NEW ROPE TECHNOLOGIES IN MARINE APPLICATIONS

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ABSTRACT
Synthetic ropes manufactured from high modulus synthetic fibers have been successfully replacing wire cables in various marine applications, such as mooring, tug, salvage and fishing for over 25 years. The substantial benefits afforded by lightweight, flexible alternatives to wire rope are becoming globally recognized by important advisory such as OCIMF (Oil Company International Marine Forum) and others.

As these high performance synthetic lines expanded to specialty applications, new technical challenges start to demand the rope manufacturers to advance their rope technologies to the next level. In this paper, we will discuss several new technologies developed recently to overcome high level of technical difficulties and challenges, including the following areas:

- Requirements for a rope with low tendency to recoil when break
- Requirements for a rope to perform in high temperature/fire environment;
- Overcoming the low coefficient of friction nature of rope made with HMPE (High Modulus PolyEthylene) fibers.

ROPE WITH LOW TENDENCY TO RECOIL

INTRODUCTION
A systematic study of recoil behavior of ropes was studied in 1966, comparing ropes made of synthetic vs. natural fiber [1]. It was concluded that the rope with higher energy absorption capability would tend to recoil more, since more energy would be stored in the rope when it broke. As more synthetic ropes were used, rope manufacturers started to address this issue, by designing synthetic ropes with lower recoil/backlash tendencies [2]. The basic principle behind the then new design was to combine the correct proportion of "high stretch" and "low stretch" components, where the "low stretch" component would break before the "high stretch component" did. Some design and testing of reduced recoil ropes using the same or other principles were also discussed [3, 4].

CID A-A-50435B [5] was developed in 1992 to provide specifications of reduced recoil rope, but it only applies to 4 strand Aramid ropes. To develop a standard which can be used for all ropes, Cordage Institute technical committee developed "The Reduced Recoil Risk Rope, CI1502" - standard testing procedure to property define how to properly test a reduced recoil rope [6]. The key property CI1502 quantifies is the "warning time stretch" - "the stretch from the point of first break to the point at which the last design component breaks". The "warning time stretch" can later be converted to the true "warning time" when the loading rate of the rope is known. This is an important improvement in comparison to CID A-A-505435B as the real warning time can now be estimated properly based on rope size and loading rate.

MODEL ANALYSIS AND PRODUCT DESIGN

A detailed discussion of the energy absorption and release before and after a rope breaks was discussed in previous discussion [7]. The analysis helped to provide the design principles for the rope. Fig. 1 show the final design of the patented product - a 12 strand construction HMPE rope with the energy absorption components. The concept is that after the first break of the rope, the stretchy component will stay connected to stop the rope from recoiling.

Fig. 1. Patented Reduced Recoil Rope

TESTING

Samson Rope Technologies has a state of the art horizontal tester specifically designed for synthetic rope testing, shown in Fig. 2. The machine is calibrated from 1,820 kg to 500,000 kg and has a 15.2 m sample bed length with 4.9 m of stroke. The test machine is computer controlled for precise data logging of elongation and tensile measurements. The hydraulic ram can reach a maximum speed of 3.7 m/min at loads up to 45,450 kg, up to 3.1 m/min at loads up to almost 136,400 kg, and up to 0.6 m/min at loads up to 500,000 kg.

Fig. 2. Samson's Rope Testing Machine

The sample is prepared following CI1502. The rope sample size is 1 in (24 mm) diameter and the overall length is 600 in (15,240 mm) with a total spliced length of approximately 65 in (1,651mm), thereby satisfying the maximum (240 x rope diameter) limitation specified by CI1502.

The rope samples were cycled 10 times to 50% of the expected strength before the final break, following the guideline of CI 1500 and CI1502. After the first break, the test continued and the "warning time" is recorded as the time difference between the first break and the last break. Crosshead speed is set such that the rope reaches 50% of its breaking strength in not less than 5 seconds and not more than 50 seconds. For the 24 mm (1 in) dia. rope test, the average loading rate is 0.6 m/min and reaches 50% of its break strength in approximately 30 seconds.

RESULTS AND DISCUSSION

Fig. 3 shows the testing results of Mooring Defender, presented as load vs. stretch. Several events are marked on the curve, 1st break (breaking strength), residual stretch, 2nd break, etc. The series of strength vs stretch loops at the left portion of the curves shows the 10 cycles to 50% of the breaking strength before the final break.

