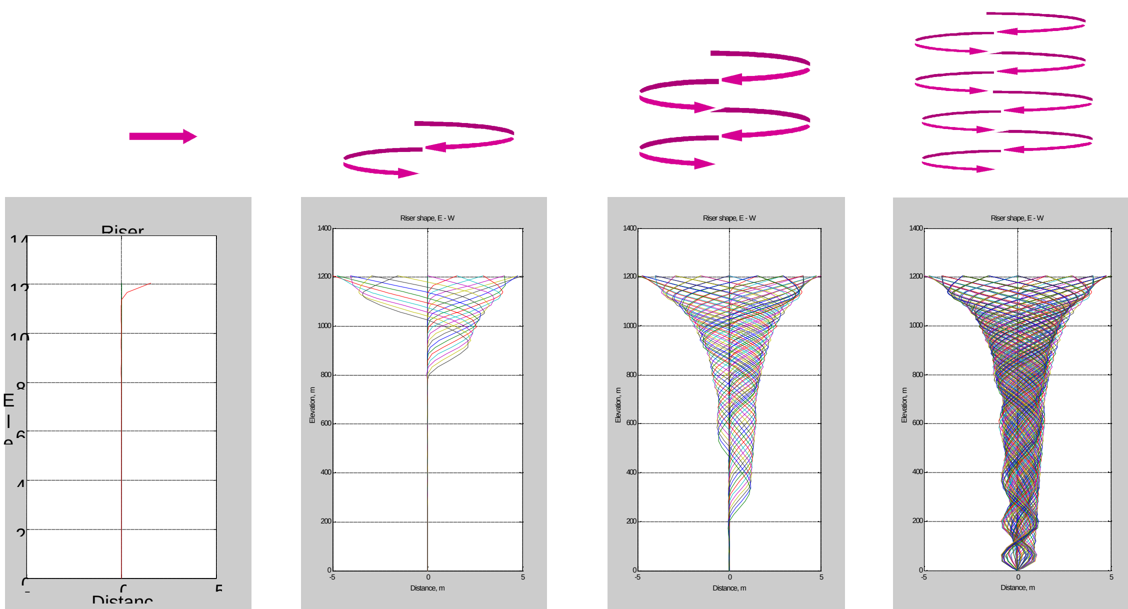
The upper riser inclinometer is mounted onto the upper part of the inner barrel of the telescopic joint. This inclinometer consists of two linear accelerometers and two angular rate sensors in order to provide accurate dynamic inclinations of the riser top. For the lower riser inclinometer, two linear accelerometers are sufficient, due to the very limited dynamics.

The dynamic riser model used by the RPR is modeled interactively in the RMS by selecting joints from a database containing all relevant data for each joint type onboard. Calibration and transformation of sensor data is also done in RMS utilizing graphical user interfaces for easy checking and correlation with other sensors.

Basic Riser Dynamics

The riser and vessel comprise a complex dynamic system influenced by the environmental forces (wind, waves and current) and the control forces exerted by the thrusters in order to maintain a stable position opposing the environmental forces.

The riser is a slender structure where the lateral deflections are controlled by the applied top tension rather than the structural rigidity of the pipe. Due to the long and slender structure there will be a significant time lag between the responses at the upper and lower end of the riser. This time lag will vary with water depth and applied top tension. This is illustrated in the figure below for a 1200 m (3940 ft) riser where displacement oscillations are forced at the top starting at time 0. In this example it takes about 30 seconds for the forced top displacements to cause a bottom end response. A fully developed response pattern is developed after about one minute.



0 s 10 s 25 s 60 s

The inclination measured of the lowermost riser joint (just above lower flex-joint) will reflect the most slowly varying components of the horizontal motions of the vessel (including steady position offset) and the actual current profile. Most of the 1st order vessel motions will be filtered out mechanically at this location.

The inclination at the uppermost riser joint (just below upper flex-joint) will also reflect the slowly varying components of the horizontal motions of the vessel and the actual current profile.

In addition also the direct dynamic wave action on the riser itself, the 1st order motions of the vessel and the thruster induced motions will be included in the upper riser inclination.

The position of the upper riser end relative to the lower end can be determined at all times provided the dynamic properties of the riser and vessel are known together with the external forces and in the upper and lower riser inclinations. The environmental forces are the main unknowns in this calculation.

