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Winch Technology - Past Present and Future
A Summary of Winch Design Principles and Developments
by

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Introduction

The singularly most common equipment used between all ocean-related applications, in everything from pleasure sailing to core sampling, including oceanographic work in practically every aspect of the field would have to be ... the winch. This seemingly insignificant and often-taken-for-granted piece of machinery is used for everything from hauling-in the jib or mainsail to anchoring ships or towing barges, to handling oceanographic instruments. Look around and you may appreciate that winches are literally used everywhere in all applications. This particular article will be limited to the performance and design aspects of science winches which are used in oceanographic applications where winches are required to spool hundreds and thousands of meters of expensive cable perfectly every time.

Winches are often required to precisely monitor various operating conditions such as cable payout length, speed, tension and are often called upon to provide such features as active motion compensation, integrated cable cleaning systems, remote control, and computer interface. Increasingly sophisticated cable technology and expensive payloads have made the handling requirements for these seemingly unimportant machines even more critical. Yet among many discussions concerning deepwater instrumentation deployments and sampling casts or tows, who has ever been heard talking about the winch that was used in these successful applications. How about the winch that outlived the vessel it was on?

From a distance, today's winch looks a lot like it's ancestor of the past (after all there is just a motor and a spool, right?) but a closer look reveals major improvements in the drive systems, cable handling, safety and reliability that utilize the best and most advantageous advances in technology like the systems they are called on to support.

The improvement in drive technology, both hydraulic and electric, have had a profound impact on the winch system of today. InterOcean has been a leader and pioneer in the field of combining high technology with heavy machinery for

delicate and long term solutions in the marine environment.

Developing the winch application

When developing a new design of a winch for marine applications, many of the time-tested classic design philosophies still apply. In addition, with the advent of new technologies, particularly in motor and hydraulic controls, many improvements and innovations are possible.

When embarking on a new design, one must consider many parameters which define the problem to be solved. Many of these parameters are dependant on each other and the design becomes an iterative process. First, one must consider the maximum live load to be deployed by the winch and the desired depth. One must also consider whether data or power is required to be transmitted between the winch and the payload. If so, one must use an EM cable, otherwise, wire rope will probably suffice. In the case of EM cable, the number, size and type of conductor must be specified. For wire rope, one must decide which type is required (torque balanced, galvanized or not, strand configuration, lubrication, etc). Once the type and size of cable or wire rope is determined, an iteration process must take place to determine the proper sizing. This occurs because with the long cables required for many marine applications, the in-water weight and hydrodynamic drag of the cable becomes a major part of the equation and often is a much larger load than that of the actual payload.

Materials of Choice

At this point, the material the winch is constructed from must be decided. For most applications, steel is appropriate. If the winch is meant to be transportable, aluminum may be the material of choice. For some rare applications such as a winch built to operate underwater, expensive, exotic materials such as titanium may be considered. Each of these materials has their own unique characteristics and require certain manufacturing techniques. Although some end-users may feel that aluminum would have superior corrosion resistant qualities compared to steel, with a proper paint system and minimal maintenance, a steel winch can provide many years of corrosion free service. Although aluminum winches can be utilized without painting, aluminum may eventually corrode and it is sometimes best to provide a proper paint system to protect them.

If one decides that aluminum is required, manufacturing techniques become very important. Due to the high distortion that can result, special techniques must be utilized to control and correct this distortion. In addition, improper welding of aluminum can result in weak joints with defects that can also accelerate corrosion problems.

Cable Spooling

Once the cable or wire rope is specified, the drum design can be specified. The minimum bend radius defines the barrel diameter, while the cable diameter and length define the width between flanges and flange diameter. If a level wind is to be utilized on the winch, drum dimensions will have to be adjusted to ensure proper operation of the level wind, especially if the winch is designed to accommodate more than one wire or cable size.

