Fiber Rope Deployment System For Ultra Deep Water Installations
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At 3000 m water depth, the required working load for the steel wire winch will be around 300 mT, while only 127 mT is required for the fiber rope winch.

Still at 3000 meters water depth, the weight of the required steel wire in air will be around 200 mT, while the corresponding fiber rope weight will only be 20 mT.

Considering an Active Heave Compensated system (AHC) with speed capacity of 1.5 m/s, the peak power supplied by the winch to the lifting line is shown in Fig. 3. For a system rated for 3000 meters water depth, the steel wire system would need to deliver 4.4 MW to the lifting line while the fiber rope system only would need to supply 1.8 MW.

From this comparison of steel wire and fiber rope the motivation and potential savings are quite obvious. However, the utilization of fiber ropes for lifting lines is not completely straightforward. There are major differences in the properties of fiber ropes compared to steel wire that need to be considered when developing a fiber rope handling system:

- Fiber ropes have lower axial stiffness, causing rope elongation with load and resonance issues at more shallow water than for steel wire.
- Fiber ropes are more exposed to adhesive wear and tear.
- Fatigue life when subjected to constant cyclic bending e.g. during heave compensation modes must be managed. This is also the case for steel wire, but an additional challenge with fiber rope is related to internal heat build up.
- Fiber ropes have a very low and variable coefficient of friction due to rope coating, contaminations, temperature etc.

Careful consideration needs to be given to these differences, or the fiber ropes will suffer from severe wear and premature failure.

**Fiber Rope Deployment System**

Development of a Fiber Rope Deployment System (FRDS) requires a system approach to be taken, considering the specific properties of fiber rope, develop a suitable handling system and qualify and validate by testing and field experience the complete system.

**Fiber rope**

Important features defined for a fiber rope used as lifting line in heave compensated systems are:

- High Cyclic Bend Over Sheave performance.
- Torque free construction.
- Field inspectable and repairable.
- High strength to weight ratio

The fiber rope from Puget Sound used in the current development is commonly referred to as “Braid Optimized for Bending” (BOB) and is based upon a 12x12 braided construction. This assures a torque free rope and at the same time, a rope that can easily be inspected internally and repaired offshore by trained riggers. Repair will typically give an inline splice with a diameter 50% above the nominal rope size. The handling system must be capable of handling these splices in order to take advantage of the repairability of the rope.

A blend of High Modulus Poly Ethylene (HMPE) fibers and Liquid Cristal Polymer (LCP) fibers has been used to provide good temperature resistance and good creep properties. In addition a lubricant coating is used to reduce friction between fibers and thereby internal wear and heat build up in cyclic bend over sheave operation. The challenge from this is that the handling system must be designed for very low coefficients of friction.

Typically minimum D:d ratio requirement for heave compensating sheaves is 30:1 for this rope.

The fiber rope used in the current system design has been extensively tested in the Dish JIP [1].
Handling system

For FRDS, the need for a traction unit between the load side and the storage side is crucial due to the huge difference in load between deployment of a heavy load and recovery of empty hook with neutrally buoyant lifting line. Recovery of empty hook without a traction unit would lead to spooling of the fiber rope onto the storage drum at very low tension which would create problems with squeezing of rope into soft layers during the subsequent installation.

Conventional traction winch systems that have been designed specifically for use with steel wire are not directly applicable for fiber rope.

- Capstan winches: Based on de-tensioning of the rope over multiple wraps around the capstan. The change in rope length during the de-tensioning process results in substantial accumulated slip on the drum surface. This will in turn cause heat build up and abrasion of the rope. Additionally, there will be sideways slip of the rope on the drum for traditional capstan winches. Handling of splices on a capstan winch also requires sophisticated mechanisms during fleeting of the rope sideways on the drum.
- Two drum traction winches: With the exception of sideways slip, traction winches suffer from the same limitations as the capstan winch. In addition, splices or other objects on the rope can not be easily run through a traditional traction winch.

