CURTISS-WRIGHT

TECHNICAL PAPER

Technology Advances in Level Winding of Multi Diameter Cable Configurations

Prepared for

Underwater Defense Technology (UDT) 2013

Revision: A
Date: 28 May, 2013

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1 INTRODUCTION

1.1 ABSTRACT

The levelwinding or spooling of multi diameter cable configurations, such as tow cables / arrays, with their various transition points and electronic modules onto handling systems has always been challenging. There is a long history of systems that have required constant operator intervention, caused excessive wear and even failures of the towed components. This paper compares and contrasts various levelwinding operational approaches such as fleet angle sensing, passive wrap adjustment and finally macro driven and their effect on levelwinding. Volumetric efficiencies and life reduction will be reviewed. Expertise gained from over 30 years of systems experience on both surface ships and submarines are presented.

1.2 EXPERIENCE AND BACKGROUND

INDAL Technologies, a business unit of Curtiss Wright Flow Control (CWFC) Company, is located in Mississauga, Ontario, Canada and employs approximately 160 technical, engineering, manufacturing and administrative staff. The company combines a high level of engineering and manufacturing capability with expertise in the management of large and complex defence programs to produce innovative solutions for the world's navies.

INDAL is part of a family of companies within Curtiss-Wright that share expertise for the supply of equipment to both submarines and surface ships. CWFC Target Rock and CW-EMD are two examples with shared design experience with the submarine environment and controls inside a submarine (Figure 1).

Figure 1: CWFC shared expertise

INDAL is recognised internationally as a leading designer and supplier of high performance and special purpose surface and sub-surface sonar and cable handling related equipment. Over the last 40 years, INDAL has built a large inventory of designs and configurations which include systems capable of operating at platform speeds exceeding 40 knots, tow tensions over 200,000 pounds and depths of over 20,000 feet. INDAL's cable handling system products are operating on both surface ships and submarines for such applications as; Variable Depth Sonar (VDS), both passive and active, Mine Countermeasures (MCM), torpedo decoy and helicopter dipping sonar. More recent examples, directly applicable to the TAHS are presented in Figure 2.

Figure 2: Examples of INDAL designed and built Towed Array Handling Systems (TAHS)

1.3 SUBMARINE APPLICATIONS

Submarine systems were first developed by INDAL for the Royal Canadian Navy Oberon Class submarines. The handling system was configured for installation between the pressure hull and the outer casing, just aft of the sail. The cable was routed inside a tube to a flexible bend restrictor and then out to sea (Figure 3).

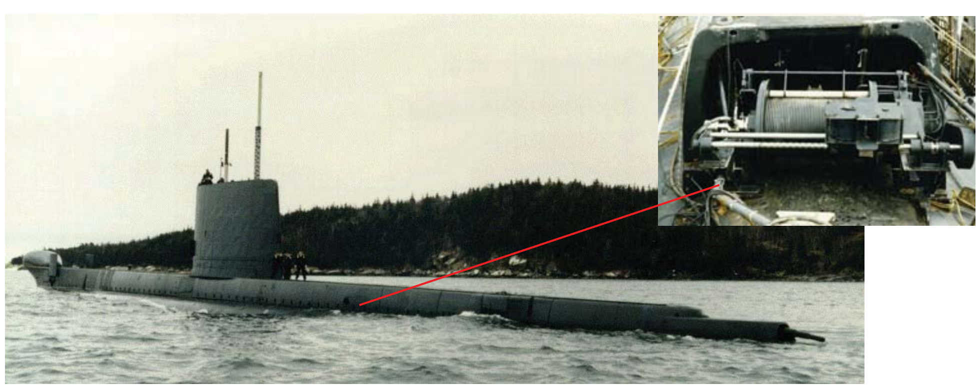

Figure 3: Oberon Class submarine

More recently, an enhanced fully reelable TAHS has been designed, built, qualified and tested for the Royal Navy's new ASTUTE Class nuclear attack submarines. During 2003 and 2004 INDAL designed and developed this innovative TAHS, with the first ASTUTE TAHS system completing installed trials in 2007 and 1st sea trials in 2010 (Figure 4 and Figure 5). The system was a departure from the problematic systems on the RN's preceding Trafalgar, Swiftsure and Vanguard class boats and incorporated a novel combination of flushing and autonomous deployment devices to deploy the array.