If a large amount of cable is to be spooled, a grooved drum or Lebus shells should be employed along with a level wind to ensure the most efficient spooling. It should be noted that in order for the Lebus shell/ level wind system to spool properly, the cable must be spooled under proper tension. In an at-sea environment, this will occur automatically from payload and cable weight assuming the winch was previously spooled properly. The first time the winch is spooled (usually at the factory), the first few wraps should be spooled with just enough tension to keep it tight in the groove, but not high enough to pull it out of the cable clamps. As more wraps are completed, the tension should be increased to about 10% of the ultimate strength (UTS) of the wire in the first layer and each successive layer tension increased to about 15% at about the third layer. Tension should be gradually reduced in the last few layers to about 10% of UTS. When the cable is spooled properly, it will spool with a very uniform "bobbin" appearance.

One necessary assumption for this proper spooling of long lengths of cable is that it is high quality cable with consistent dimensions. Torque balanced wire rope presents some interesting challenges since it has a "triangular" rather than "round" cross-section. Even worse is a cable that was manufactured with loose diametrical tolerances. More than one end-user has been unable to get a cable to spool properly on an otherwise excellent winch because they purchased a cable with poor diametrical tolerances.

Spooling performance also depends greatly on proper level wind design and operation. The level wind must be designed to track exactly with the grooving pattern. Even with only a 0.004 inch error per groove, after 80 wraps/layer and 3 layers, the level wind will be off by over one inch, which is more than enough to cause the cable to jump wraps or lay back over itself. In addition, the level wind must be designed for smooth operation. If the grooving in the drive shaft isn't correct and/or the shuttle design is improperly matched, the shuttle may bind or eventually become loose causing excessive wear and inconsistent operation. Some manufacturers have had to manually grind the shuttles to fit, and since shuttles will eventually wear out there's little hope that a new shuttle will fit properly. InterOcean level wind drive shafts and shuttles are computer designed and manufactured with numerically controlled milling machines to ensure consistency, precision matching, long term use and repeatability.

Although the combination of level winds and Lebus shells are usually a necessity for compactly spooling long lengths of cable onto the drum, reasonable spooling can be achieved with just a level wind to properly guide the cable onto a bare drum. A level wind is also necessary if a winch installation results in a significant fleet angle from the winch to the first sheave.

Selecting the Drive System - Horsepower Calculations

In selecting a drive system for a winch, there are a lot of considerations which must be taken into account. First is the required horsepower to drive the winch at maximum required performance corrected for efficiencies. Efficiency of the drive system as well as losses in the winch such as driving the level wind must be taken into account.

There are many interrelated factors that contribute to the calculations that have to be made to create a winch design. The starting point is to determine the horsepower necessary to handle the load which is a function of the load to be lifted and the speed at which this load must be lifted.

$$HP_c = (L)(S)/550$$

$$\text{or} \quad HP_c = (L)(S)/76.2$$

Where

HP_c = raw cable horsepower

L = load in pounds

S = speed in feet/second

where:

HP_c = raw cable horsepower

L = load in Kg.

S = meters/sec

This is raw cable horsepower and does not allow for any efficiencies, losses or safety factor. Bending the cable over sheaves and around the drum takes power and for large stiff cable, this can be surprisingly large (perhaps 10%). The mechanical efficiency of the winch with good quality bearings is usually of the order of 92-95% without a level wind which in itself can account for 5-10% of losses. If the cable wrap around the level wind requires the level wind to work against the cable at a substantial wrap angle, then an additional 10% power loss may be experienced. The result of these mechanical factors in the basic winch mechanism could result in an overall winch losses of 15% to 38%.

The efficiency of the prime mover that drives the winch must also be considered to determine the input power to the winch. Typical drives such as hydraulic motors have losses of 5-10% and electric motor losses are 4-5%. The other components used that must be considered are the gear reducer losses which are 4-5%, the motor controller for variable speed motors at 10% and any other losses such as losses in hydraulic piping. If the requirement states that the winch is to be electro-hydraulic, then the losses in the electric motor (5%) must be added to the losses in the hydraulic pump (5-10%) and the losses in the hydraulic motor (5-10%) plus flow losses (usually 5%) to result in an overall loss of 20%-50% for this system.