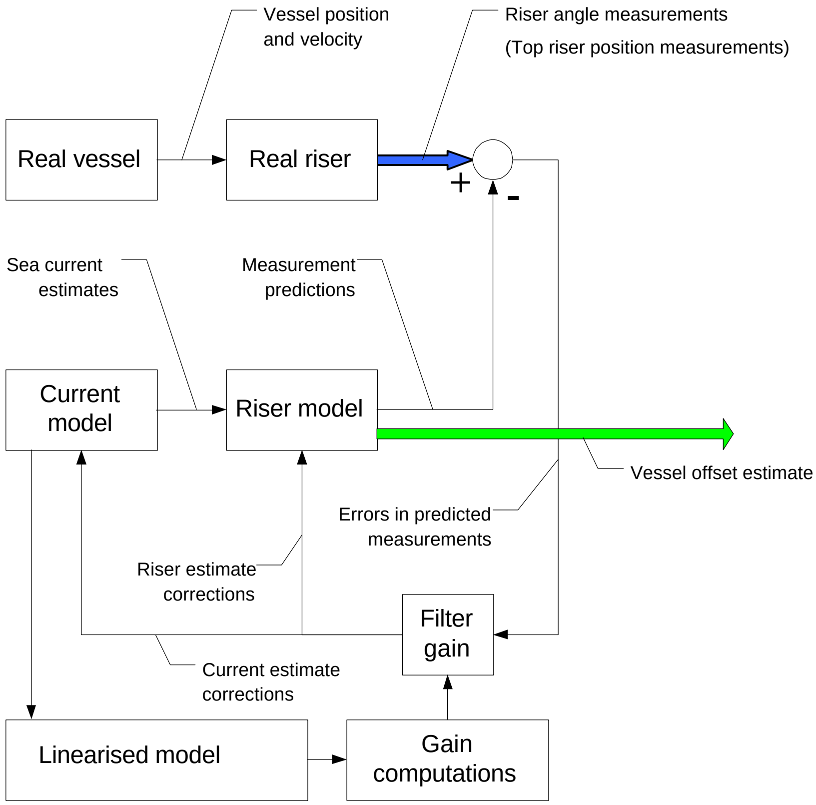
Knowledge of the current profile is crucial in order to predict position estimates based on the measured riser inclinations. The current profile is also essential for the dynamic behaviour of the riser due to quadratic drag forces. The DP system will not counteract the 1st order motions due to waves, hence the 1st order riser responses due to waves can be removed by filtering.

As long as good position input from at least one position reference system, such as e.g. DGPS, is available, a linear current velocity profile may be continuously updated. This may be considered the "calibration mode" for the RPR. The combination of mean vessel position, upper and lower riser inclinations and riser top tension may be used to derive a current profile consistent with the sagging of the riser as experienced at the uppermost and lowermost riser joints. When the current profile has been established, the RPR will provide dynamically correct position information on its own, and with minimal bias, based on monitoring riser inclinations only.

RPR - Vessel Position Estimator

As already mentioned the measured riser inclinations are highly influenced by the riser dynamics. This is experienced in drilling operations with respect to the lower flex-joint, and also from taut wires in deep waters. The Position Estimator compensates for these dynamic effects. This is done using Kalman filtering technique.

A block diagram for the Extended Kalman filter computations and its interaction with the real vessel/current/riser system is shown in the following figure.



The blue arrow represents the riser input: upper and lower riser inclinations. The green arrow indicates the output: the real-time estimate of vessel position relative to the well head.

Concerning the global shape of the riser, the north and east motions may be de-coupled and described by two independent sets of non-linear partial differential equations.

$$M_R(z)\frac{\partial v(z,t)}{\partial t} + \frac{\partial}{\partial z}\left(T(z)\frac{\partial x(z,t)}{\partial t}\right) + D_C(z)\cdot\left|v(z,t) - v_C(z,t)\right|\cdot\left(v(z,t) - v_C(z,t)\right) = 0$$

$$\frac{\partial x(z,t)}{\partial t} = v(z,t)$$

where:

t	-	Time
z	-	Elevation
$x(z,t)$	-	Position offset from BOP as a function of elevation and time
$v(z,t)$	-	Velocity as a function of elevation and time
$v_C(z,t)$	-	Current velocity as a function of elevation and time
$M_R(z)$	-	Mass + added mass of riser as a function of elevation
$T(z)$	-	Riser tension as a function of elevation
$D_C(z)$	-	Hydrodynamic drag coefficient as a function of elevation