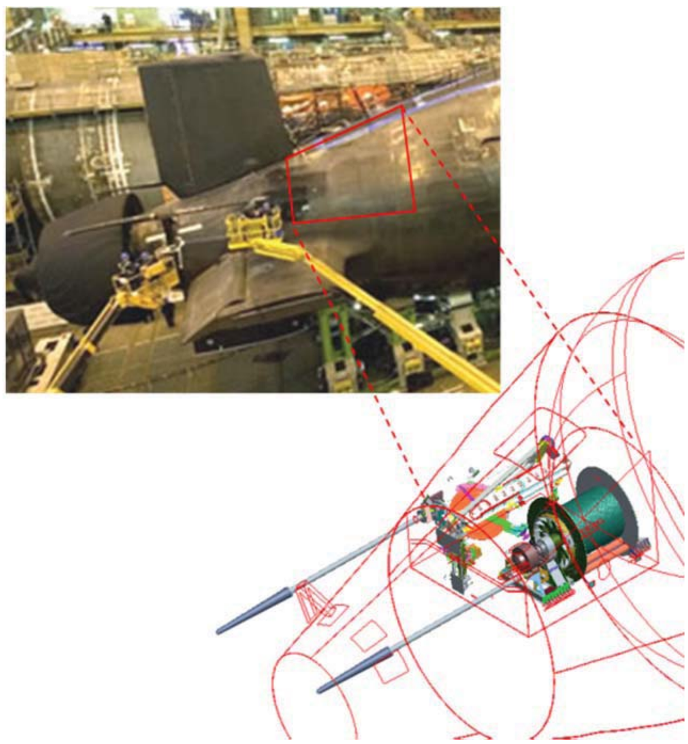

Figure 4: Astute TAHS

The ASTUTE TAHS system is designed to full UK MoD military requirements including a stringent set of environmental specifications (EMC, Handling Strength, Shock, Vibration & Firefighting spray). The system has successfully completed a full environmental qualification testing (EQT) program to UK Naval Engineering Standard NES1004 and other applicable military specifications and standards. Current trial results indicate the TAHS system is contributing to an anticipated extended array life between 7 and 14 years, which will establish a new endurance record for UK MoD towed arrays.

Figure 5: Astute TAHS under test at INDAL'S Facility

2 HISTORY OF PROBLEMS

Levelwinding or evenly spooling cables onto winches has been the subject of many engineering handbooks over the years. There have been many guides and handbooks produced attempting to eliminate the levelwinding issues; and to their credit, these have been quite successful at level-winding wire rope onto mine hoists and similar applications.

Damage can occur due to individual elements of the TAHS or poor levelwind performance. Excessive contact pressure from a roller can thin out cable jacket materials (Figure 6). Poor levelwind performance can damage cables by allowing the cable to wedge between wraps of a previous layer thus increasing the contact pressure or cross over thus creating a point contact where the two cylinders cross (Figure 7). In the case of fluid filled elements such as array modules, the wedging and cross overs are equally damaging but the danger due to stacking or riding turns is a special risk. A riding turn is when the array being wound onto a drum wraps on top of itself in ever increasing layers rather than properly falling beside itself. Figure 8 shows an array module wedging but also a riding turn. A wrap of array intended for the newly started layer warped onto its neighbor instead of properly lying beside it. Additionally, as the wrapping continues these “riding turns” often snap down into place violently contributing to premature skin failures and resulting in the loss of array fluid.