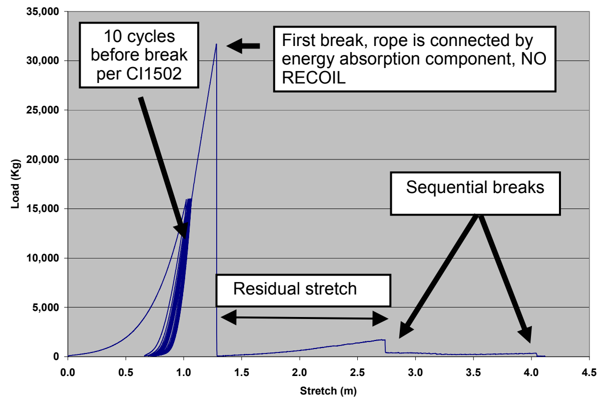

Fig. 3. Strength vs. stretch of 1 inch diameter rope.

As the load vs. stretch curve shows, the rope is still connected together, as shown in Fig. 4, by the stretchy component after the 1st break. It continues to stretch until one of the stretchy components breaks at the first peak marked as the "sequential breaks", followed by additional stretch till the whole rope separates into two pieces.

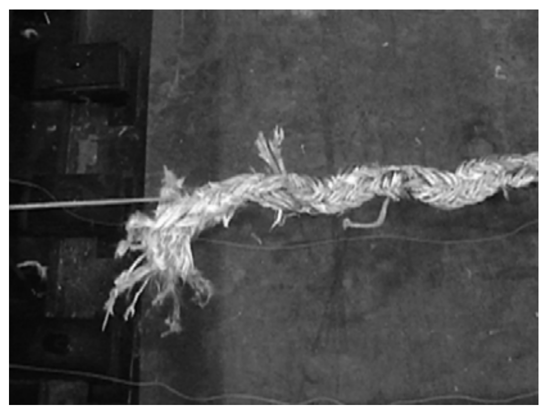

Fig. 4 Rope does not recoil after the 1st break, held together by the stretchy component. The picture in the right shows a close up of the intact stretchy component.

The warning time stretch, between the first break and the last break is approximately 2.8m, which means that if the rope breaks at 0.6m/second, the last break will not occur until 260 seconds after the 1st break, making it an extremely safe rope comparing to the UA Navy's CID A-A-50435B's 10 second warning time requirement.

It is also important to note that the 2nd break, which breaks the energy absorption component, is very low, only about 7% of the original strength of the rope. This strength level further enhances the safety of the rope as the recoil of the 2nd break, if it occurs, will be very low so the rope remains safe even beyond the warning time.

Additional Comments

Although this study focused on reduced recoil behavior of a rope, this patented technology also has other important performance advantages including:

- easy to splice
- capability to incorporate energy absorption in the rope design easily
- torque balance
- easy to inspect
- flexibility

In addition to the above considered factors, the surface of this rope can also be modified with Polyester and a proprietary coating to increase its coefficient of friction to enhance the surface characteristics.

CONCLUSION

The tests and analysis show that the energy absorption component needs to have enough energy storage capability to dissipate the energy released from the strength members to reduce the rope recoil. This patented rope design, based on this principle, is proven to be a good reduced recoil rope with other important rope performance attributes. Lab testing also demonstrated that its reduced recoil property is not affected by tensile fatigue up to 1000 cycles loading to 50% of the breaking strength of the rope [7].

"Warning time stretch", as CI1502 specifies, being a rope property, can be used to estimate the true "warning time" considering both the rope and the loading condition, is a good parameter to determine the reduced recoil requirement.

ROPE WITH HIGH TEMPERATURE RESISTANCE

INTRODUCTION

Of interest to the petroleum tanker industry is a synthetic replacement of the Emergency Tow-Off Pendant (ETOP), commonly referred to as "Fire Wires." These pendants are required by OCIMF (Oil Company International Marine Forum) for use anytime a petroleum tanker ship is moored to a dock or berth. Its purpose is to provide a means of towing the ship away from the dock in the event of a fire. Wire rope is currently used in this application.

The ETOP is positioned along the side of the vessel and monitored to maintain a certain distance from the water. The ETOP must be adjusted as the ship's ballast changes during the loading or offloading process. This "repositioning" of the ETOP is often done manually. The handling of these heavy wire ropes has resulted in many injuries to deckhands.

