FIELD PILOT OF DEEP WATER INSTALLATION IN TWO-FALL USING FIBRE ROPE

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This technical paper was prepared for presentation at the Rio Oil & Gas Expo and Conference 2010, held between September, 13-16, 2010, in Rio de Janeiro. This Technical Paper was selected for presentation by the technical committee of the event according to the information contained in the abstract submitted by the author(s). The contents of the technical paper, as presented, were not reviewed by IBP. The organizers are not supposed to translate or correct the submitted papers. The material as it is presented, does not necessarily represent Brazilian Petroleum, Gas and Biofuels Institute’ opinion, nor that of its members or representatives. Authors consent to the publication of this technical paper in the Rio Oil & Gas Expo and Conference 2010 Proceedings.

Abstract

This paper gives a summary of the 250Te FRDS (fibre rope deployment system) joint industry project (JIP). The background for the project is the industry’s need for lifting capacity of 250Te in 3,000m of water depth as expressed, for instance, by the DISH (deepwater installation of subsea hardware) JIP. The main objective of the 250Te FRDS JIP was to develop a FRDS with an installation capacity of 250Te in 3,000m based upon a 125Te FRDS operation in a two-fall configuration, and to demonstrate through a field pilot that deepwater lifting operations can be executed safely with this system. The project kicked off in September 2006 with conceptual design of the system, based on scaling up the field-proven 46Te ODIM CTCU (cable traction control unit) based FRDS system. Building, testing of the system, installation on the Skandi Santos vessel and execution of the field pilot were conducted from October 2007 to December 2009. The field pilot consisted of a deepwater lifting test in two-fall configuration. Its main purpose was to demonstrate that combining a torque-free fibre rope with a handling system which minimises the introduction of twist in the rope solves the inherent twist problem of a steel wire system. All phases of a subsea installation and recovery operation were demonstrated with 100Te payload and empty hook operations in two-fall configuration to 940m of water depth. The test results were very convincing, with twist levels well within the acceptance criteria established for the test. This proves that combining a torque-free rope with a suitable handling system which does not introduce twist in the rope opens up for using two-fall lifting arrangements in deep water, and that a proven system with the capacity of 250Te in 3,000m is available.

1. Introduction

The 250Te FRDS JIP aimed to demonstrate that deepwater subsea lifting operations can be performed safely and successfully by using a fibre rope deployment system (FRDS) in two-fall configuration based on the CTCU technology in combination with a torque-free fibre rope instead of steel wire as the lifting line. This opens the way for using smaller construction vessels for heavy deepwater lifts up to 250Te, where the weight of a steel wire system disqualifies the use of this traditional solution.

Participants in the project were:
- Research Council of Norway/Demo 2000 (sponsor)
- Shell Technology Norway (sponsor)
- Statoil (sponsor)
- Aker Oilfield Services: buyer and owner of the system, and responsible for conduct of the field pilot
- ODIM: JIP organiser and supplier of products and services for the field pilot.

The 125Te FRDS designed for two-fall operation with a lifting capacity of 250Te down to more than 3,000m of water depth was the key product for the project. In order to make a field pilot possible, this system had to be mobilised on a vessel with additional equipment for handling the test weight and the two-fall arrangement.

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Aker Oilfield Services decided to purchase the 125Te CTCU system in addition to a module handling system from ODIM - Rolls-Royce. This complete system was to be placed on the *Skandi Santos* newbuilding for operation off Brazil on a five-year contract from Petrobras for installing Xmas trees. This vessel was considered an adequate platform for conducting the field pilot, although some additional equipment had to be provided.

### 2. System Description

The main equipment needed for performing a two-fall lift in deep water is basically a torque-free rope combined with a handling system which minimises the introduction of twist in the rope during operation. Furthermore, a two-fall block suitable for deepwater operation and a hang-off point for the dead end of the rope are needed. For the test, it was also important to have additional instrumentation to document the results.

