PERFORMANCE OF HIGH MODULUS FIBER ROPES IN SERVICE ON DUAL CAPSTAN TRACTION WINCHES:

A SIMULATION OF ROPE/WINCH INTERACTIONS DURING DEEP SEA LONG CORING OPERATIONS

1.0 INTRODUCTION

At present, UNOLS systems for collecting sea floor sediment samples are limited to the recovery of large diameter [10 cm] cores approximately 25-meter long. The current technology employs a Kullenberg piston corer [wt = ~5,000 lbs.] suspended and controlled by a torque-balanced wire rope [9/16” Dia. / MBL = 16 tons] and single drum trawl winch system. A new and much larger coring device is under development at the Woods Hole Oceanographic Institution. The goal of the new project is to create an integrated yet portable system capable of recovering cores up to 50 meters long in full ocean depths [~ 5500 meters]. The new corer alone has a weight of 25,000 lbs.; and numerical modeling has shown that in operation, the expected maximum tension that the overboarding arrangements will endure [during core extraction] is between 50 and 60,000 pounds.

The new system will, for the first time, employ high modulus synthetic fiber rope to replace the ‘traditional’ 3 X 19 wire rope. The change to synthetic rope is necessary, as the weight of a wire rope sufficiently strong to support the proposed corer would have inherently excessive mass to allow reasonable shipboard handling and provide an acceptable factor of safety during operations. This change to fiber rope is possible due to the recent introduction of suitable products made from high performance synthetic fibers. These new high modulus braided ropes are stronger than equivalent diameter wire rope, but are buoyant or lightweight in seawater. In the proposed layout these ropes will require the use of a custom designed articulating stern sheave for final overboarding, and a dual capstan traction winch and low-tension take-up drum for control and storage. The components of this winch, including its power supply are to be installed on a reinforced area on the aft deck of selected [UNOLS] oceanographic research vessels.

By their nature, fiber ropes are more susceptible to surface wear, inter-strand abrasion and elevated levels of frictional heat than similarly sized wire ropes. The entire handling system has to be designed to avoid damaging frictional [slipping] and abrasive contact between rope and winch components to protect the fiber rope from excessive wear and accidental operational failure.

2.0 PURPOSE OF TEST EFFORT

The planned evaluations are aimed to make performance comparisons on a test setup, which simulates the rope interaction with a dual sheave capstan winch. On the dual capstan winch the sheaves have to reduce the coring rope tension from a high of

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1 In a parallel effort, a customized rope handling system [traction winch] for the coring operation is being developed. The future winch design is likely to be affected by the results of this rope-testing program. The purpose of the rope handling system design is to develop a unit which maximizes rope service life and minimizes rope wear, while maintaining effective winch operation and rope control.
~50,000 lbs. to a low load range (500 lbs. to 2000 lbs.). This will allow spooling of the rope on a large storage drum under low tension. The design of the dual capstans of the winch and the rope composition, construction and coating will all influence the operative effectiveness of the winch and the wear of the rope in service. A large number of variables in the design of the dual capstan winch combined with a range of rope candidates require screening of test options to make the effort both meaningful and affordable. This test plan is prepared with input from winch manufacturers; fiber rope winch test results, rope manufacturers and users, plus numerical modeling of the coring process to reveal the range of dynamic events expected. The plan is designed to gain knowledge of the rope behavior on its handling system, and learn how to assure that coring rope handling system hardware details such rope groove shape and rope groove material will minimize abrasion and wear of the fiber rope that they handle. Through the test effort the coefficients of friction of the rope candidates with the selected sheave groove configuration and material will be determined, which will help the winch engineers to design the dual sheave capstan and take up arrangements of the winch system with optimized efficiency.