Figure 6: Jacket Damage Caused By Roller Contact

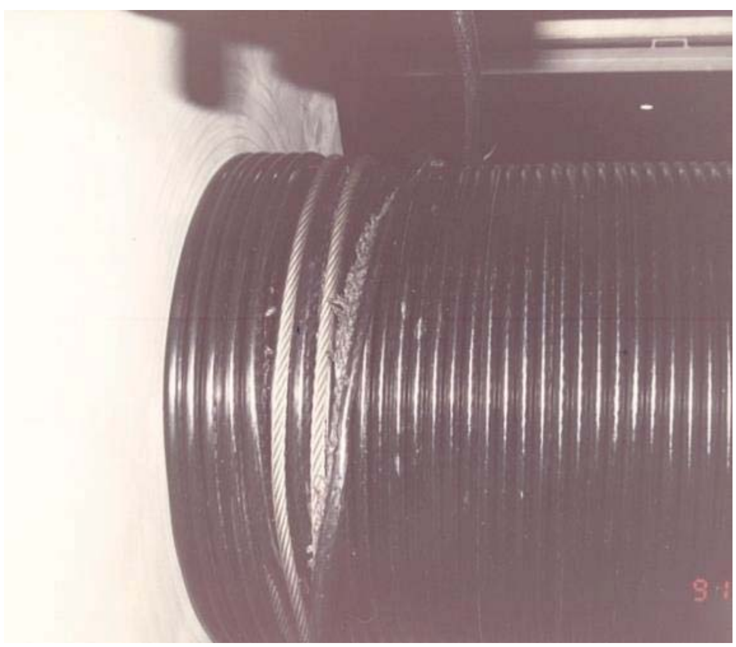

Figure 7: Jacket Damage Caused By Wedging and Cross Overset

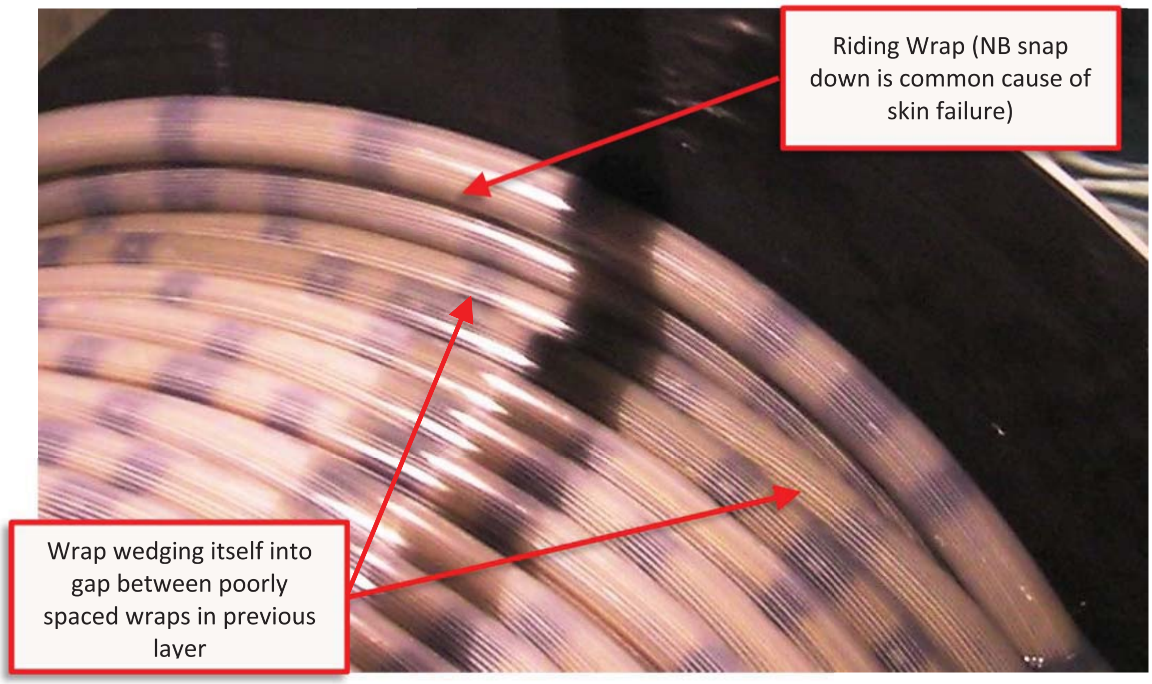

Figure 8: Two Poor Levelwinding Scenarios that can lead to array failure

Many TAHS have been designed with features to facilitate operator intervention, allowing the adjustment of the levelwinding process to avoid problems or just as often, stop the process, reverse it for a short period and then redo it while applying a bias to avoid the problem from reoccurring in the same place. However, the ultimate objective is to develop a levelwinding system that eliminates the problem.

3 CHALLENGES

3.1 ORGANIZING THE WRAPS

One of the early methods for improving levelwinding was to groove the drum in order to provide a fixed pattern for the cable to lie in. Single layer systems often used a helical groove which is relatively straight forward to machine into a drum. For multiple layers, a parallel scheme was developed shortly after World War II which vastly improved the levelwinding of multiple layers. Because of the parallel nature of the grooves and hence the wraps that followed, each successive layer still had a pattern to follow (Figure 9). However, as the number of layers increases so does the tendency toward unevenness and ultimately and if enough layers are wrapped, the same problematic issues as noted in the previous section are reintroduced. While this scheme is a vast improvement it still has limitation for levelwinding multiple diameters of cable onto the same drum.