The overall result of the above discussion is that depending on the drive system specified and the quality of components chosen, the overall losses could be as low as 30% for an electric drive winch using a variable speed AC controller (such as a flux vector drive) and as much as 68% for a poorly designed electro hydraulic winch. Therefore the actual horsepower input to the system can be expressed as follows:

$$HP_i = HP_c / (1 - L)$$

where:

HP_i = horsepower input required to the system

HP_c = cable horsepower calculated above, and

L = winch system losses as discussed above.

As a practical rule of thumb for an electric drive winch, the input power required will be 1.4 to 1.5 times the cable horsepower and, for an electro hydraulic winch (which is incidentally the lowest efficiency drive method), the input power required will be 2.0-3.0 times the cable horsepower.

Electric or Hydraulic Drive?

If selecting an electric drive winch today, there are many more choices available compared with those available just a few years ago. Not too many years ago, if one wanted an electrically driven winch, the only method of providing the speed control to the winch was a DC motor. Although an AC power supply may have provided external power, the motors were DC which meant that the system was

inefficient and maintenance intensive. With the advances in electronics in the last decade, inverter and vector drives have allowed the use of sealed Brushless AC motors which provide greater efficiency and reduce maintenance expenditures.

Hydraulic systems have also provided some innovations in hydraulic winches. Electric displacement control in hydraulic pumps allow for a smoothly varying speed control in a closed loop system. Since winch speed is controlled by a low-voltage signal, this system easily lends itself to future computer control and possibly even programmable casts. In recent years, low speed high torque hydraulic motors have become available in compact versions which lend themselves well to winch applications and have the advantage of eliminating the gearbox in the drive train.

Winch Instrumentation

The next thing to consider in the winch design is instrumentation required. One might opt for little or no instrumentation or a traditional instrumented sheave which would provide the operator with cable tension, length and direction and by differentiating length, could provide cable speed. Some of the new motor drives also allow a method of interfacing with a PC which could allow some of the cable speed, direction and cumulative amount of deployed cable to be extracted directly from motor speed without the use of a costly instrumented sheave. In addition, one could even pre-program an entire cast to automate ones work.

The use of advanced microprocessors in todays technology permits the sensing of almost anything on the winch and by providing suitable rugged and reliable enclosures, this equipment can successfully survive in the harsh environment experienced by deck equipment. The subject is best examined by reviewing the range of what can be sensed and than examined with respect to what can be done with this data.

The most common item of interest is "how much cable is out" (scope) and the compliment question "how much cable is left on the winch" (remaining cable). The first is primarily used to estimate the depth of the device at the end of the cable and to avoid entangling the device at the end of the cable with the sea floor. The "remaining cable" can be used to determine if a target depth can be reached under conditions of drift causing a particular cable angle under the deployment conditions.

A companion item of interest which is often measured by the instrumentation is "what is the load on the cable" (tension). Usually the winch will have enough pulling power to break the cable if operated at full power and in conditions where the cable may encounter loads in excess of the combined cable and payload weight. This information is of great importance to the operator. Much can be learned from scope and tension data and several important parameters inferred from this data.

Historically, cable scope and the tension are measured by sensors on the same instrumented sheave assembly. Cable scope is commonly sensed by counting rotations (or fractions of rotations) of a sheave wheel by means of permanent magnets mounted on the sheave passing a Hall effect sensor mounted on the sheave frame. Cable tension is usually sensed by means of a load pin which is used as the axle in a sheave. However, these traditional methods may result in errors in measurement caused by factors such as slippage between the cable and

sheave, changing of the sheave groove diameter by excessive wear, lack of consideration for dimensional changes of the cable (flattening) under load, or by attempting to monitor conditions at the overboarding sheave where the wrap angle is not controlled and may result in large computational errors in tension measurement. New designs in winch drive equipment can provide more reliable data which can be used to determine these and other data parameters in new and innovative ways to provide greater operator information and improve system capability.