3.0 THE DUAL CAPSTAN WINCH DESIGN INFLUENCE ON ROPE LIFE

The Dual Capstan Winch has to be designed to allow gradual transfer of most of the coring rope overlapped tension onto the capstan surface, so that the rope can be spooled onto a storage winch drum under a relatively low nominal tension. The service life of the coring lift rope will be greatly influenced by the size and arrangement of the two capstans and the detail design of the rope grooves that are machined into the capstan surface which are the contact interface with the rope. Factors influencing the rope service life and effective transfer of the main coring rope tension onto the winch include:

a) The shape of the rope groove,
b) The size of the groove relative to the rope diameter,
c) The groove surface smoothness and hardness,
d) The actual sheave/groove material,
e) The fiber rope material and rope construction,
f) The static coefficient of friction of the wet capstan groove surface with the wet rope,
g) The optimized number of rope grooves,
h) The ratio of sheave diameter to rope diameter ratio,
i) The sheave base diameter changes along the rope path.

2 Spooling of a low tensioned rope avoids the possibility that an incoming highly tensioned rope might be buried and wedged into already spooled rope layers on the storage drum. This phenomena can cause serious local rope surface wear when the rope is being pulled out of its wedge grip during the deployment. In the worst case, tension on the deploying coring rope may be insufficient to free the wedged-in rope section on the spool and this could completely compromise further operations with the winch.

3 Changes in the sheave base diameter influence how much sliding friction will occur when the coring rope is guided around and through the dual sheave area. The incoming loaded and elongated coring rope, while traveling over the traction winch towards the storage drum, is progressively losing its tension and stretch due to the frictional grip along its path. The dual capstan winch can accommodate the rope length reduction by reducing the groove base diameter of consecutive grooves. The rate of this reduction is sensitive. Too little wrap diameter reduction retains unwanted tension since the rope cannot retract enough unless the coefficient of friction is so low that the rope can slide, thereby reducing its length and tension. Too much wrap diameter reduction causes rope slackness on the forward end, and allows the suspended coring head to pull the slack overboard, again causing sliding friction. Too high coefficients of friction will maintain the rope tension over a number of wraps on the capstan, exposing the rope to unnecessary flex cycles under high loads while passing around the capstan. Sliding friction should be kept to a minimum. There is an
j) The angular position of the aft versus forward capstan axes to eliminate rotating forcing of the rope running over the winch

k) Special capstan features which allow sheave rims to rotate against rim grooves

4.0 DESCRIPTION OF THE CORING PROCESS

When fully rigged the massive new corer will be comprised of a lead filled head [weight stand] and a long [up to 50 meters] ‘coupled’ barrel assembly. The mass of the corerhead is adjustable according to the total deployed barrel length and the physical properties of the targeted sediment. It’s expected that the total weight of this portion of the system will fall in the range of 15,000-25,000 pounds. In addition, a shaped mass [5,000-10,000 #: the ballast or ‘drag’ plate] will be located at the termination of the synthetic rope [See figure 1]. The purpose of the drag plate is to control/dampen the elastic rebound of the high-modulus synthetic rope when the core is triggered for penetration. In addition the drag plate will contain and support the modem controlled acoustic release system and altimeter. The total weight of the corer and drag mechanism will range from 20,000 to nearly 35,000 pounds.

Once deployed from the deck of a research vessel, the entire assembly will be lowered to the sea floor [as deep as 5500 meters] at a speed of approximately 1 meter/sec. When the corer nears the bottom, the altimeter will be activated [see Figure 2] and the system will continue to be lowered until a predetermined height off bottom is reached. At this point the winch will be stopped and the modem will then be used to activate the robust release mechanism. The corer will free-fall a modest distance [3-5 meters] before beginning to penetrate. During this brief [0.2-0.25 sec.] period of free fall, tension on the synthetic rope will be reduced by the weight of the corer and the drag plate is will react to the force of the recoil of the rope. When free fall is complete and the corer just begins to penetrate, the ‘pennant’ between the drag plate and a well-sealed piston that is located in the nose [lowermost portion] of the core barrel becomes taut. The friction and suction action of the piston will re-tension the synthetic rope gradually as penetration proceeds [2.75-4.5 sec. depending on core length]. During penetration the piston is immobilized at the sediment/water interface as the core barrel proceeds ‘beyond’ it.