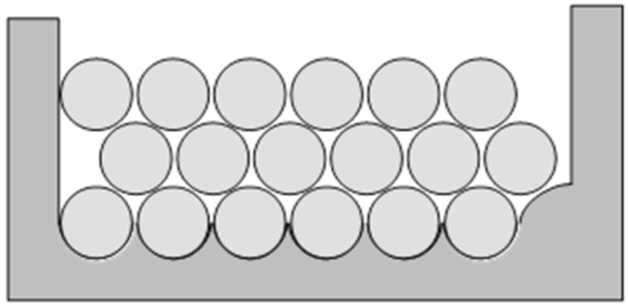

Figure 9: Stacking patter for multiple layers using parallel grooving

Figure 10: Parallel grooving first layer compared to seventh layer

3.2 THE CASE FOR VARIABLE TIMING

Levelwinding timing is usually thought of as a fixed ratio process. The levelwinding head moves in proportion to the drum feeding the cable perfectly in line with the grooves. Figure 11 shows exaggerations of three timing scenarios for clarity. As shown on the left diagram, advancing or leading the levelwinding head will cause the wraps to open up, not pack the cable tightly and present dangerous spaces for subsequent layers to drop into. Keeping the head directly inline with the wraps as shown in the middle diagram, is also often unsatisfactory especially on a bare drum. Clearly, the scenario on the right diagram is ideal; the cable is kept tight against the previous wrap, maximizing space usage and ensuring neat subsequent wraps.

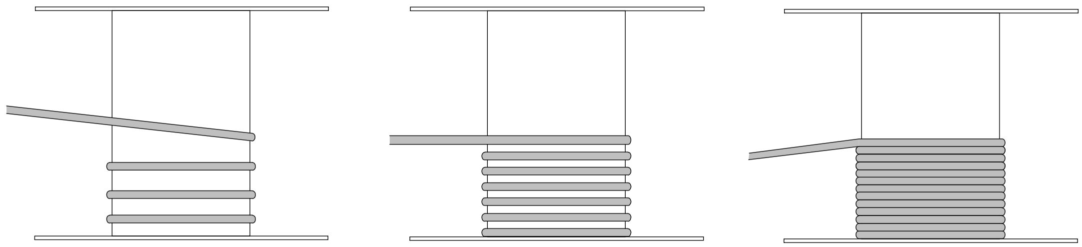

Figure 11: Levelwind Timing for the First layer

The next layer presents some opposing requirements especially at the transition point to the next layer as shown in Figure 12. Clearly a lagging timing (left view) will force the cable to stack up on itself and form growing diameters against the flange. This affect is often called a *riding turn*. In fact, even levelwinding directly in line with the desired cable position will often cause a *riding turn* (middle view). The only way to ensure this doesn't happen is to lead the levelwind head away from the flange a bit early as shown on the right view.

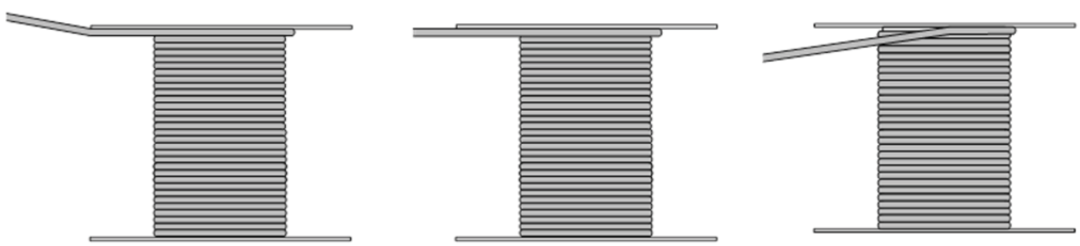

Figure 12: Levelwind Timing for the Transition to the Second Layer

3.3 SENSORS AND FORE/AFT LEVELWINDING

Scenarios where the winch drum is parallel to the axis of the levelwind present some challenges for sensors when two diameters of cable are used and level wound. In these cases, the levelwind pulley or sheave travels fore/aft beside the drum as shown in Figure 13.