Return to Session Directory ►

The Extended Kalman filter encompass a finite state dynamic model on the form:

$$\underline{x}_{k+1} = \underline{f}(\underline{x}_k) + C\underline{v}_k$$
$$\underline{y}_k = D\underline{x}_k + \underline{w}_k$$

where:

$\underline{x}_k$	-	Vector of dynamic states (offset and velocity of the riser at discrete locations along the riser and unknown current profile parameters) at discrete time k.
f (.)	-	Non-linear state transition vector function representing the riser dynamics
C	-	Process noise input matrix
$\underline{x}_k$	-	Process noise vector (wave forces, current fluctuations, etc)
$\underline{y}_k$	-	Measurement vector (containing riser offset at the top, and upper- and lower flex joint inclinations)
D	-	Measurement matrix converting the state vector into measurements
$\underline{w}_k$	-	Measurement noise vector.

The above Extended Kalman filter model is derived from the partial differential equations by space and time discretization.

The Extended Kalman filtering works as follows:

1. Assume an *a priori* estimate (prediction) of the state vector $\underline{\bar{x}}_k$ at time k
2. Update this estimate by applying the residual error between predicted- and real measurements $\underline{y}_k - D\underline{\bar{x}}_k$ and the Kalman filter gain coefficients, i.e.

   $\underline{\hat{x}}_k = \underline{\bar{x}}_k + K_k(\underline{y}_k - D\underline{\bar{x}}_k)$.

   K_k is calculated according to the standard Kalman filter algorithm taking into account the effect of process and measurement noise described above.
   The position data to be used in DP is then the position offset at the riser top.
3. Prepare for next time step by predicting the state vector one-time step into the future, $\underline{\bar{x}}_{k+1} = \underline{f}(\underline{\hat{x}}_k)$. Continue at step 2.

Because the sea current has a significant impact on both the static and dynamic behaviour of the riser, it is necessary to include some kind of "automatic calibration" in the position estimator. The current is modelled as a linear profile parameterised by a top and bottom current velocity. This current enables matching the riser model to real data at the top and bottom, both statically and dynamically. During start-up, the position estimator enters a "tracking" mode, where riser inclinations as well as position measurements are used to estimate the current profile. When this "tracking" phase is completed, the position estimator requires riser inclinations only. The bottom current is frozen, whereas the top current is updated, reflecting the variations in the riser inclinations. This is denoted "active" mode. In this mode the position estimator is a totally independent source for DP position data.

Return to Session Directory ►

Simulation and Test Results

Extensive benchmark testing of the performance of the position estimator was performed prior to the offshore tests. Tests were performed using time series of riser responses generated by the riser analysis program RIFLEX. Furthermore, real-time simulations were performed using a dynamic riser simulator and a vessel simulator in an integrated test set-up including the DP system as well as the RMS.

INITIAL SIMULATION TESTS

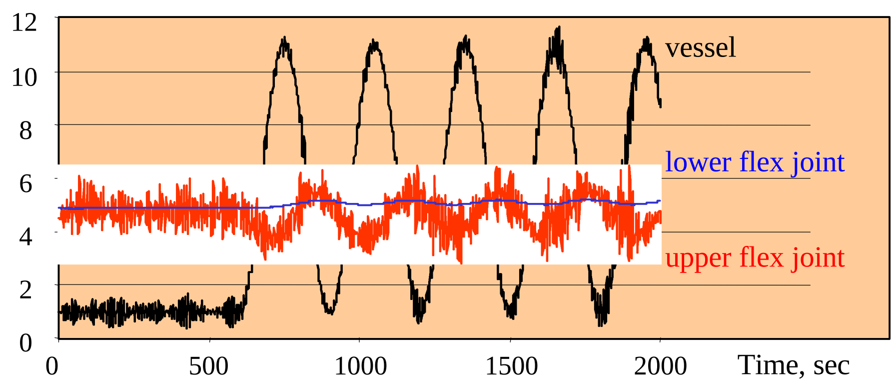
For the initial tests a RIFLEX model was prepared for simulating the drill ship "*Saipem 10000*" and its drilling riser, exposed to irregular sea states, and user defined vessel position trajectories. The water depth was set to 1500 meters

The riser was accurately modelled reflecting a proper tension distribution and dynamic properties.