#### 2.1. Fibre Rope

The rope used for the test was an 88mm braid optimised for bending (BOB) rope from Puget Sound/Cortland companies. It has an MBL of 567Te, which represents a safety factor of 4.5 compared with the working load of the 125Te FRDS in single fall configuration. The rope has a 12x12 strand construction, and features high strength, low elongation, long-term creep resistance and good cyclic fatigue performance in bend-over-sheave applications. BOB is a proprietary construction in which each strand of the primary braids is constructed using a blend of high modulus polyethylene (HMPE) and liquid crystal polymer (LCP) fibres. Each of the 12 primary braids contains six strands with S-twist and six with Z-twist, and are braided in a secondary braid to form the final rope. The rope is therefore totally balanced by design. It has a specially formulated coating designed to maximise the rope's durability during bending.

![Image of fibre rope](image1.png)

**Figure 1. Fibre rope**

#### 2.2. The Fibre Rope Deployment System

The fibre rope deployment system (FRDS) is shown in figure 2. It has a working load of 125Te in single line configuration and 250Te in two-fall configuration. The main components of the system are listed in table 1. The storage winch (pos. 1) has a capacity of 7 000m of 88mm rope, giving the system an installation capacity of 250Te in more than 3 000m of water depth.
Figure 2. 125/250Te fibre rope deployment system

Table 1. Fibre rope deployment system components

<table>
<thead>
<tr>
<th>System</th>
<th>Component</th>
<th>Pos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre rope deployment system</td>
<td>Storage winch</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Spooling device</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Inboard damping device</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Cable traction control unit, CTCU</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>StW electrical container</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>CTCU electrical container</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Accumulator units</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Fibre rope</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Cable counter (not visible in figure 2)</td>
<td>9</td>
</tr>
</tbody>
</table>

The rope is stored on the storage winch mounted on top of the CTCU. The spooling device guides the rope onto the storage winch to ensure that the rope is properly spooled on the drum, while the storage winch pull setting gives the storage tension for the rope. To assure robust synchronisation between the CTCU and the storage winch, a flexible inboard damping device is used. Any transient mismatch in speed between CTCU and storage winch will cause the flexible inboard damping device to either extend or retract.

The patented CTCU is a traction unit which handles the load difference between the load and storage sides of the system. Tensioning and de-tensioning of the rope are assured by individually driven traction sheaves, which automatically compensate for rope elongation to avoid damaging slippage on the rope. Furthermore, all sheaves have
been aligned to assure zero fleeting angle. This is an important feature for a two-fall lifting system in order to minimise the introduction of twist in the rope owing to handling.

To provide an accurate measurement of the deployed length and speed of the rope, a cable counter is fitted at the rope outlet. Containers are used to provide a protected environment for the node cabinets of the individual machines. An accumulator system is used to store surplus hydraulic energy when available and release it on demand, e.g. in active heave compensation and constant tension operations.

The 125Te FRDS is a fully active heave compensated system with all required functionality for performing deepwater installation and recovery operations. All functions are available in both single line and two-fall configurations. The performance of the active heave compensation system in single line configuration is +/- 2.4m amplitude at a period of 10 seconds, with a peak speed capacity of 1.5m/s at full load. In the two-fall configuration with a payload of 250Te, speed performance at the hook is 0.75m/s.

2.3. The Two-fall System
The two-fall block was designed and sized for the scope of the test and not for the full capacity of the system. It had a working load of 110Te, and consisted of the following main elements:

- Sheave with grooves suitable for 88mm fibre rope.
- Frame with rope guides to prevent derailing.
- Weight at bottom to secure stability/low centre of gravity.
- Frame with bumper bars for instrument package.
- Hinged arm to counteract twist with remotely operated vehicle (ROV) (contingency measure).
- Pad eye for 120Te shackle.
- 300-bar pressure rating.

A parking cradle was supplied with the block to secure safe transport and easier rigging of the two-fall arrangement. To fix the dead end of the rope in the two-fall configuration, a hang-off beam was supplied and installed on top of the skidding rails on the main moon pool hatch. The beam was secured to the hatch with clamps and turn buckles.

2.4. Test Instrumentation
Two different methods were planned for monitoring twist during the two-fall test.

- Real-time monitoring based upon comparing vessel and ROV headings. The ROV should align with the two-fall block at every 100m in order to perform the reading, while the vessel heading should remain fixed.
- Twist logging based upon an instrumentation package installed on the two-fall block.