Preparing the Installation

Once the design of the winch itself is well underway, plans for integrating the systems into the ship or other platform where they will be installed must be considered prior to finalizing the design specifications and building the winch. First a location on the ship must be selected to ensure the winch will physically fit not only from a weight and size aspect but also looking at reeling of the cable to the overboarding location, access to clean hydraulic or electric power lines and access to data lines.

Newest Advances

The latest technology in use at InterOcean systems, inc. to build winch systems utilizes the time proven mechanical structure of the many fine winches produced by the company over the last 30 years combined with the microprocessor technology and solid state devices to produce flux vector all electric drive systems with many unique features not available in other winch drive technologies.

With flux vector and inverter drives, ships AC power is used to produce a variable frequency drive current that operates an AC motor. The AC unregulated current from the ships supply is converted to DC current which is then reconverted to a variable frequency AC drive current that operates the winch motor. By varying the frequency of the drive current the speed of the winch (cable speed) can be controlled and by varying and controlling the amount of current, the power of the winch (cable tension) can be controlled.

This all-electric winch drive system hardware normally consists of an electrical power cabinet of modest size that contains all of the power components as well as a controller that converts drive commands into the necessary electrical signals to activate the power switching components to create the necessary frequency and current to produce the desired winch cable speed and tension. The power cabinet is operated from an operator terminal that can be a PC in the central control room or a PC based local controller configured for operator ergonomics and environment suitably for direct exposure on deck.

Thus this type of winch system consists of three components - the winch with a totally enclosed electric motor, a power cabinet that is normally fully water tight and located near the winch for the smaller sizes or in an enclosed location for the larger sizes and the operator console which contains the operating keys and a display. The owner options and enhancements usually consist of alternate approaches to the control scheme including full integration into the ships science computer system and various configurations of small portable operator control units at the winch or on umbilical cords for use at any convenient location such as at the deployment (overboarding) point of the cable.

The main advantage of this type of drive system is that since it is all electric, data is available in the electronics control units that permit direct measurement of many parameters. For example the drive pulses are directly related to the cable scope; the drive frequency is directly related to cable speed; the drive current is directly related to the motor torque and therefore the cable tension. From a performance point of view the all electric winch can match the performance of any other drive system and offer some unique operating features. The electric drive can deliver full torque (cable tension) at any speed down to zero and hold the load indefinitely and it can also vary the winch torque (cable tension) at any time and at any speed from full rated tension down to zero speed. The ability to control the winch speed and cable tension remotely using computer control signals and to use the electrical drive signals to determine performance opens many possibilities. Adaptive control systems are possible in which the entire cast can be predetermined and entered in the winch controller including reaction to unexpected conditions. In this case the winch could even be programmed to dwell for preset times at various depths including automatic adjustments of cable length to compensate for drift as well as to spool cable in and out for motion compensation in rough seas.

An important aspect of any cable deployment is to avoid damage to the cable due to overload conditions and to provide information to the operator when cable performance must be degraded or to inform the operator when the useful life of the cable has been reached making cable replacement necessary. The electric winch with control software provided by InterOcean can perform these and other tasks as well. All software is windows based with self prompting and interactive operator interface. The cast data is saved to file and archived as related to any specific cable. The main feature of this control system is safety for the personnel, the payload, the winch and the cable in that at all times the cable can be restricted to operation within a safe envelope to avoid failure. InterOcean has delivered winch systems in sizes from three horsepower to three hundred horsepower with fully automated controls handling cables in lengths up to 14000 meters.

