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A SURVEY

OF

UNDERWATER WINCHES

Leslie W. Bonde
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31 March 1972
Technical Report No. 348
Contract Number N00600-72-D-0612

Prepared for
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ABSTRACT

This report presents a brief survey of underwater winch technology. Ten previously developed underwater winches were selected for review, and the data gathered are presented. A summary of lessons learned through the developmental and operational experiences associated with these programs is given together with critical design features to which attention must be paid for the design of deep-water, long life winch.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

Section 1

INTRODUCTION

The Naval Facilities Engineering Command is presently involved in programs to develop large, deep-ocean structures. In the past, most deep ocean structures have consisted of one or more flexi le lines attached at the upper end to either a ship or surface or subsurface buoy and anchored to the bottom at the lower end. By including underwater winches in the design of such structures, adjustments can be made after, and perhaps during, installation.

In order to assess the current state-of-the-art in underwater winch technology, a task order was given to Hydrospace Research Corporation by the Naval Ship Research and Development Center under Contract Number N00600-72-D-0612. This reports presents a distillation of data gathered under this task.

Section 2 contains background information and a general functional description of winch components. Ten previously developed underwater winches were selected for review, and the data gathered are presented in Section 3. Section 4 contains general performance specifications and a summary of lessons learned through prior underwater development programs and critical design features to which attention must be paid for the design of a successful underwater winch.

Section 2

BACKGROUND

2.1 GENERAL

For the purposes of this report, a winch will be functionally defined as a device that is capable of handling (deploying, retrieving, maintaining tension, etc.) a cable in an essentially continuous motion, and of storing the required amounts of cable in a reliable manner. In order to perform these two functions, any winch must be composed of elements such as a drum or drums for traction and storage; a level wind mechanism; a power drive unit including motor, transmission and brake; sensors; a frame and hardware such as seals, bearings, etc. Furthermore, if the subject cable is carrying electrical energy (for power, data transmission, etc.) the winch must be equipped with sliprings or some equivalent means of conduction.

2.2 WINCH TYPES

There are two basic approaches to providing the traction force necessary for cable handling: direct and indirect tension devices.

A direct tension, conventional drum winch is one wherein the cable is stored on the drum in either a single or multiple layers. Conventional drum winches are potentially the most compact of all cable handling systems because they integrate the storing and traction functions on the drum. In addition, they offer the intangible but very real advantage of a highly developed technology. Conventional drum winches usually transmit most of the tension to the cable by friction, but they have the fail-safe feature that a properly designed cable terminal on the drum can transmit the tension in the absence of drum friction. This secure fastening of the end of the towline to the drum minimizes the possibility of catastrophic loss.

Indirect tension devices by contrast drive the cable solely by contact friction. At a sacrifice of compactness, indirect tension winches separate the storing and traction functions allowing the storage device to be maximized towards its function. When very great lengths of cable are to be stored, indirect tension winches become the most compact. They have the added attraction of prolonged cable life due to low storage tension as contrasted with the high tension storage on a conventional drum winch.

There are two main categories of indirect tension devices: cable haulers and powered capstans. Cable hauler winching devices were originally developed for handling extremely long lengths of relatively rigid cable, as for example laying submarine cables. They consist of a pair of linked belts carry treads looped over a driven sprocket and roller or track assembly (not unlike military tank tracks). The loops are parallel tread-to-tread so that the cable can be squeezed between them and driven along as the tracks are driven. Cable haulers with properly shaped tracks have worked well with continuous cable lengths. The possibility of cable slippage and the intricate track roller mechanism, together with the serious lubrication, sealing, and fouling design problems, do not make them attractive for prolonged unattended operation.

The single drum indirect tension winch consists of a capstan-like drum surrounded by either grooved cable rollers or fleeting knives to cause side-wise motion of the cable across the drum. Back tension is provided either by the storage unit or by a set of driven pressure rollers. These units are more compact than cable haulers but share the possibility of cable slippage and low reliability due to the complexity and number of moving parts.

Double drum indirect winches employ a pair of grooved or canted drums driven in tandem, side-by-side, with several wraps of cable passing around them. This concept eliminates the potential mechanical problems inherent in the complex roller and track of the cable hauler and the guide roller of the single drum, but it is potentially the most bulky of all the approaches considered except for applications involving extremely long cables where the storage bulk far exceeds that of the winch drums.

2.3 LEVEL WINDS

In order to provide for orderly storage of cable on a winch drum, several techniques have been developed for controlling the spooling of the cable. In installations where the cable passes over a lead sheave and then on to a drum, it is important that the lead sheave be located at a sufficient distance from the drum so that the side angle at which the cable approaches the sheave from the drum (the fleet angle) is small, say under two degrees. One of the most common types of mechanisms for accomplishing level winding incorporates the diamond lead screw familiar to fishing tackle enthusiasts. For single lay applications ordinary helical screw drives are used.

In the Lebus level wind the drum is grooved with a continuous groove that is parallel to the flanges except for two cross-over sections where the groove moves across the drum one-half pitch (1/2-line diameter) to give a full pitch of movement per revolution. This controls the formation of the first layer of cable in a predetermined pattern that is reproduced on the second and all subsequent layers. The groove supports 120° of the circumference of the cable which eliminates the wire from shifting on the drum and also guides the line into a pyramidal pattern in the parallel section which prevents one layer from cutting-in the layer below.