An obvious solution to this would be to replace the wire rope with a synthetic rope. A synthetic rope would be much lighter and would eliminate the problem with "fish-hooks" (broken wires that protrude from the wire rope and result in many hand injuries). The problem with this solution is that the ETOP is required to be heat and fire resistant, and be able to withstand severe heat and/or direct flames for a reasonable amount of time.

TECHNOLOGY DEVELOPMENT

The chosen fiber for this application is a p-Aramid. This selection was due to the need for a fiber that was heat resistant and able to retain its properties at elevated temperatures. A p-Aramid fiber has the following desirable characteristics:

- Higher initial tenacity at elevated temperatures
- Good heat cycling properties
- Good abrasion properties
- Good chemical resistance
- Not effected by hydrolysis

Fig. 5 below shows typical strength characteristics of a p-Aramid fiber as a function of time and temperatures.

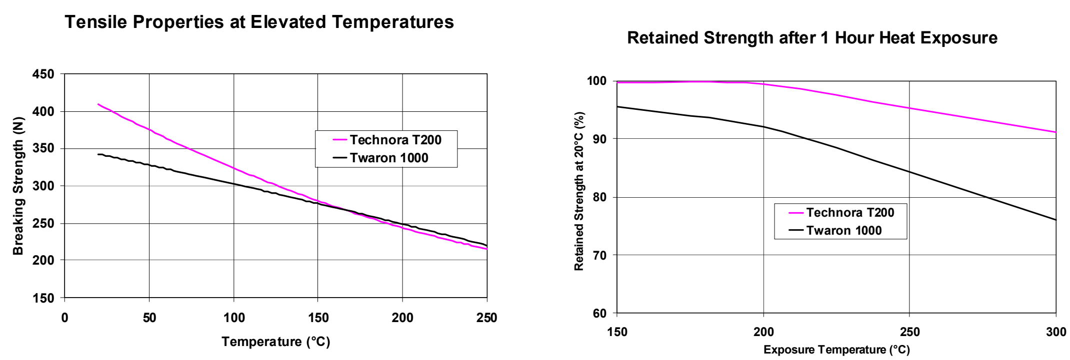

Fig. 5. Thermal Properties of p-Aramid fibers.

The p-Aramid fiber rope alone is unable to withstand direct flames as required for the ETOP application. To further enhance the flame resistance, a proprietary coating containing a proprietary fire resistant ingredient can increase the damage resistance of direct flames. When applied to the rope, the coating will provide protection allowing the rope to withstand direct flames considerably longer than without the coating.

TESTING

For Heat testing on ropes under load, a tubular heat chamber was build, as shown in Fig. 6. Testing chamber capabilities are:

- Max Temperature – 500°C
- Accuracy - +/- 2°C
- Overall length of rope exposed to heat – 1 meter

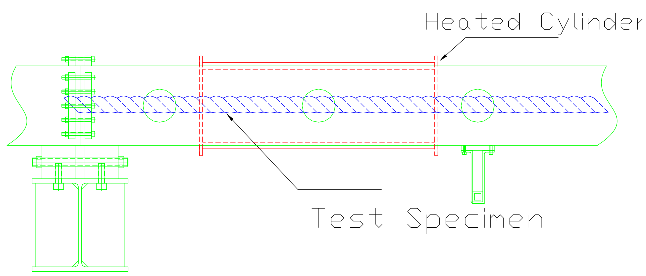

Fig. 6. Hot chamber for rope testing under tension

For Flame testing the rope was exposed to a 600°C open flame, as shown in Fig. 7.

Fig. 7. Flame chamber at Teijin Aramid Inc., to expose rope directly to fire

FLAME RESISTANCE COATING

Fig. 8 shows the increased protection the coating enhancement provides. The rope with the fire retardant ("FR") shows an approximate 3x improvement. The graph also shows that a typical polyurethane coating does not offer any improvement.

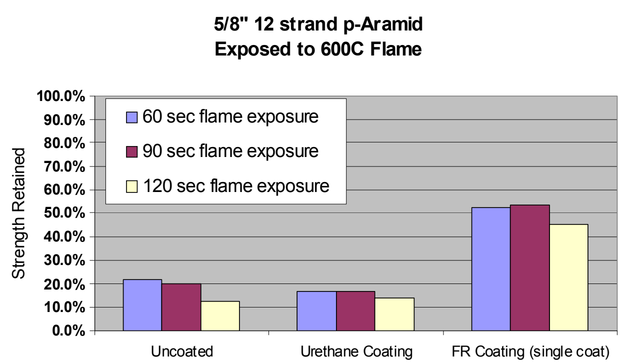

Fig. 8. Effect of Coating Protection on Rope

Another favorable attribute is the ability of the FR coating to provide insulation: therefore, protecting the inner fibers of the rope. In the 5/8" diameter rope shown in Fig. 9, the core temperature remains significantly lower than the surface (flame) temperature.