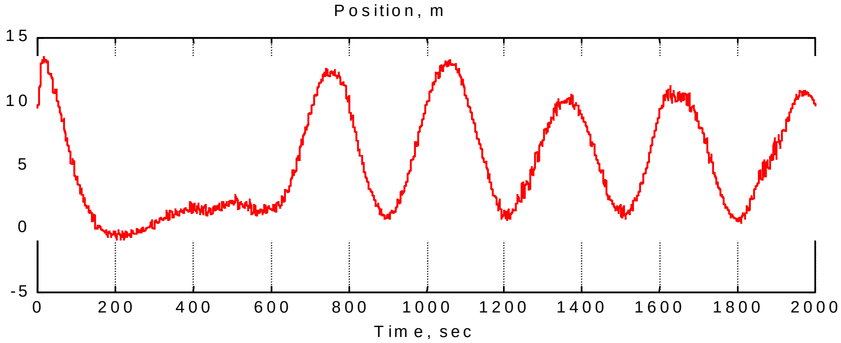
In RIFLEX, the vessel motions were generated using the vessel motion characteristics and irregular sea states, and superimposed by user-defined low-frequency position offset variations.

The position estimator was run with simulated input data from RIFLEX vessel/riser simulations.

Below, the position estimator response is shown with time series from one of these simulations. The first frame is the RIFLEX generated data. Below, the true position (blue) and RPR estimated position (red) are shown. The test was run with an oscillating vessel position that initially started with a fixed position but after 10min, the offset becomes a cosine function with amplitude = 5m, and period = 300s. The Position Estimator started off with an initial error of 10 m due to unknown current, but after some 300 s with current estimation it follows the true position reasonably well.



RIFLEX simulation



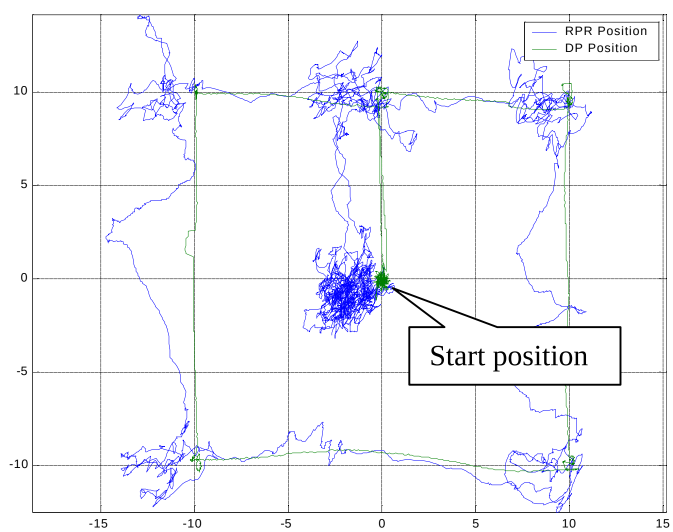
True position (blue) and position estimate (red)

This case shows very clearly that the riser dynamics are effectively filtered out. From the RIFLEX simulation we observe that the upper riser inclination measurements follows the position closely and that the lower riser inclination measurement lags behind. However, the estimate position tracks the true position very well.

FULL SCALE TESTS

The prototype testing has taken place offshore Congo in 2350 m (7710 ft) water depth. The test period started mid June 2001 and will continue until late October.

In the first test campaign, the RPR was used in pure monitoring mode, which means that it was fully operational but not used to control the station keeping. This was done in order to separate the RPR completely from the DP system.