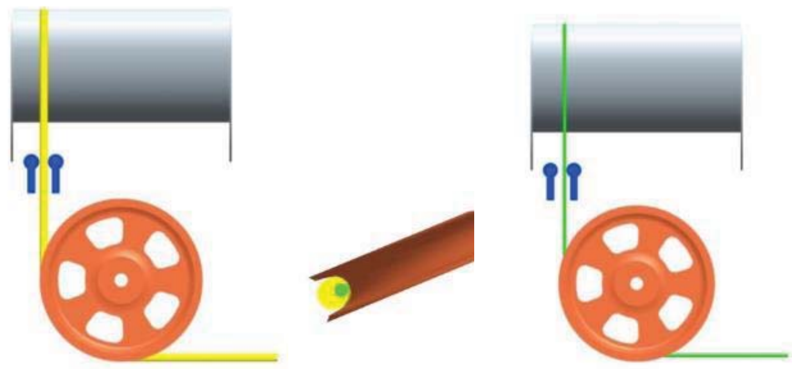

Figure 13: Sensors and Fore/Aft Levelwinding

As shown in the middle view, the tension pulls the cable to the root of the sheave. On the left view, when the larger diameter (yellow) cable is being level wound it contacts the (blue) sensors on both sides. On the right view however, when the small diameter (green) cable is being level wound there is now a gap between one of the sensors and the cable. This introduces an error proportional to the gap size resulting in the levelwinding control being giving inaccurate fleet angle information. The resulting system behaviour will cause inefficient spool and increases the probability of a mis-wrap.

3.4 NON-PARALLEL LEVELWIND HEADS (ROLLER BOXES)

A similar issue to that presented above is the sensor error that occurs when non-parallel levelwind heads (roller boxes) are used. These heads are used because they accommodate a range of diameters, but as can be seen in Figure 14, the smaller diameter cable runs on opposite sides of the box depending on the direction of travel. This again results in measurement errors and a less than ideal levelwind positioning as shows in Figure 15.

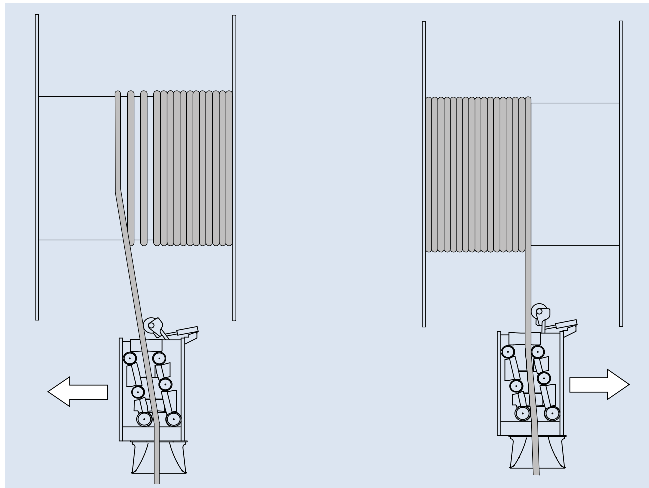

Figure 14: Non-Parallel Levelwind Head (Roller Boxes)

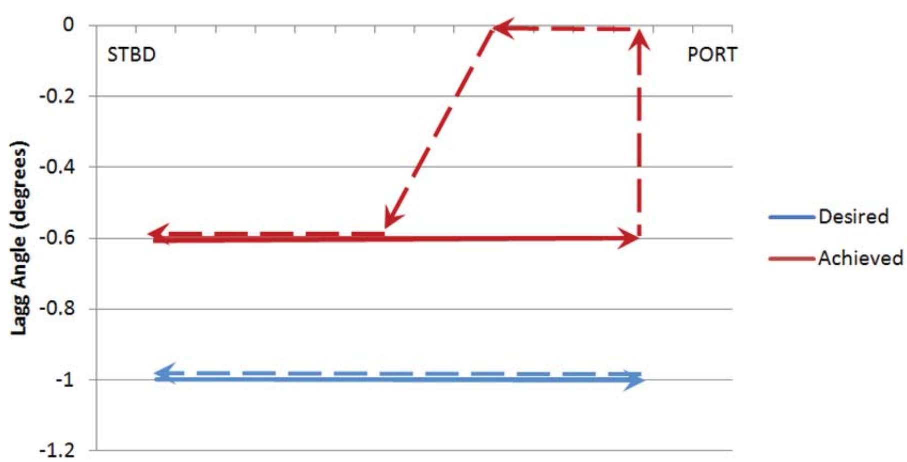

Figure 15: Sensor Error

3.5 2-DIAMTER LAYERING

Layering of multiple diameters presents a unique challenge as shown in Figure 16. If the two diameters are whole multiples of each other, then the groove presented by the smaller diameter can act as grooves for the first layer of the larger diameter. This scheme assumes the length of the smaller cable is exactly manufactured so that when wound onto the drum it forms a series of complete layers. In practice however, lengths are never exact and cable can be re-terminated in service changing its length. A number of scale experiments have been carried out to investigate the sensitivity of levelwinding two diameters. These concluded that if the layer wasn't complete, less wedging occurred with the layer a bit short rather than long. These experiments were corroborated by full scale trials and schemes for storing excess length inside the drum in order to ensure the layer was exactly complete.