The instrumentation package was delivered by Aquadyne and comprised the instruments listed in table 2.
Table 2. Instrumentation package on two-fall block.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heading sensor</td>
<td>Orion inertial navigation system (INS)</td>
</tr>
<tr>
<td>Depth sensor</td>
<td>Digiquartz® submersible depth sensors series 8000</td>
</tr>
<tr>
<td>Data logger</td>
<td>UW SmartDII™ subsea logger V3</td>
</tr>
<tr>
<td>Batteries</td>
<td>HydroC™/PowerPack</td>
</tr>
</tbody>
</table>

2.5. The Vessel

The vessel for the field pilot was the DOF-owned *Skandi Santos*, which has been chartered and outfitted by Aker Oilfield Services for deepwater installation of Xmas trees under a five-year contract with Petrobras (SESV project). The vessel has been outfitted with a complete module handling system from ODIM – Rolls-Royce, comprising the following subsystems:

- main lift system: handles modules between a pallet on the moonpool hatch and the seabed
- test cursor systems: handle and stack modules brought by a skidding system on deck
- skid system: securing and transporting modules on aft deck and in tower area
- moonpool tower system: base for main and test cursor systems
- hydraulic system: provides and distributes hydraulic energy for all consumers
- control system: implements system functionality and user interface.

![Figure 4. Skandi Santos.](image)

The main lift system uses the 125Te FRDS as the main lifting winch. The fibre rope is routed from the FRDS to the top of the moonpool tower system and through a cursor system. The cursor system guides payloads during deployment through the moonpool.

3. Field Pilot Preparations

Although the system has a capacity of 250Te in 3 000m of water, the steering group for the project agreed that the overall scope for the two-fall test should be 100Te to 1 000m. This was considered to be sufficient to demonstrate the main objective of the project while lying within its practical and financial limits. James Davidson Construction Services Ltd performed a pre-study of the two-fall tests. This included theoretical and practical considerations of twist in terms of disturbing and restoring torques, as well as suggesting a conservative criterion for acceptable twist during the two-fall test.

Some scaled tests were performed before the field pilot in order to study identified critical factors for the two-fall test and to achieve better understanding of the behaviour of a two-fall lift configuration. Three types of tests were conducted:

- small-scale twist test using braided fibre rope and steel wire
- small-scale abrasion and friction test using 18mm braided fibre rope
- rope torsional stiffness tests using 88mm braided fibre rope.
An important success factor for the project was to find a suitable test site for performing the two-fall test. This should satisfy the depth requirement (1 000m) and also be suitable for conducting operations on the seabed (landing, constant tension operations, unloading the lifting line and lift-off). Furthermore, the two-fall test was scheduled for December 2009, when weather conditions off Norway are generally harsh. For these reasons, a test site in a deepwater Norwegian fjord was sought. Shell and Statoil came up with a test site which had been established and used by the Ormen Lange project for deepwater testing of a pipeline repair system. The water depth was 940m, the area had been rock-dumped and sea conditions were predictable. This site was selected for the field pilot.

The following test procedures for the sea trials were established:
- offshore tuning procedure: tuning and verification of active heave compensation system
- sea acceptance test (SAT): functional verification of the complete module handling system
- two-fall test procedure: installation and recovery operations with 100Te payload.

This paper focuses on the two-fall test which was the main target of the 250Te FRDS JIP. The programme comprised two tests. The first covered installation and recovery of a 100Te payload, while the second concentrated on deployment and recovery of the empty hook. The acceptance criterion for twist was +/- 60° for both tests. The empty hook test was considered to be the toughest where twist was concerned, since the restoring torque from the geometry of the two-fall configuration is a function of the rope tension. A four-level contingency procedure was developed and implemented to handle potential twist problems with minimum risk of damaging the rope:
- level 1: remove twist introduced from current acting on the lifted system by aligning the two-fall block with the current through changes to the vessel heading
- level 2: should the twist in the system be greater than an acceptance criterion after alignment with the vessel, a ROV would connect with the arm on the two-fall block via a flexible connection to ensure that further twist was not introduced
- level 3: should twist be introduced to the system at a level where the ropes were touching each other, the clump weight would be recovered by the crane before further recovery of the system.
- level 4: in the event of severe problems with the two-fall block or twist, the two-fall block could be recovered to deck by the crane.