The type of traction unit used for the Fiber Rope Deployment System presented in this paper is called Cable Traction Control Unit (CTCU) patented by the Norwegian company ODIM. The CTCU consists of a number of individually driven sheaves. Thus, speed and torque on each sheave can be controlled to avoid accumulated slip due to rope elongation. Further, splices and other objects can easily be handled. De-tensioning of the rope is done gradually in a user pre-defined pattern within the physical limitations as defined by frictional capacity and drive system performance for each sheave.

System description

The CTCU system is briefly described below.

The main parts of the CTCU system are:
- CTCU: A series of sheaves with individual drives that are used to de-tension the rope.
- StW: Storage Winch to store the rope at low tension. It will also assure a constant back tension for the CTCU.
- IDD: Inboard Damping Device that will smoothen the tension between the CTCU and the StW.
- ODD: Outboard Damping Device used for constant tension and pull limit control.
- OBD: Over Boarding Device.
- HPU: Hydraulic Power Unit with accumulators that supplies the system with high and low pressure oil.
- Control System: Computer system used for dynamic control of individual machines and interactions between machines. The control system also includes a Rope Management System keeping track of bend fatigue life for each meter of the rope.

The fiber rope is stored at constant tension on the storage winch on top of the structure. From the storage winch, the rope is fed through the spooling device and inboard damping device before entering the individual sheaves of the CTCU. From the CTCU, the rope is guided over the outboard damping device before entering the overboarding device.

Important feature of the CTCU traction unit are:
- Active load distribution: Shares the load between the sheaves within the physical limitations of each sheave.
- Slip control: Controls the speed of the sheaves to compensate for rope load elongation and variations of diameter due to splices.
- Anti spin control: Detects and react upon emerging spinning situation.
- D:d ratio according to requirement for cyclic bend over sheave of fiber rope (active heave compensation).
- Differentiated sheave coatings optimized with regards to load and required frictional capacity for each sheave.
- Sheave groove profile allowing for splice handling.
- Rope pre-conditioning: Brings the rope size down to nominal size during first time spooling of new rope.

From a system point of view, all needed functionality for deep water installation and construction operations are present:
- High speed deployment of heavy loads.
- High speed deployment and recovery of empty hook.
- Powerful and accurate active heave compensation: speed capacity of 2 m/s and 90-95% accuracy according to signal representing vessel motions.
- Accurate constant tension.
- Pull limit: Active limitation of allowed pulling force that can be combined with AHC. This can also be extended to a splash zone transition function (avoid peak loads or slack slings during splash zone transition).
- Automatic landing function: Automatic transition from active heave compensation to constant tension upon landing. This function may also be combined with Pull Limit.
- Automatic lift-off function: Automatic transition from constant tension to active heave compensation during liftoff. This function may also be combined with Pull Limit.
- Crane mode: Brake handling according to requirements for offshore cranes, thus the FRDS can be integrated with crane, A-frame or other overboarding devices and handle the payload in air / on deck.

**Rope Management System**

Any kind of steel wire or fiber rope will suffer from fatigue when being bent around a sheave. In fact, knowledge of bend fatigue life of large low rotation steel wires is not well documented to date.

Cyclic bending over sheave will occur in active heave compensation and constant tension operations. Real time knowledge of the condition of the rope at any point of the rope is crucial information, in order to avoid failure of the rope or to be able to utilize the rope asset in an efficient manner.

Fiber ropes being repairable provides the operators with a unique opportunity to utilize the rope-fatigue-life for all parts of the rope. However this further emphasizes the need for a reliable system for monitoring and managing the condition of the rope as the rope configuration changes upon cutting and splicing of the rope.

To date, there are limited field data available to support rope wear calculations and the establishment of retirement criteria for the rope. Hence, conservative calculations must be applied at the current stage. To speed up and assure quality of the development of wear calculation methods and establishment of less conservative retirement criteria, a system providing data for this development process is highly important.

For the CTCU based Fiber Rope Deployment System, a Rope Management System (RMS) has been developed as an integral part of the winch control system. Real time signals on position and applied tension of any part of the rope is available. This information is then compared with geometrical data of the FRDS, such as sheave diameter and distance between sheaves. On this basis the RMS is capable of counting the number of bends at every position of the rope and weighs each bend according to a factor given by e.g. bend radius and rope tension at each bend point.