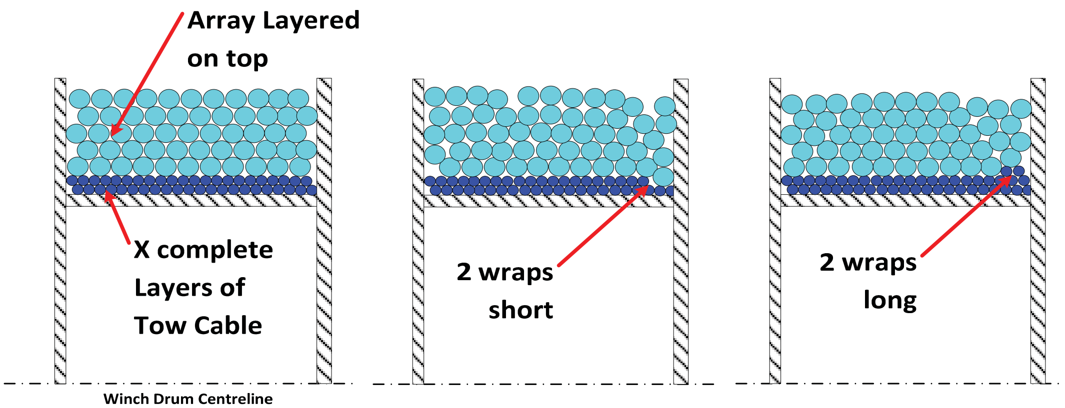

Figure 16: 2-Diameter layering

3.6 4-DIAMTER LAYERING

As sonars advanced the make-up of the arrays got more complicated and created additional challenges. In the example of Figure 17 there are four distinct diameters used on one drum. Elements can include rope drogues, multiple array modules and variations in diameter of each element and electronic canisters that can also be either rigid or flexible.

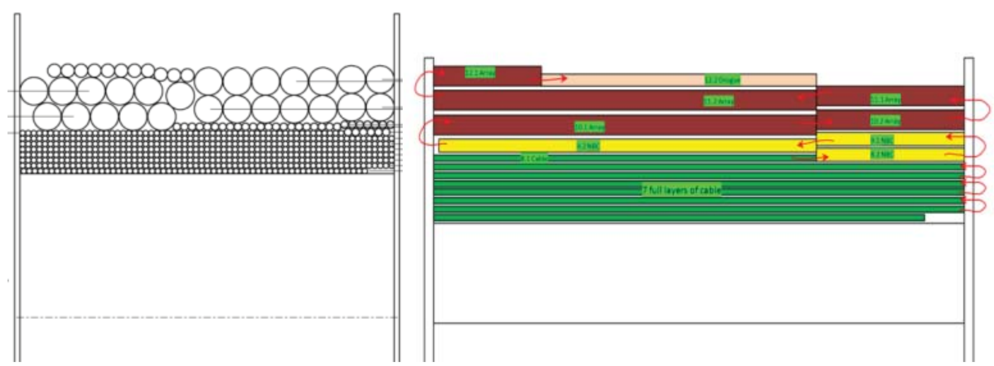

Figure 17: 4-Diameter layering

4 COMPARING LEVELWIND SCHEMES

4.1 FLEET ANGLE SENSING

Fleet angle sensing involves using a small roller or similar device that is spring loaded against the cable as shown in Figure 18. The cable is allowed to naturally follow the groves on the drum or establish its own pattern if the drum is un-grooved (bare). Initially (left view) the levelwind head is aligned with the first wrap on the drum and sensors measure a zero angle (Θ). As the successive wraps move the contact point on the drum away from the flange, the angles increase until a tolerance (δ) is exceeded and the levelwind head is commanded to move (middle view). This process repeats until the opposite flange is reached, the cable successfully transitions to a second layer on its own (right view). As with the first layer, the successive wraps move the contact point on the drum away from the flange, the angles increase until a tolerance (δ) is exceeded and the levelwind head is commanded to move in the opposite direction. Some of the key points to making a system such as this work well are; parallel grooving and a limited number of cable diameters (ideally one but possibly two). Multiple diameters will lead to a compromise in the ideal tolerance (δ) and an average tolerance may not work well.