Moments after penetration is complete, the winch will be engaged and build up tension to extract the corer and it’s recovered sample from the seabed. Our modeling has shown that tension during this brief moment of ‘pullout’ may reach ~60,000 pounds. Once the breakout of the corebarrel has occurred, tension will again stabilize to the weight of the hardware. The weight in water of the included sample is negligible. The rope will be retrieved at 1 meter/sec. until the release mechanism nears the surface. In pelagic water depths this process may take up to 2 hours. Dynamic loading is likely to occur due to ship motion throughout the lowering and recovery of the corer but will have optimum smoothness and coefficient of friction of the groove surface in contact with the rope. The optimum smoothness allows unavoidable contraction or elongation of the rope under load changes, and maintains sufficient frictional grip to effectively reduce the rope tension during retrieval with an acceptably low number of rope grooves on the winch. The coefficient of friction cannot be too high, as with some polyurethane lined sheaves, because it would reduce the tension in the rope too rapidly. The amount of force transferred depends on the coefficient of friction and the number of wraps around the capstans. Additionally the sheave diameter has a significant effect on the compressive force between the rope segments, which are bent around the rope grooves’ bearing diameter on the sheave. The smaller the bend diameter, the higher the rope pressure, and the more tension transferred per unit bent length of the rope path on the winch at unchanged coefficient of friction. However the sharp bends cause excessive shear strength between the outer rope strand surfaces and accelerate tearing and abrasive destruction of the rope on the capstan.
a more pronounced effect on the rope where the corer is near the surface. The final phase of the operation is the transfer of the equipment load to the shipboard capture system. Table 1 summarizes the coring process, assuming a core station from a sea floor depth of 5,500 meter as maximum system capability.

<table>
<thead>
<tr>
<th>EVENT</th>
<th>Rope tension [lbs.]</th>
<th>Duration</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.) Lowering of corer to sea floor</td>
<td>20,000-35,000</td>
<td>120 min.</td>
<td>Corer and ballast /drag plate weight</td>
</tr>
<tr>
<td>2.) Modem release of Corer</td>
<td>5,000-10,000</td>
<td>.25 sec.</td>
<td>Corer free falls before penetration</td>
</tr>
<tr>
<td>3.) Core Penetration</td>
<td>10,000-20,000</td>
<td>2.75-4.50 sec.</td>
<td>Piston suction gradually retensions rope during sample recovery.</td>
</tr>
<tr>
<td>4.) Core extraction [Pullout]</td>
<td>50,000-60,000</td>
<td>Peak 5-10 sec.</td>
<td>Highest [dynamic] tension of the entire process.</td>
</tr>
<tr>
<td>5.) Retrieval of the corer to the ship</td>
<td>25,000-35,000</td>
<td>100-150 min.</td>
<td>Retrieval slows as corer nears surface: dynamic loads increase</td>
</tr>
<tr>
<td>6.) Dynamic loading near sea surface during retrieval</td>
<td>27,500 +/- 10,000 lbs.</td>
<td>15-30 min.</td>
<td>Estimated sea state loading</td>
</tr>
<tr>
<td>7.) Corer captured by shipboard equipment</td>
<td>Near zero</td>
<td></td>
<td>Core head on deck</td>
</tr>
</tbody>
</table>

Table 1: Expected Maximum loads and load duration at 50 meter coring cycle

5.0 THE CORING ROPE CANDIDATES

The following selection of rope fiber/construction candidates is based on an extensive pre-test evaluation and comparison of potential product strength, durability, and a wide range of additional performance parameters. This pre-survey of options included the review and analysis of existing test data that affords insight as to candidate fibers probable performance in our [quite] specific application. The choice of ropes has been reduced to three different products all made from high performance synthetic fibers. Two ropes are manufactured from Ultra-High Molecular Weight Polyethylene (UHMWPE). The third rope candidate is made from a 50/50 blend of UHMWPE and Vectran⁴. The ropes are manufactured in competing designs by two of the leading domestic rope manufacturers, Puget Sound Rope (PSR), and Samson Rope Technologies.

Candidate rope size is a based on the following considerations:
1. Maintenance of a high factor of safety during all phases of the coring operation. Target levels: 10-12:1 during system deployment and recovery; 5-6:1 at maximum dynamic loading [core pullout].
2. By keeping the weight of system/rope strength ratio extremely high, pre-release elongation and subsequent rebound after core triggering will be minimized. This enhances our ability to further control/dampen the elastic recoil and adjust system parameters to avoid sample disturbance.