In the RMS, the rope is split into rope segments with configurable length of e.g. 0.33 meters for which rope data is recorded. Data are processed and displayed in real time on the winch operator computer as shown in Fig. 5. Alarms for inspection and replacement of a rope segment that has reached a configurable alarm limit are also implemented as part of the FRDS alarm system. Data is also stored such that it is possible to post process data e.g. using a new factor for bend weighing.

![Fig. 5: Rope Management System main screen.](image)

To account for changes in rope configuration when a section of rope is cut out or a new section of rope is spliced in, the RMS has functionality for managing data in such operations. When a section of rope has reached its retirement criteria or if the operator would like to check the actual condition of the rope, this section of rope is cut out and sent to laboratory for testing of residual strength. Data corresponding to the corresponding section of rope will automatically be retrieved from the RMS database in this process. Based upon results from residual break tests, the retirement criteria and weighing formulas can be improved. Thus, the RMS is a powerful tool to speed up and assure quality in rope wear and retirement calculations.

For steel wire, repair by cutting out and splicing in sections are not possible. The wire may be cut of at the end, and thereby reducing the total length, or the complete rope replaced.

**Pilot System**

The 46mT SWL Fiber Rope Deployment System (FRDS) was built and tested in 2003-2004 in a Joint Industry Project (JIP) conducted by the Norwegian company ODIM. This system was extensively tested onshore and on a barge.

**Tests**

The workshop testing of the pilot system culminated in a Factory Acceptance Test to verify basic features with regards to rope handling. This was followed by 8 weeks of test in an inshore location from a barge. The barge test was done using a clump weight of 35 mT in water. Tests included extensive active heave compensation testing to verify both winch and rope performance. The rope used for testing was a 225 m of 56 mm BOB rope with a Minimum Breaking Load of 218 mT. Tests were conducted at 100 m water depth.

Rope performance was tested by running in active heave compensation with temperature sensors inside the rope. In this way, temperature build up in the rope due to cyclic bending over sheave, could be monitored. Effect of rope cooling was also tested. After the test, the test rope contained a huge amount of data that was used to establish rope retirement criteria as explained later in this paper.
In addition to testing a single fall 56 mm rope with a 35mT clump-weight, a 4-fall configuration test, using an 18 mm rope, was done with the same clump-weight. The primary objective of this test was to demonstrate that the rope would not induce any torque on the lifted object.

All the tests onshore and on the barge were witnessed by DNV. Some of the results from the barge test are given below.

**Test results**

The following gives some of the highlights of the performed tests on the barge.

**Hoist and Slack:** The system can be operated smoothly in hoist / slack throughout the speed range. The system is operated from one joystick only, the synchronization between the storage winch and the CTCU is done by the control system.

**Spin:** No spin between the handling system and the fiber rope can be observed during operation in all functional modes. Spinning conditions were provoked by reducing the back-tension (tension on storage winch side of the system). The system responds by reducing torque on the spinning sheave and re-distribute load to the other sheaves.

**Load Distribution:** The load on the CTCU is the difference between outboard and inboard tension. Ay constant back tension, the load of the CTCU sheaves remained according to the predefined pattern even at outboard loads varying between 5 and 45 mT.

**Redundancy:** The system can be operated with one CTCU sheave and one storage winch motor is out of operation.

**Emergency Operation:** The system can be operated with reduced functionality independent of the main controller through the emergency operation panel.

**Rope Tests:** The control system continuously logs the load profile and events throughout the system. On completion of these workshop and barge tests, the rope was inspected for internal and external wear by rope manufacturer. The rope was still considered fully operable after 8000 bend cycles.

**Spooling:** The lifting rope is properly spooled onto the storage winch at constant tension.

**AHC:** The system was tested using the installed Motion Reference Unit (MRU) in addition to simulated sinusoidal signals and more realistic computer generated signals. The computer generated signal used was made to represent the Subsea 7 construction vessel Toisa Perseus at a weather situation corresponding to a significant wave height of 3 meters. When using computer generated motion reference signal, the payload is actually moved up and down in the water column. This results in quite high tension variations (+ - 8 mT). Thus, this is a very hard test compared to normal operational conditions where the tension variations will be almost eliminated by the AHC system.