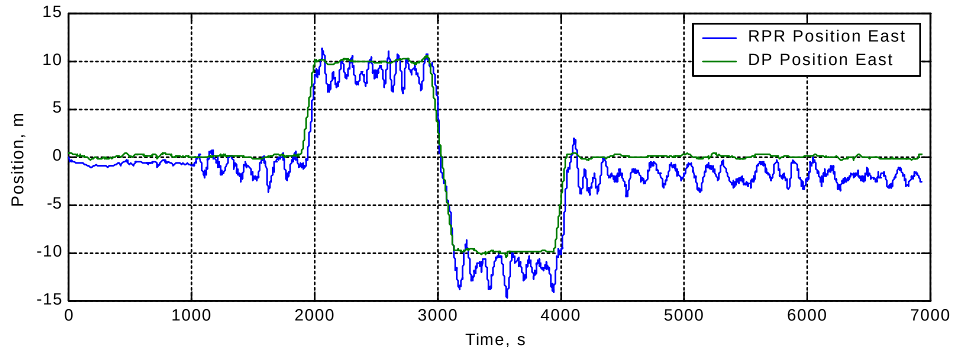


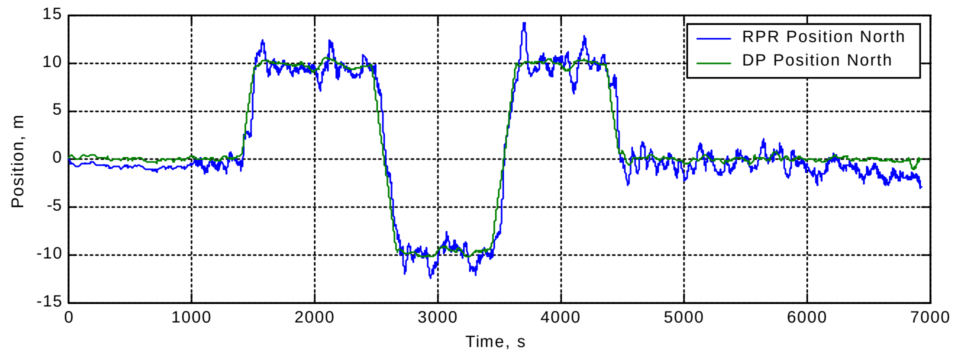
The vessel was commanded to move in a quadratic pattern ±10 m north and east as shown in the figure to the right. The green lines represent the real vessel position as recorded from the DP system and the blue lines the position output from the RPR.

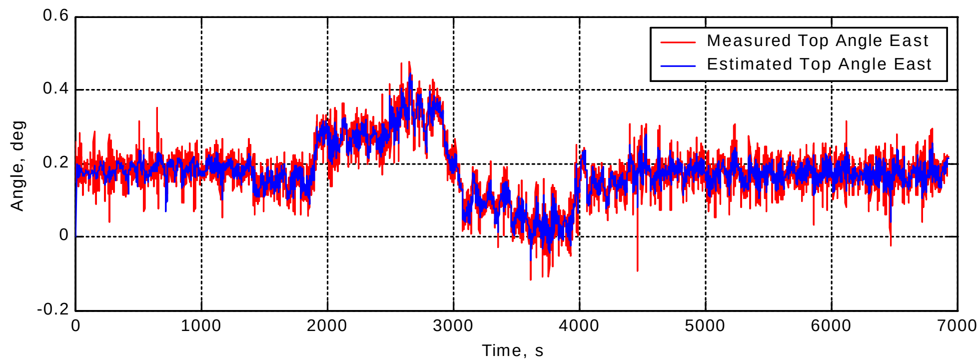
Later the RPR was used together with DGPS and LBL to see whether the DP accepted it as a valid reference or not. This test turned out successfully. We observe, however, that the RPR is affected by significant colored noise caused by the riser dynamics, which cannot be fully filtered out.

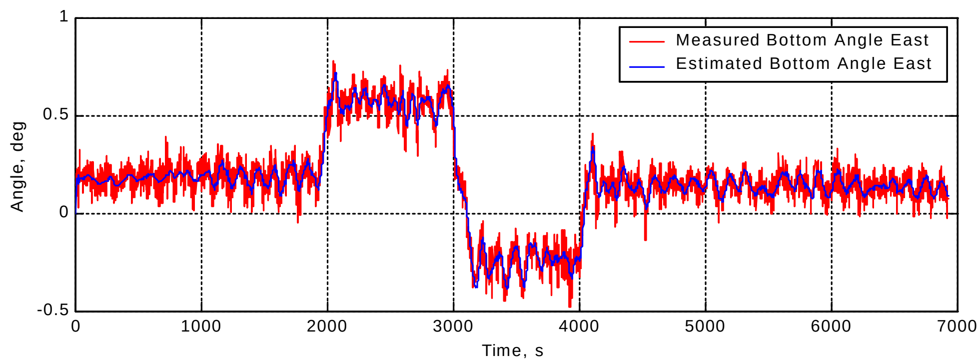
The next figures show the time plots of the movements.