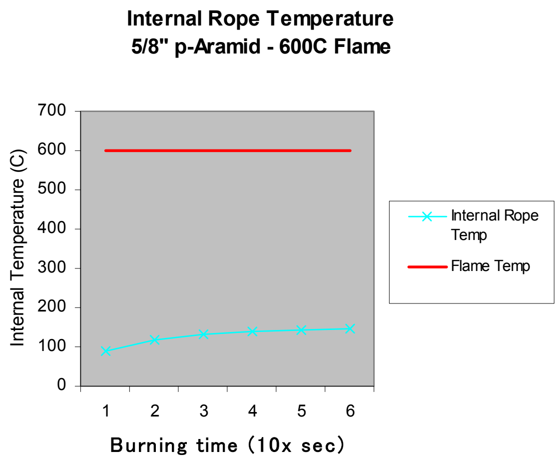

Fig. 9. Temperature Profile in rope showing the core is much cooler than the ambient due to the coating insulation.

APPLICATION MODELING

Tables 1 and 2 model the system properties of both wire and p-Aramid. Wire, as expected, does have a higher retained tensile over the p-Aramid fiber; however, the p-Aramid fiber does retain approximately twice the recommended working load (20% MBL) over the same time period.

Table 1 Wire System Model

	Unite	Measured at 20°C	Measured at 300°C	Measured at 300°C (after 30min at 300°C)
Break Strength	GPa	2.37	1.8	1.74
Retained Strength	%	100%	75.9%	73.4%
Density	kg/m3	7600	7600	7600

Table 2 p-Aramid System Model

		Measured at 20°C	Measured at 300°C	Measured at 300°C (after 30min at 300°C)
Break Strength	GPa	3.42	1.5	1.5
Retained Strength	%	100%	43.9%	43.9%
Density	kg/m3	1390	1390	1390

To equal the performance of wire rope, it is possible to upsize a p-Aramid and still maintains a significant weight savings. Table 3 shows that by increasing the diameter of the p-Aramid rope, 100% of the residual strength (compared to wire rope) can be achieved. The increased diameter still provides great handling characteristics at less than half the weight.

Table 3. Comparison of p-Aramid Rope vs. Wire as a function of time and temperature

p-Aramid Rope Diameter	Rope Strength at 20°C	% Strength vs 40mm Steel Rope			Weight	% Weight vs 40mm Steel Rope
		at 300°C			of Rope	
(mm)	(tons)	30 min	1 hr	1 day	(kg/m)	
40	112	68	62	61	1.3	22.7
45	142	90	82	77	1.7	28.6
47	155	100	91	84	1.8	31.2
50	175	116	101	95	2.1	35.7
52	190	128	111	103	2.2	44.2

CONCULSION

From this study the conclusion can be drawn that a rope produced from a p-Aramid fiber, along with a specialized coating can replace wire rope in high heat applications. The combination of heat resistant fiber and the fire resistant coating is now patented by Samson.

The following have been noted [8]:

- P-Aramid fiber has the ability to withstand and perform under high temperatures
- A FR coating is necessary to resist direct flames and to provide thermal insulation
- When compared to wire rope, of equal diameter, a rope made of p-Aramid fiber can still exceed the recommended working load after exposure to a high temperature environment.
- Upsizing will allow a rope of p-Aramid fiber to equal the performance of wire rope, at a significant weight savings.

HMPE WITH ENHANCED SURFACE CHARACTERISTICS

INTRODUCTION

In many applications HMPE fiber is considered an ideal strength member based on the following characteristics:

- high strength and low weight
- superior fatigue resistance
- superior abrasion resistance
- superior weather resistance
- flexibility
- elongation characteristics similar to wire

A limitation of HMPE is the low Coefficient of Friction (COF). DPX, a patented unique blend of HMPE fiber and polyester, has been created to address this issue. It provides a "pre-fuzzed" fiber appearance which wears well and grips winch drums. Using this fiber, Samson has developed a series of products, to take advantage of DPX's enhanced surface properties.