The system compensated for more than 90% of the motion when employing computer generated MRU signals of different periods and amplitudes (from 6 to 15 sec.) and speeds up to 2 m/s. One example is shown in Fig. 6 (15 sec. period and 8 m amplitude) were the deviation (blue curve) between the reference signal (red curve) and the CTCU system compensation (black curve) is scaled up 10 times, demonstrating a minimum compensation of 95% (0.4 m residual motion).

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**Constant Tension:** In constant tension mode the system will work to maintain a constant tension in the rope independent of vessel motion. The constant tension setpoint were increased in 5 mT steps from 5 to 30 mT. The rope tension remained within ±2 mT of the setpoint throughout the test.

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Fig. 6: Barge test of Fiber Rope Deployment System.

Fig. 7: AHC using a simulated motion reference unit
**Auto Landing:** When Auto Landing is used, transition from AHC to constant tension is done automatically when the tension corresponds to the pre-set constant tension setpoint. This is demonstrated in Fig. 8 where the 35 mT clump weight was landed on the sea floor using auto landing with a tension setpoint (red curve) of 5 mT. Actual tension (black curve) and depth (blue curve) are also show.

**Auto Lift-Off with Pull Limit:** When Auto Lift-Off is activated, the system will perform an automatic mode transition based on simultaneous signals from the control system and the operator.

Fig. 9 shows the rope tension, tension setpoint and depth during a lift off from the seabed:
- Initially, the clump weight is on the seabed in constant tension mode with a 20 mT setpoint (red curve).
- Auto Lift-Off is activated approximately at T = 0 seconds.
- At T = 10 seconds, required conditions for the transition are achieved, and the system automatically switches from constant tension to AHC.
- The Pull Limit set point (red line for T>10 seconds) of 40 Te is then activated at the same time as the actual lift off is started. Rope tension, shown as the black line in the plot, swiftly increases from 20 mT to 40 mT. The operator is continuously pulling in with the joystick during this operation.
- As the clump weight is stuck in the mud, the system pull is limited by the Pull Limit setpoint at 40 mT for a period of 74 seconds before the clump weight leaves the seabed.

**Field pilot**
The barge test of the 46 me Fiber Rope Deployment System had proven the capability of the rope and handling system in shallow water and with limited vessel motions. To prove the system at deep water and in an offshore environment, a field pilot was the next natural step in the development process.

Hydro and the Ormen Lange project provided the JIP with the possibility to install 3 gravity anchors at 855 meters water depth at the Ormen Lange gas field outside the west coast of Norway. The installations were done in April 2005.

The gravity anchors have the following main data:
- Weight in air: 35.4 Te.
- Weight in water: 30.8 Te.
- Footprint: 7 x 7 m.
- Skirt length: 3 m.

With 150 m$^3$ of trapped water, the anchors had a significant added mass. Deployment calculations showed that resonant conditions could be expected both during deployment and landing. This provided the project with a unique opportunity to actually test and verify performance of the active heave compensated Fiber Rope Handling System in resonant conditions.
The installation of the anchors was led by Geoconsult, using the vessel Geofjord. Geofjord is a high utility ROV / construction support vessel, with flush deck and 6x6 m moonpool.

Fig. 12: Geofjord at ODIM site during mobilization.

The CTCU was installed to work through the moonpool. The anchors were to be launched over the side using the vessel crane. Load transfer to the CTCU was to be done at 100-200 m.

Field pilot tests

To study the behavior and performance of the active heave compensated Fiber Rope Deployment System in resonant conditions, a test was planned during the deployment.

Two of the three anchors were instrumented with a MRU (Motion Reference Unit) and a data logger. The purpose of this was to compare the measured motions of the anchor with the measured vessel motions at the over boarding point for the rope. The signals were not used for the actual control of the CTCU, but the recorded data was used in analysis of the AHC and the amplification of vessel motions to the anchors motion.

Three gravity anchors were installed in the following main steps:
- Launching of anchors from deck to 100 - 200 meters using vessel crane.
- Load transfer from vessel crane to CTCU.
- Lowering to 5 meters above seabed.
- Positioning, landing and penetration of the anchors.
- Recovery of equipment.