Return to Session Directory ►

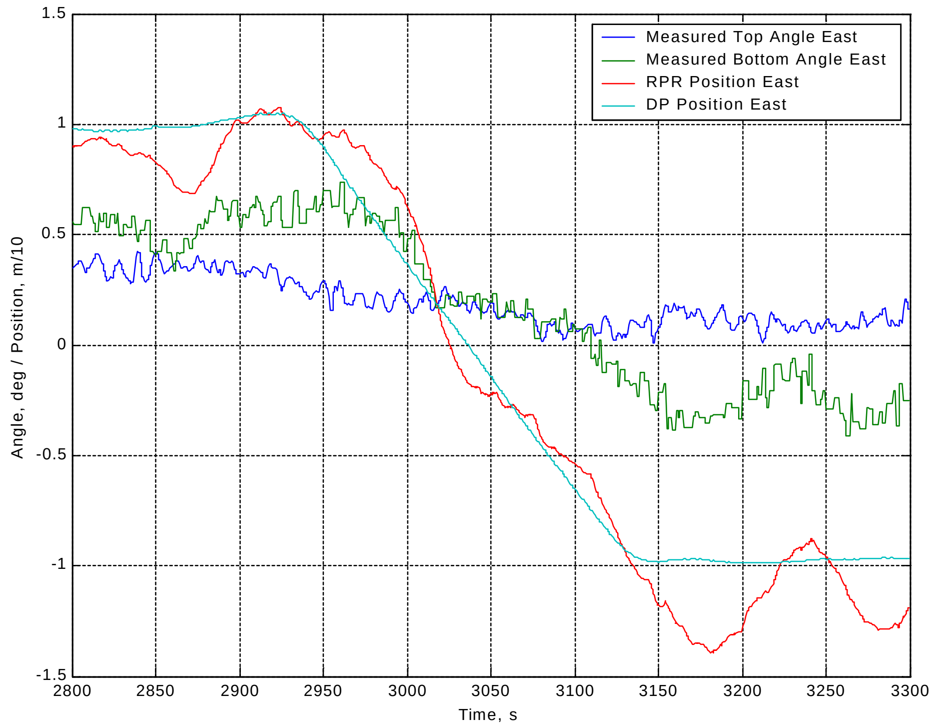








As can be seen from these figures, the noisy behavior of the RPR position is mainly caused by fluctuations in the measured lower riser angle. These fluctuations have a period of about 100 s and can therefore not be filtered out without impairing the dynamic response properties of the RPR. To be suitable as a DP reference, it is required that the RPR position estimate not be lagging significantly compared to the real position of the vessel. In below figure, time-traces are shown for a vessel position shift, where the vessel was deliberately moved 20 meters during 200 seconds.



It is interesting to note that the upper flex joint inclination is quite insensitive to the move, compared to the lower flex joint. This is because a deepwater drilling riser behaves more like a catenary (chain) rather than a rigid beam.

Also note the considerable time for top end motions to affect the bottom end of a deepwater riser like this. The upper inclination is immediately effected by the move, whereas it takes about 100 s until the lower inclination responds. The above figure also shows that there are some low-frequent bottom end oscillations that influence the position estimate. These oscillations correspond very well to the 1st natural period of the riser of 146 s but the source of the excitation is not yet identified.

As already mentioned, the offshore testing is ongoing. The performance of the RPR is continuously monitored. All essential data are being logged for onshore post-processing, to enable further development of the filter and optimize filter settings. Both the accuracy and reliability of the RPR needs be verified before it can be released as a commercial product, to work as a companion to DGPS and hydro-acoustic references.

Acknowledgement

The authors want to thank Steinar Saelid, Predictor, for valuable contributions in the initial phase of the development work and Mauro Brambilla, Saipem, for his effort in making the offshore testing onboard the “*Saipem 10000*” possible.