4. Test Execution

The main part of the sea trials was conducted in the Sogne Fjord (inshore testing) and off the Sogne Sea (offshore testing) in the 5-16 December 2009 period.

4.1. Sea Acceptance Tests

Functional testing and tuning of the system were conducted in accordance with the SAT procedure without any major incidents. The system’s ability to perform deepwater installation and recovery operations using fibre rope as the lifting line was demonstrated. Test results from the active heave compensation tests inshore and offshore proved that performance and accuracy lie within the system specification. The conclusion from these tests is that the system has the specified functionality, performance and accuracy, and that deepwater installation and recovery operations can be performed safely using the CTCU-based 125Te FRDS.

4.2. Two-fall Test

Rigging for the two-fall test was done on 14 December 2009. That included installation of the subsea instrumentation package with local logging of heading and depth data. The two-fall block was deployed through the moonpool of the vessel, with the 100Te clump weight overboarded by the vessel crane. Load transfer from the crane to the two-fall block was done at a depth of about 150m.

The first test consisted of deploying the 100Te clump weight in steps of 100m and verifying twist in real time using vessel and ROV heading information. This was done in order to check the twist condition in real time in accordance with the criteria, and to initiate contingency procedures if needed. It also provided a back-up of twist recording should the instrumentation package fail.

In 900m of water, the active heave compensation mode was entered and the auto landing function initiated. Tension at the bottom of the two-fall block was reduced from 90Te to 64Te during the landing operation. After landing, the constant tension setpoint was gradually reduced so that the load at the bottom of the two-fall block was reduced from 64Te to 11Te and then back to 64Te before the auto liftoff operation was initiated.
Recovery from 900m to 200m was also conducted in 100m steps for real-time twist monitoring purposes. At 200m, the 100Te clump weight was transferred back to the vessel crane to prepare for the next test.

The second test consisted of deploying the empty hook down to 900m and back to 100m in 100m steps. After this test, the two-fall block was recovered to deck and data from the subsea instrumentation package were secured. Real-time twist monitoring did not show any twist which called for contingency procedures to be initiated.

5. Test Results

The complete time series for twist and depth loggings is shown in figure 5. This provides the basis for the data analysis in the next chapter.

![Figure 5: Heading and depth data from the instrumentation package.](image)

6. Analysis of the test Data

Recorded data from the subsea instrumentation package on the two-fall block, as shown in figure 5, were analysed for the different phases of the test. A heading of 311° was used as the base line for all the subsequent plots.

6.1. Installation and Recovery of 100Te Payload

The first test involved deployment, landing, constant tension operations, liftoff and recovery of the 100Te clump weight in a two-fall configuration.

The first step comprised a load transfer from the crane to the two-fall block. This was initiated in 175m of water. First, the ROV hooked up the second forerunner from the clump weight and connected it to the ROV hook of the two-fall block. The load was then transferred to the two-fall block by pulling in with the CTCU. The two-fall block started to pick up the load in 145m of water, and the full load was transferred in 139m. Winch speed was 0.1m/s during load transfer. The two-fall block changed heading from -6°, through a peak of 9°, and back to -3° during the load transfer. The peak twist during the transition probably reflected the connection between the crane and the two-fall block. Once the forerunner was slack, a sudden drop in twist from 9° to 0° can be seen in figure 6.
Deployment began from 136m at a winch speed of 0.4m/s and ceased in 200m of water. Vessel and two-fall block headings were compared in order to estimate the twist in real time. The real-time twist estimate was used as a decision input in accordance with the criterion of 60° for initiating the contingency procedures. Deployment continued in steps of 100m down to 880m of water for the two-fall block. The winch speed was 0.5m/s from 200m down to 400m, and 0.6m/s from 400m to 880m. The maximum recorded twist was about +4°/-8° during deployment and +5°/-11° during recovery, as shown in figure 7.