TESTING

Coefficient of friction (COF)

COF is measured based on the principle shown in Fig. 10. A Rope is placed over a round stainless steel surface, with a dead weight applied to one side at T1. The load at T2 is then increased until the rope slips on the drum. Knowing the bending angle, T1, and T2, we can compute the COF using equation also shown in Fig. 10.

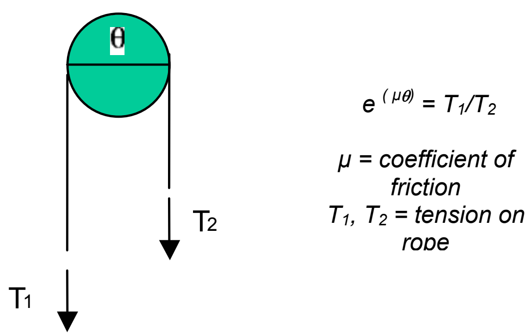

Fig. 10. COF Measurement

Abrasion Resistance

Fig. 11 is the schematic drawing of the apparatus used for comparing the abrasion resistance of ropes. Rope samples are placed under a fixed load, where the load is based on the diameter of the rope sample. The load (lbs) applied is 1600 x the diameter in inches. Thus, for a 1/2" dia. rope, the load applied would be 800 lbs. While the rope is under load, the wheel turns at a rate of approximately 15 revolutions per minute. Each revolution results in 8 "spokes" (smooth pins) abrading against the rope surface. The

wheel continues to rotate until either the entire rope parts (for a single braid rope) or until the cover parts (for a double braid rope). The number of cycles or revolutions required to cause the rope to fail is then recorded as the abrasion resistance index value.
The turning rate of the wheel is slow enough to avoid heat generation to isolate the abrasion resistance from the heat resistance measurement. The fibers tested for this study included HMPE, polyester, nylon, spun polyester, DPX, and 100% polyester blend of DPX type construction.

Different coatings on polyester fiber were also evaluated to compare the improvement of abrasion resistance from coating. The same tests were also conducted on jacketed HMPE ropes with DPX and HMPE fiber jackets to compare the abrasion resistance of the two different jacket constructions.

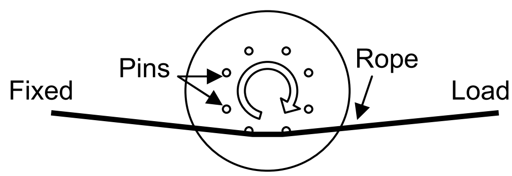

Fig. 11. Abrasion Resistance Measurement

RESULTS AND DISCUSSION

Fig. 12 compares the COF and abrasion resistance of different fibers used for rope jackets. It is clear that DPX technology has the best combination of COF and abrasion resistance.

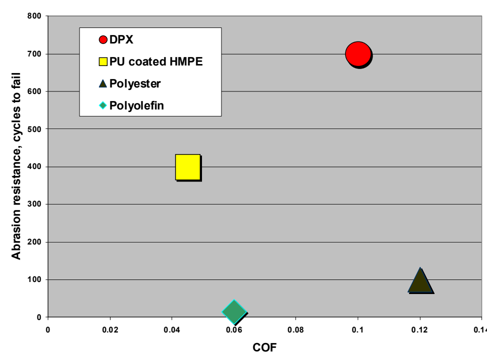

Fig. 12. Comparison of Fiber Surface COF vs. Abrasion Resistance

Abrasion Resistance of different synthetic fibers and coatings is compared with uncoated polyester in Figs. 13 and 14.

Fig. 13 shows that among all the fibers tested, HMPE fiber and DPX have the highest abrasion resistance. Tests were also conducted on polyester with various coatings to investigate if we can improve the abrasion resistance of polyester fiber to the level of DPX or HMPE fiber. As shown in Fig 14, DPX significantly outperforms these coated polyester fibers in abrasion resistance.