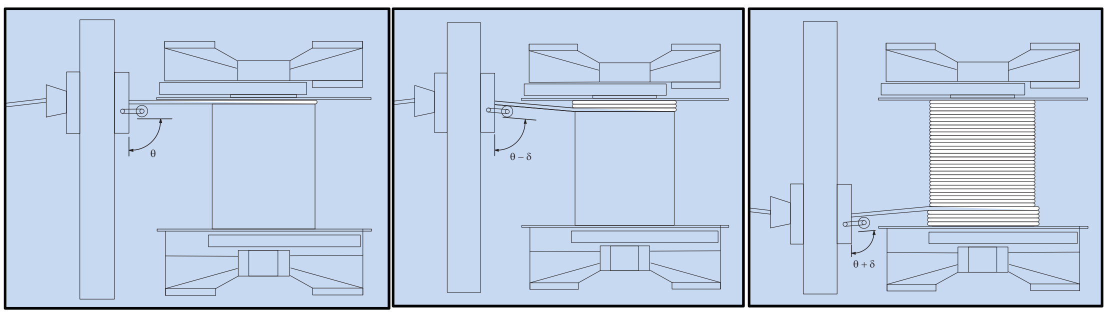

Figure 18: Fleet Angle Sensing.

4.2 MACRO DRIVEN

In a macro driven scheme, the levelwind head is driven from side to side based on signals from an electronic controller (Figure 19). The drum position is measured by an absolute encoder and fed to the controller. Similarly, the levelwind head position is measured and also fed to the controller. As part of the system design a table of pre-defined ideal levelwind carriage positions is generated for each incremental length of cable stowed on the drum. During operation the carriage is driven to the corresponding position as dictated by the table.

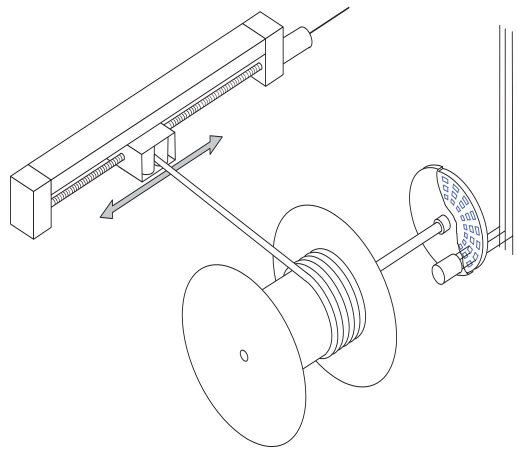

Figure 19: Macro Driven Levelwinding.

4.3 MACRO DRIVEN WITH LEARNING

This is the same scheme as before except in this design the system has the ability to learn. The system will levelwind the cable based on the ideal table. During the first operation, the operator adjusts the levelwind to account for anomalies thus creating the best levelwinding performance. The system remembers the operator's adjustments as an improved table. The system will then continue to use the improved table until it is disabled, updated or the table is reset.

4.4 PERFORMANCE OF MACRO DRIVEN WITH LEARNING

Figure 20 shows the performance of a smart levelwind. In the photograph several layers of tow cable have been wound onto a bare drum using only the levelwind to correctly position the cable so that if forms a parallel pattern as if the drum were grooved. The transitions at the flanges have been performed flawlessly. Of significance is the smooth transition to a lumpy, tapered transition segment (hidden by the drum in this photo) followed by the array section. To achieve this smooth transition in diameters, the levelwind learned from the operator actions such as leading aggressively for the transition segment and then rapidly reverting to a lagging for the array to keep the wraps tight.