⁴ UHMWPE is ultra-high molecular weight polyethylene; fibers are available from Honeywell under the trade name Spectra, and from the Dutch DSM group under the trade name Dynema. These fibers have a melting point of 240⁰ F. The specific gravity of UHMWPE is 0.98; the ropes float in freshwater and seawater. Vectran is a liquid crystal polymer fiber developed by Celanese, with a specific gravity of 1.40, and a softening point of 662⁰ F. The ‘blend’ has a specific gravity of ~1.20.
3. As a result of dialog with end users, rope applications consultants, fiber suppliers and rope manufacturers, it's become clear that the ‘bigger the rope’ that we can employ, the longer it will last.

Based on budget limits and careful assessment of system sheave requirements and storage issues, a 2” diameter rope [6” CIRC] with an average minimum breaking strength of around 175 tons is being specified.

For all candidates the basic rope design is a twelve-strand braid, modified by PSR to a 12 by 12 strand construction, where each of the 12 strands is a small 12-strand rope. This 12 X 12 construction is distinguished by the fact that because the primary strands are actually ropes, it’s possible to repair a damaged rope in the field by removing the section of bad strand and splicing in a replacement. All the candidate ropes are furnished with company proprietary [urethane] finishes which increases their abrasion resistance, enhances their coefficient of friction and improves overall structural coherence. Because of thorough prior testing and evaluation of various coating alternatives on ropes of identical fiber make-up, construction, and similar size, we’ve elected not to compare or alter coatings but stand by those already proven effective in applications far more rigorous than ours. The twelve-strand rope design is non-rotational, easy to splice and has found wide acceptance in commercial shipping, in particular as towlines on tugs, replacing their traditional wire ropes.

<table>
<thead>
<tr>
<th>Rope Trade-Name</th>
<th>Made By</th>
<th>Diameter</th>
<th>Fiber Material</th>
<th>Specific Gravity [gr/cm³]</th>
<th>Softening Point [°F]</th>
<th>Breaking Strength Min. [lbs]</th>
<th>Rope Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma</td>
<td>PSR</td>
<td>2.0</td>
<td>UHMWPE</td>
<td>0.98</td>
<td>150</td>
<td>355,000</td>
<td>3.00</td>
</tr>
<tr>
<td>AMSTEEL-Blue</td>
<td>Samson</td>
<td>2.0</td>
<td>UHMWPE</td>
<td>0.98</td>
<td>150</td>
<td>342,563</td>
<td>3.00</td>
</tr>
<tr>
<td>Blend</td>
<td>PSR</td>
<td>2.0</td>
<td>Vectran/ UHMWPE</td>
<td>1.2</td>
<td>350</td>
<td>350,000</td>
<td>3.66</td>
</tr>
</tbody>
</table>

Table 2: The Twelve-Strand Rope Candidates

Table 2 lists the rope candidates that will be procured for the comparative testing effort described in the test plan. The length of the test samples required for each evaluation will be determined and the rope manufacturers will furnish the samples with factory-installed eye-splices.

6.0 Rope Test “Philosophy”

Elements of the test procedure and test process are developed to simulate the rope exposure during its service life. The arrangements of our proposed rope handling system during operations subject any given section of the high modulus rope to a series of sequential over-sheave events. When industry experts compare these physical parameters to more rigorous circumstances experienced in typical cyclic bend over sheave situations the consensus is that the long coring application of high modulus fiber rope is “relatively benign”. This is especially evident when the large projected rope diameter/sheave diameter ratios [D: D 30:1] and relatively high factor of safety [generally 12:1] we’ll maintain are considered. The most critical repetitive moments in the rope life are:

a) The passage of the tensioned rope over the capstans of the traction winch as well as the stern roller during normal payout and retrieval of the coring system.
b) The short high tension peak during the core extraction from the sea floor.
c) Dynamic loading of the last 100 meters of the rope length during retrieval in the case of significant sea state interaction (heave)
d) The responses to sudden load reduction following the corers release.