Recent Experience

Excellent examples of integrating new, efficient, and high performance technology can be found within several of the recent winches supplied by InterOcean. One such example is the recent delivery of an integrated suite of science winches for the new US Coast Guard research vessel Healey, following the successful supply of 2 similar vessel sets for the USCG cutters Polar Sea and Polar Star several years ago. The new ship set of winches just recently delivered consist of two 75 Hp oceanographic winches each with the capacities for 10,000 to 14,000 meters of 1/4 inch to 3/8 inch wire rope and EM cable. These winches had an ultimate pulling load of 17,000 pounds at 570 feet per minute. Spare drums and cable for the winches were also supplied so that cable is easily changed at sea by removing and replacing the winch drum. Completing the supply of the winch hardware was a 300 horsepower independently-driven dual-drum Trawl/Core winch with capacity of 10,000 meters of 3/4 inch or 14,000 meters 9/16 inch wire rope on one drum and 12,000 meters of .680 inch cable on the other drum, 58,000 pounds pulling load at any layer and variable speed up to 560 feet per minute.

Another recent winch system provided a 75 Hp light-weight transportable winch designed to fit in a 20 foot sea van. This winch is being used for controlling a remote camera system from ships of opportunity with 4,000 meters of .680 inch EM cable. This winch utilized a closed loop hydraulic system with a dual voltage

fixed speed AC motor driving a high efficiency axial piston variable-displacement hydraulic pump which in turn drives the drum mounted low speed high torque radial piston hydraulic motor. The electric displacement control provided very fine speed control and seamless reversing capability.

InterOcean has also recently designed and delivered a new class of several 3 to 25 Hp winches for profiling and side scan sonar applications. These winches utilize inverter controllers driving sealed AC brushless motors and provide very precise speed control for the full range of speed specified. In addition, the computerized controller automatically applies and releases the integral electric brake seamlessly. These systems can also be made to transmit and receive data from the controller to a PC through serial communication ports.

Conclusion

The successful winch for any application will be able to repeatedly perform it's required task for many years without compromise. Yet for all the modern tools and technology available to extend performance and efficiency, InterOcean maintains that the most successful winches working in the field have been the result of a close cooperation between the user and winch manufacturer (InterOcean) during the specification and selection stages. The relationship between basic specifications, overall performance, reliability and longevity must all be balanced with the realization that a failure to achieve or to address any one of these criteria (perhaps in the worst case at sea with thousands of meters of cable deployed) can very easily exceed the cost of the winch, and also quickly highlight the critical importance of this equipment.

The availability of improved electric drive controllers has provided smooth operating all-electric low-maintenance solutions for drive systems from 3 to 300 horsepower. At the same time, new developments in high-torque low-speed hydraulic motors has completely eliminated the need for gearboxes in most cases, providing smoother operations with lower maintenance and lighter weight systems. Computer operated drive systems are able to pre-set cable speed, length, load limitations, and alarm settings, for completely automated operation.

Yet, for it's many years of repeated and successful operation it seems as if the all-important and still under-appreciated winch will probably continue to go unnoticed as long as it meets it's ultimately demanding task time after time again.

David R. Gordon is InterOcean systems Chief Mechanical Engineer and has been working with InterOcean since 1995. He holds a BSME degree from the University of California, Berkeley and an MSME from the US Naval Postgraduate School, Monterey and is registered Professional Engineer in California. Prior to joining InterOcean, he served in the US Navy for sixteen years within the Nuclear Submarine Force as well as many other assignments.

Michael D. Pearlman, CEO of InterOcean systems, inc. has been actively involved in the design of oceanographic instruments and marine equipment for over 30 years. He holds patents on acoustic release equipment in sizes up to 2.5 million pounds for offshore drilling applications and has been instrumental in the InterOcean winch products since their inception. Mr. Pearlman has published

papers on many oceanographic products and projects and is a charter member of the Marine Technology Society as well as SNAME, ASME and other professional groups.

Stephen Pearlman has been International Sales Manager for InterOcean for the last 6 years and has previously been involved with the management of several large remote ocean data acquisition and telemetry projects. He has also been involved with several winch projects and has worked for InterOcean for about 10 years.

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