Anchors 1 and 2 were lowered to the seabed in steps, stopping approximately every 100 meters to conduct testing with and without active heave compensation.

Landing and penetration of the anchors were performed with AHC. The AHC proved to be more than sufficiently accurate for anchor installation, and effectively reduced oscillations in outboard tension that normally would have been caused by vessel motion. Landing and penetration was performed with great ease and high precision, without any form of disturbances due to residual motion on the anchors.

Keeping in mind that no swivel was installed on the fiber rope, careful monitoring of the rope was done as the load was gradually reduced during penetration. The rope showed no sign of rotation at all.

Field pilot test results

The effect of AHC on rope tension is shown in Fig. 18. Without AHC, the tension varies from 24 to 40 mT. AHC is engaged, the tension variations are reduced to ± 1 mT. This clearly shows the importance of AHC during deployment and installation of modules with potentially high hydrodynamic loads.

Fig. 13: Effect of AHC on tension at 300 m.

From 318 to 322 min, the AHC was switched off. During this period, it can also be seen that anchor movements is amplified by a factor 1.5 and that there is an emerging phase lag between the vessel motions and the anchor motions. This indicates that the period of the vessel motions is approaching the natural period of the system.

Resonance and dynamic amplification: Fig. 19 shows that the dynamic amplification at 100 meters is almost negligible. There is practically no phase lag between the vessel and the anchor motion.

Fig. 14: Dynamic amplification at 100 m.
The amplification of vessel motion was significant, often exceeding a factor of 2 for depths above 500 meters. Fig. 15 and 16 show that the dynamic amplification at 500 and 800 meters is between 2 and 2.5. The phase lag is also between 90° and 180°. This indicates resonant conditions.

![Graph showing dynamic amplification at 500 m.](image1)

![Graph showing dynamic amplification at 800 m.](image2)

These tests have shown that accurate active heave compensation efficiently reduces harmonic motions and dynamic loads in resonant conditions for a Fiber Rope Deployment System. Further, the field pilot also demonstrated that the technology is well suited for use in an offshore environment.

**Ultra Deep Water Installations in Gulf of Mexico**

In January 2006, Subsea 7 decided to use the CTCU based Fiber Rope Deployment System for an ultra deep water installation contract in Gulf of Mexico. The scope of the project was to install approximately 100 units in water depths from 2500 – 2750 meters. The vessel to be used was the subsea pipelay and construction vessel Toisa Perseus. The installation campaigns is scheduled from September 2006 to June 2007.

**Preparations**

In order to prepare the system and required personnel for this project, an upgrade project for the pilot Fiber Rope Deployment System was launched.

One of the most important things to get in place was the Rope Management System. This involved establishing a rope wear calculation method and inspection and retirement criteria for the rope. Data to support this was established by cutting the 225 m test rope from the barge test into 25 meter sections and performing residual breaking strength test on the samples.

Residual strength was compared with the knowledge of bend history for the rope. To calculate rope wear, a formula taking actual rope tension and sheave diameter into account was developed. Further, a minimum safety factor was established and the number of weighted bend cycles to reduce the safety factor from the initial value to the retirement value was estimated. To account for uncertainties in the input data and the calculation method, additional safety factors were applied. The weighing formula and the inspection and retirement criteria were implemented in the RMS.

To be able to fully exploit the unique repairability feature of fiber rope, the system was upgraded to a fully self contained unit capable of performing these operations in an offshore environment. Procedures for operations were developed and tested and vessel personnel trained.

If a new section of rope is spliced in at the end of the rope or an end section cut off, a new eye splice must be made. Proof load of the new eye splices is done by connecting the spliced eye with thimble to a dedicated fixed point in the system and then pull and hold using the FRDS to a proof load limit according to DNV rules and regulations.

In order to make an inspection or repair in the middle of the rope, the rope section in question is positioned between the last sheave of the CTCU unit and the over boarding sheave. The fiber rope can then be unloaded by hanging off the load using a specially developed Chinese Finger capable of hanging off full load if necessary. The load holding capacity was tested according to DNV lifting appliances to a proof load of 67 mT. Test was witnessed by DNV.