In order to effectively evaluate the rope handling system/rope interactions expected to occur while ‘our system’ is in use we propose to test spliced rope samples under laboratory conditions that best simulate the action of a traction winch during dynamic coring operations. Candidate ropes will be full sized [2” Dia.] and critical sheaves in the test beds should maintain the project specified 30:1 D/d ratio.

Additional test are proposed off the ‘winch simulator platform’ that will help us quantify and understand other aspects of loading and coring dynamics on the ropes. These tests will include precision elongation measurements, rope shape, and comparison of the effects of fiber and construction in response to rapid release of tension.

7.0 Rope Test Equipment

A principal piece of equipment at TMT Laboratories proposed for use in winch/rope interaction tests is a modified CBOS platform. This CBOS unit which usually determines the flex fatigue behavior of various cables and ropes consists of two single or multi-grooved sheaves, mounted in a test frame with an adjustable distance (up to 34 ft) between the two sheave axes, see Figure 1. The sheaves are available with different outer diameters and rope grooves. The sheaves on the right are mounted on stationary bearings; the sheaves on the left are connected to a clevis and hydraulic piston head. The rope sample(s) are wrapped around the two sets of sheaves and connected to opposing clevis assemblies of a “traveler” carriage, which can move along the test frame on guided rails. This arrangement forms a closed loop of the full-sized test sample. The piston head on the left side of the frame is used to tension the rope loops. Parallel to this sheave arrangement is a powered link chain drive loop, the “stroker”. The ends of the link chain loop are terminated in suitable clevis hardware, which is part of a “stroker traveler”. The stroker traveler is connected to the traveler securing the rope ends. The link chain drive moves the stroker back and forth between adjustable end switches, thereby forcing the rope test loop to roll onto its sheaves, travel for a minimum of 180 degrees around the sheave and roll off again into the straight section of the rope test loop. When the traveler touches one of the end switches, the stroker drive motor reverses its turning direction, and the test sample is subjected to a ‘reversed’ flex cycle.

This CBOS machine will be specially modified for coring rope test by replacing the standard sheave on the stationary bearing [in Figure 1 the sheave on the right] with an independently powered sheave. The material, groove and groove finish of this powered sheave can be modified by replacing the outer ‘rim’ of the assembly. This sheave also has the potential of being locked in a stationary position.

The test machine will be set up with sheaves with 60 +/- 3 inch groove wrap diameter and 7 +/- 0.5 percent larger groove diameter than the rope diameter at near zero tension.
8.0 Rope Samples and Sample Preparation

The rope samples will be fitted to form the rope test loop in Figure 1, with eye-splices on each end connected to the clevis components of the Traveler Carriage. The stroke length will be reduced, to allow that the piston can stretch the rope loop to a selected test load. TMT Laboratories will advise on the suitable overall length of the spliced rope samples, which will be prepared by the rope manufacturers.

9.0 Rope Test Plan

What follows are details of the actual proposed lab testing procedures. By nature, this process must remain flexible and subject to change. Additional tests of new types may be warranted by examination of initial results. Certain aspects of the proposed tests may as well be expanded upon or deleted. Our goal is to initiate the process with fundamental evaluations and build upon these results with the intent of maximizing our understanding of the critical interactions of winch and rope and rope response to coring dynamics.

A. EVALUATION OF HM ROPE/SHEAVE INTERACTION: FOCUS ON FRICTION COEFFICIENT in ‘STATIC TESTS’.

Purpose:
- Determine the coefficient of friction of candidate ropes at different tensions in alternative sheaves.
- Resolve the effect of rope wear on the COF
Variables:
- Sheave material with groove surface finish ‘defined’.
- Tension
- Wet samples vs. Dry [seawater]
- Rope type
- Worn vs. new.

Platform: Modified CBOS Test Apparatus

Procedures: [Wet and Dry]
- Lock the ‘powered’ sheave
- Manipulate the stroker to force test loop to slip on locked sheave
- Expose new section of test rope for variable tension comparisons
- ‘Wear’ a section of rope by repetitive BOS and/or slip cycles
- Do ‘selected’ tests to compare performance worn vs. new.