Landing was performed using the auto landing function of the FRDS system. This is an automatic transition from active heave compensation (AHC) to constant tension (CT) mode, triggered when tension is reduced down to a CT setpoint. Rope tension below the two-fall block before landing was 90Te. The CT setpoint accorded with 64Te tension below the two-fall block after landing. Once landing had taken place, the CT setpoint was reduced in steps of 10Te of tension below the two-fall block down to about 11Te. Recorded data from the instrumentation package in figure 8 show that the change in twist was only 5° during this operation.
Figure 8: Twist during constant tension operation

After the recovery operation had been completed, the 100Te clump weight was transferred back to the crane. The interaction between the crane and the two-fall block during the load transfer operation gave an intermittent twist of 35°. The twist difference before and after load transfer was about 6°.

6.1. Deployment and Recovery of Empty Hook

The deployment started in 170m of water, and the operation was halted every 100m for twist to be estimated on the basis of vessel and ROV headings. The maximum twist was estimated to be 37°, which was well within the criterion of 60° set for the test. As a result, no contingency procedure was initiated. The recorded heading information from the instrumentation package is shown in figure 9. The maximum twist was about +24°/-21° during deployment and +3°/+37° during recovery.

Figure 9: Recorded twist during empty hook operation.

7. Summary and conclusions

The main objective of the 250Te FRDS JIP was to demonstrate that deepwater subsea lifting operations can be performed safely and successfully by using a 125Te FRDS in a two-fall configuration, based on the CTCU technology in combination with a torque-free fibre rope as the lifting line. This was achieved through building and testing a full-scale 125Te FRDS and performing a two-fall test in deep water. The test results were very promising, and showed twist levels well within the acceptance criterion established for the test.
The main conclusions from the analysis of the log data were as follows.

- Load transfer from the crane can introduce an intermittent twist owing to the direction of pull. This should be handled by careful planning of the load transfer operation.
- Deployment and recovery of a heavy load was demonstrated with a very low level of twist, showing that the restoring torque from the geometry of the two-fall system was dominant in relation to disturbances during the test.
- Unloading landing and tension reduction from 90Te to 11Te gave only a small change in twist. This provides a further demonstration of the torque-free construction of the fibre rope.
- Deployment and recovery of the empty hook were demonstrated with an acceptable level of twist. As expected, twist was greater during this test than with the high-load test owing to a reduced restoring torque from the geometry of the two-fall arrangement at low loads.
- It was observed that some twist had been introduced to the rope before the two-fall test. This is considered to be one of the torque-creating factors which must be counterbalanced by the restoring torque. But the fact that the test was successful even with this disturbance indicates that the system is quite robust with regard to such issues.
- The current profile logged prior to the test indicated that the current was very small and probably not a significant source of disturbance. In real operations, this could be a significant factor which must be controlled.

Results from this successful test open the way to a wider use of a two-fall configuration in deepwater lifting operations. Using a torque-free fibre rope combined with an adequate handling system which does not introduce twist in the rope substantially reduces the risk for complications compared with steel wire systems.

The motive for using a two-fall configuration is to permit the application of a smaller rope and a winch system with a lower working load to deepwater lifting operations. This provides a rope with better fatigue properties and a more compact winch system. It also gives a flexible system which can typically be used for high-speed operation in single line configuration for the majority of lifts, and with high working load capacity but reduced speed for less frequent heavy-lift operations.

The project has also proven a significant scale-up of a FRDS, taking it from 46Te to 125Te and expanding the rope size from 56mm to 88mm (the MBL is increased from 218Te to 562Te). This has been established through an extensive test programme from workshop testing of rope and winch as a system, through residual strength-testing of test ropes to establish retirement criteria, to a comprehensive sea trial which challenged the system to the limit of its specified performance.

7. Acknowledgements

Thanks are due to all the participants and funding partners of the JIP for making this comprehensive development and demonstration possible, and for their valuable and enthusiastic contribution to taking the FRDS solution a big step forward.

ODIM was acquired by Rolls-Royce plc during April 2010 and is now part of the Rolls-Royce Marine Offshore business.