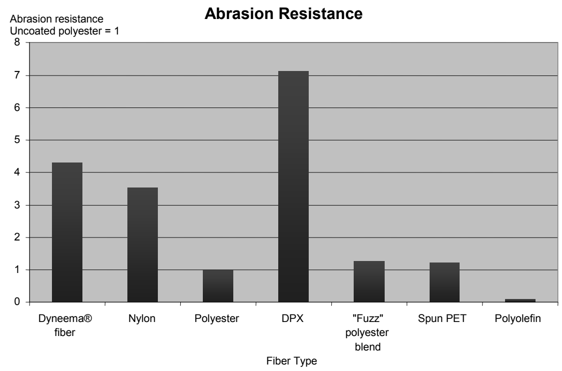

Fig. 13. Abrasion resistance of different fiber types.

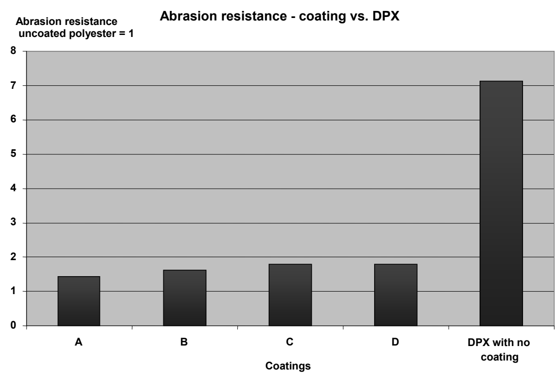

Fig. 14. Abrasion resistance improvement through coating on Polyester.

Abrasion tests were also conducted on HMPE jacketed ropes with DPX, and with 100% HMPE fiber jackets. As shown on Fig. 15, both showed comparable cover strand integrity after 5000 abrasion cycles. Quantitative analysis of the covers was conducted by identifying the percent of original fiber intact at the end of the test, as shown in Fig 16. This showed very similar abrasion performance between DPX and HMPE fiber.

Fig. 15. Visual comparison of the Dyneema® fiber jacket (left)
and DPX (right) showed similar wear.

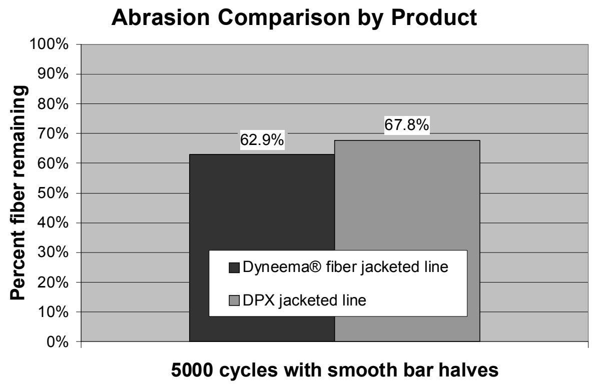

Fig. 16. Remaining cover fibers after 5000 abrasion cycles
DPX vs. Dyneema® fiber, showing comparable abrasion resistance

FIELD PERFORMANCE

DPX-75, a jacketed HMPE rope, as shown in Fig. 17 compares new line to a line after 6 months in service. There is little wear shown after 1800 hours of mooring operations. It was also observed that utilizing a DPX jacket improves the grip on the working side of the winch drum, reducing the slippage and load transfer from the working to the storage side of the drum.

Fig. 17. DPX-75 new (left) vs. 6 months in service (right)

Quantum 8, as shown in Fig. 18, is a non-jacketed HMPE line incorporating DPX technology. Like a jacketed rope, the DPX provides the surface enhancements of better grip and excellent abrasion resistance, while still retaining the benefits of a non-jacketed rope such as easy inspection of the inner yarns, easy splicing, and flexibility.

Fig. 18. Quantum 8 tug assist line

DPX technology has also been extended to 12 strand ropes. Quantum 12 is a 12 strand single braid with DPX enhanced surface. Fig. 19 shows Quantum 12 being used on an "H-Bitt" that without DPX technology would be nearly impossible for a HMPE rope.

Fig. 19. Quantum 12 tug assist line

Another area where DPX technology has increased the use of HMPE products is with traction winches, as shown in Fig. 20. A traction winch works on friction. Sufficient grip must be maintained between the "bull-wheel" grooves and the rope.

Fig. 20. Quantum 8 on a turret pick up winch.

CONCLUSION

DPX, based on Samson manufacturing technology, provides:

- COF comparable to polyester and superior to pure HMPE fiber
- Abrasion resistance comparable to HMPE fiber.

DPX has received good reviews as a surface enhancement for both jacketed and single braided ropes. This technology has the potential to be utilized with many fibers, allowing the option of engineering yarns to create unique surface characteristics based on the requirements of specific applications [9].

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