Monitoring:
- Record all tension sensors on bed [including gradient around sheave?] to enable precise determination of friction coefficient.
- Capture temperature conditions at critical points along sample with optical laser pyrometer.
- Evaluate/record-[photograph] rope deterioration at fixed steps during wear cycle.

B. EVALUATION OF HM ROPE/SHEAVE INTERACTION: ‘DYNAMIC TESTS’.

Purpose:
- Simulate actual traction winch sheave/rope dynamics by applying torque to the ‘fixed’ end powered sheave of the test bed while simultaneously stroking the linear drive system.

Variables:
- Sheave material with groove surface finish ‘defined’.
- Tension
- Torque on the fixed-end sheave.
- Dry vs. Wet samples [seawater]
- Rope type
- Worn vs. new.

Platform: Modified CBOS Test Apparatus.

Procedures: [Wet and Dry]
- Apply various amounts of torque [via hydraulic motor] to the fixed-end sheave of the test bed.
- Manipulate the stroker to ‘rotate’ test loop over the torqued fixed end sheave.
Increment the bed tension and torque on the sheave through specified range.
“Wear” a section of each rope with repetitive BOS and ‘slip’ cycles
Perform selected test’s to compare results with new vs. worn rope.

Monitoring:
Record all tension sensors on bed [including gradient around sheave?] per event.
Capture temperature conditions at critical points along sample with optical laser pyrometer.

C: ELONGATION, TORQUE BALANCE ASSESSMENT, AND EFFECTS OF RAPID TENSION RELEASE ON CANDIDATE ROPES.

Purpose:
Compare precision elongation measurements for prescribed critical program load levels.
Compare load induced rotation resistance.
Determine the effects of rapid load reduction on minimum breaking load of candidate ropes.

Variables:
Rope type
Tension
Tension at quick release.

Platform: 300,000 pound linear test bed equipped with friction-compensated swivel/rotation sensor.

Procedures:
A: Stretch and Rotation tests.
By repetitive evolutions, establish elongation characteristics of candidate rope samples at specified ‘coring-load’ levels.
Monitor torque balance characteristics [rotation] throughout the range of tests

B: Quick release tests.
Install mechanical fuse [weak-link] in linear sample arrangement.
Tension candidate sample until link is sheared.
Repeat [n] times for each sample.
Break test Q/R samples and new samples.

Monitoring:
Tension during all cycles
Rotation during cycles assessing torque balancing.
D: PERFORMANCE AND DURABILITY OF ROPEs UNDER EXTREME SLIP/STICK SIMULATIONS

Purpose: Monitor temperature and collect information on internal and 'surface effects' of worst-case slip conditions under average working tension.

Variables:
- Rope Type
- Slip/stick cycle rate

Platform:
Modified CBOS test bed with 'powered sheave'. Special additions include imbedded thermocouples in the rope samples to monitor and record internal temperature, and optical laser pyrometer[s] to assess surface temperature.

Procedures:
- Pre-tension test bed to ~25,000 pounds.
- Cycle 'stroker' at a slow [~.25 m/sec.] rate.
- Engage then disengage the hydraulic brake on the 'powered sheave' repeatedly during the passage of an indexed and instrumented portion of the rope [~10 '] sample over the 180 degree bend of the sheave.
- Continue for 6 complete cycles [12 passes of sample of rope over sheave] or until temperature conditions stabilize.

Monitoring:
- Surface and internal temperature of rope sample
- Surface condition [visual and photo] of ropes.
- Effect on minimum breaking strength. [Pull selected samples to failure after specific test intervals.]

10.0 Consulting and Reporting

The reporting format should include short descriptions and test observations of each of the specified tests, graphic displays of the test results where appropriate, and a short summary with references. Final reports should be submitted no later that 45 days after completion of the test program.

11.0 Detailed Quotation

It is requested that TMT provide separate budgets for each test plus a summary budget for the entire test effort and subsequent reporting. Individual test budget estimates should breakdown: Set-up cost; cost of special test monitoring sensors; cost per day, cost for repetitive cycles and multiples thereof, and reporting costs. Consulting time spent by members of TMT Laboratory with WHOI personnel to review and modify tests should be part of the estimate.