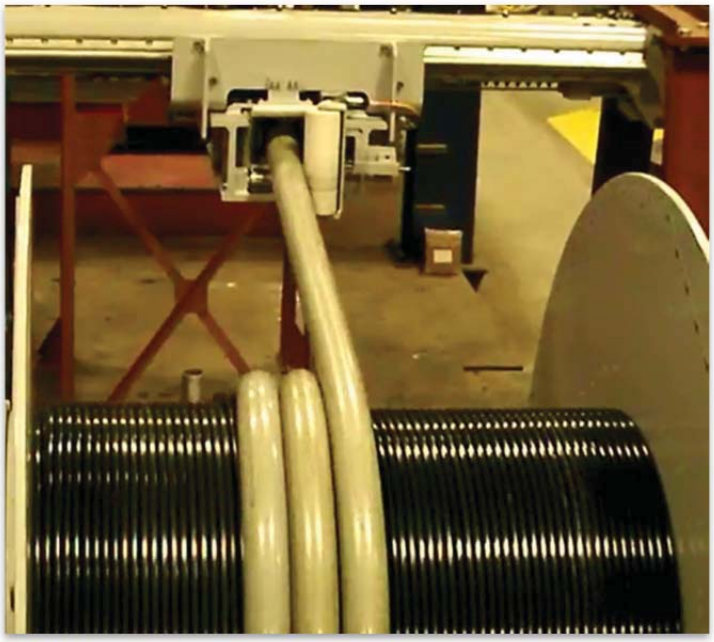

Figure 20: Smart Levelwind performance.

4.5 VOLUMETRIC EFFICIENCY

In figure 21 if we compare the first three sets of data starting on the left only, some trends emerge. The inefficiencies of cable storage on a drum increases as we move from an ideal drum on the left, to a parallel grooved drum then to a bare drum. Similarly, the number of wraps that can be fitted on a 1400 mm wide drum decreases as we move from the ideal drum on the left, to the parallel grooved drum then to the bare drum. However, the bare drum with a Smart Levelwind (macro driven with learning) beats both of these trends. It stores almost as many wraps as a parallel grooved drum as well it approaches the efficiencies of a parallel grooved drum and it does both of these with the ability to handle multiple diameters of cable well.

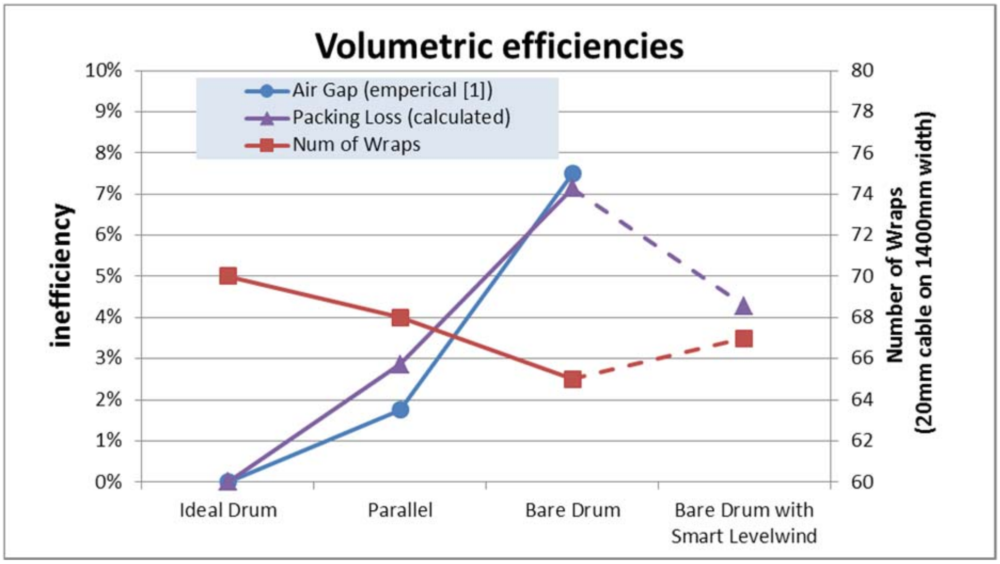

Figure 21: Volumetric Efficiencies

5 CONCLUSIONS

The overall objective is to reliably deploy and recover cables and/or arrays without damage or intervention. There have been many examples in industry of TAHS that routinely damage arrays and tow cables. These poorly performing levelwinds have caused missed wraps, wedging, riding wraps, bird caging and cross-overs damaging tow cables or array elements. The result is often sonar system failures.

Key TAHS systems design features extend array life by a factor of 14 over competitors with smart levelwinds and other features that have resulted in major increases in array life.

The Smart Levelwind will:

- Handle different diameters of tow cables and arrays without hardware changes; and
- Allow the storage of almost as many wraps as a parallel grooved drum and still achieve the efficiencies of a parallel grooved drum.

6 REFERENCES

[1] Single Drum Winch Design, M. Markey, 2000

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