![Image of load hang-off using Chinese Finger.](image3)
An in-line splicing method that can easily be performed offshore has been developed. The cutting, insertion and splicing of the fibre rope is be done by pulling out a loop of rope between the last CTCU sheave and the over boarding device. To proof load in-line splices, a Chinese Finger is installed downstream of the in-line splice and hooked up to a dedicated fixed point in the system. The splice is proof loaded by pulling and holding using the FRDS according general requirements for load tests in DNV lifting appliances.

Fig. 18: In-line splice made in two colors for illustration.

Fig. 19: In-line splice before proof loading.

Fig. 20: Chinese Finger for proof loading of in-line splice

To assess the safety aspects of the system and make sure to comply with Subsea 7 safety requirements, a PUWER (Provision and Use of Work Equipment) analysis was performed and the system upgraded accordingly. To reduce the risk of down time, the FMEA (Failure Mode and Effect Analysis) was reviewed and a suitable spare package procured.

3300 meters of new rope was procured for this project. It was delivered in a container from the rope manufacturer. The diameter of new rope is almost twice of the nominal diameter, thus it was necessary to pre-tension the rope before spooling it onto the system. This was done by using the unique pre-conditioning function of the CTCU which brings the rope down to nominal size during the spooling process. The rope tension was increased to 25 mT using the first 3 driven sheaves and brought down to 7 mT storage tension using the next 3 driven sheaves.

Mobilization

The Fiber Rope Deployment System was mobilized on Toisa Perseus in Mobile Alabama in September 2006.

Fig. 21: CTCU being lifted onboard Toisa Perseus.

The system was installed to work over the:

Fig. 22: CTCU installed on Toisa Perseus

All the testing prior to this project had been done in North Sea climate. To prepare the system for Gulf of Mexico climate, a temperature review of the system was conducted. This resulted in installation of a deluge system for the rope to be used during prolonged active heave compensation at fixed depth. Other modifications were installation of AC units and sun screens for electrical cabinets.
To assure some tension on the Fiber Rope Deployment System during recovery of the empty hook, a clump weight of 0.8 mT is used. A 25 meters pennant with protective jacket on sub-ropes is used between the clump weight and the ROV hook. This was installed to avoid damage on the rope during ROV handling of the hook.

**Installation tasks**

The scope of work for the Fiber Rope Deployment System consisted of approximately 100 lifts at 5 different locations in the Desoto Canyon and Lloyd Ridge in Gulf of Mexico at water depths ranging from 2500 to 2750 meters. The type of planned lifts are:

- Installation of mudmats.
- Lowering and stabbing of second end of umbilicals.
- Installation of manifolds.
- Installation of spool pieces.
- Installation of jumpers.

The installation tasks are done by deploying the units by the vessel crane and make load transfer to the Fiber Rope Deployment System at 1000 meters water depth. The load is then deployed to a few meters above the seabed. Positioning and landing is normally done using active heave compensation.

For the lowering of second end of umbilicals, the load is cross hauled from the vessel A&R winch working through the moonpool to the Fiber Rope Deployment System at 1000 meters depth and lowered to the sea bed. During stabbing of the umbilical into the Stab and Hinge Over Mudmats, active heave compensation has proven to be very useful.

The rope has also performed very well, without any major issues. After 60 installations the rope is still only at 40% of the conservatively defined retirement criteria.

**Further plans**

An internal inspection of the rope at 50% of the retirement criteria is planned. A section of the rope will then be cut out and sent to laboratory for residual strength test upon reaching the defined retirement criteria or by the end of the project. Data from this test combined with the recorded bend history from the Rope Management System will be used to adjust the retirement criteria and improve the wear calculation model for the rope.

**Conclusions**

The general challenges associated with using fiber rope in lifting operations have been solved and fully field proven through this project.

Through the field pilot of the system at Ormen Lange gas field it was demonstrated that accurate AHC can be efficiently used to control a payload in resonant conditions.

Extensive use of the system in ultra deep water installations in Gulf of Mexico has confirmed the applicability of the technology in question in a real offshore environment, and important savings in vessel time has been achieved.

Management of rope condition is crucial for utilization and control of repairable rope. Methods and tools for this purpose have been developed through this project.

**References**