In order for the cable to spool properly, the angle from the drum to the first fixed point or fairlead should fall within the range of $1/4^{\circ}$ to $1\text{-}1/4^{\circ}$ off the flange or an included angle (fleet angle) of $2\text{-}1/2^{\circ}$. If sufficient space is not available, a fleet angle compensator can be installed. This is an eccentric shaft mounted on self-aligning ball-bushing type bearings with a bronze bushed fleeting sheave. There is no connection between the drum and the compensator except for the cable itself. The tension in the cable controls the oscillating motion of the shaft, and the grooved pattern on the drum controls the fleeting of the sheave.

2.4 POWER DRIVES

The propulsion system for conventional winches consists of a power unit, a brake and a transmission drive unit. Submersible electric motors have been developed for continuous operation in sea water and are found in three basic types: open-winding, water-filled; open-winding, oil-filled; and hermetically sealed.

Open-winding, water-filled motors have stator coils wound of magnet wire insulated with a heavy, waterproof coating, usually polyvinyl chloride (PVC). The ambient water is permitted to enter and cool the motor, and the PVC wire insulation protects the electrical system.

Open-winding, oil-filled motors generally use standard varnish-insulated magnet wire in the stator windings, and the interior of the motor is filled with a dielectric oil for insulation resistance, lubrication and cooling. A shaft seal prevents entrance of sea water. The oil is pressure compensated so that a minimum pressure differential exists across the shaft seal.

Hermetically sealed motors have the stator windings encapsulated in an epoxy resin and sealed in a welded, corrosion-resistant metal case. The electrical system is isolated from the sea water, and the mechanical system can be designed for oil or water lubrication.

Hydraulic motors have been popular in winch propulsion unit design because of minimal transmission losses as compared to more complex mechanical gear reducers and the braking feature that is provided when the hydraulic motor functions in reverse as a pump. Other types of brakes that are used include disk, drum and band-type mechanical and/or electro-mechanical brakes. Power transmission has been accomplished using planetary gear sets, worm gears, chain drives, etc.

2.5 SENSORS

Provisions are usually made in the design of winches to monitor the amount (scope) and speed of cable inhauled or payed out and its tension. Line speed and scope are usually measured by a gear driven rotary potentiometer in a pressure compensated housing. Line tension sensing is measured by a waterproofed load cell incorporated in a sheave mount.

2.6 WINCH FRAME AND HARDWARE

The frame of the winch provides structural integrity to the unit and supports the various elements that go together to make up the total system. Also included in this category are the miscellaneous hardware items ranging from seals and bearings to nuts and bolts. Material types and selections represent the chief differences among various winch designs.

2.7 SLIPRINGS

For applications where the cable must serve an electrical as well as mechanical function, some sort of slipring-type device must be used in order to maintain electrical continuity between the cable, which must rotate on the drum, and a stationary terminal or junction box. One such alternative to conventional sliprings is the Gleason sheave and reel approach. Newer and less complex devices include mercury wetted contacts, and the flat ribbon cable.

Section 3

PREVIOUSLY DEVELOPED UNDERWATER WINCHES

3.1 GENERAL

The development of winches for surface applications spans several centuries, and the current state-of-the-art is reasonably well documented in manufacturer brochures and trade journal articles. There exist a plethora of such devices, and custom fitting for a particular application seldom requires an extensive developmental program. In contrast, winches for underwater application have a developmental history of only a couple of decades, and technical data on experience with such winches are meager at best. This section is an attempt to gather the limited data and experience available at this time on ten previously developed underwater winches.

Due to the paucity of available data, this section cannot be considered as all-encompassing, but the examples chosen for review are representative of a broad spectrum of underwater applications. They range from experimental, one-of-a-kind systems, such as CHAN, to fully operational systems such as the AN/BRA-8. Intended useful life ranges from hours in expendable sonobuoy winches such as the LOLITA to years in the Mark II DDS for example.

Performance characteristics of the ten underwater winches to be reviewed are listed in Table 3-1. Cable diameters and storage lengths are given for each winch, together with its rated depth, pull and line speed. Table 3-2 provides a brief comparison of winch design characteristics addressing the functional components as discussed in Section 2. In the following, each winch will be discussed in turn from its design approach and experience.

Table 3-1. Underwater Winch Performance Characteristics

Name	Cable		Rated		
	Diameter (in.)	Length (ft)	Depth (ft)	Pull (lbs)	Speed (ft/min)
CHAN	0.30	240	1000	3500 1000	75 150
AN/BRA-27	0.219	1000	1000	600	100
AN/BRA-8	0.35	classified	classified	2500	150
BIAS	0.35	classified	classified	5000	50/150
VERSUS	0.95 2.25 x 32 long*	2000 1000	classified	2000	200
Makai	0.25	800	600	500	30
MARK II DDS	0.375	1200	1000	2500	15/40
NEMO	0.25	750	unlimited	1000	30/60
LOLITA	0.096	1200	1200	750	20
WEBS	0.50	1000	1000	6500	15

* modules on 32-foot centers

Table 3-2. Underwater Winch Design Characteristics

NAME	DRUM (1)	POWER DRIVE	LEVEL WIND	MOUNTING FRAME MATERIAL	BEARINGS
CHAN	Deep grooved single lay cast Aluminum Bronze	AC motor and gear box(3) Final reduction exposed, Nickel Copper	Acme Screw K Monel	Medium - Steel	Imp egnated, Bronze Sleeve
BRA-27	Multi lay CRES Drum with Aluminum lagging	DC Motor in air non-comp, Gear & Chain reduction	Diamond Screw Hastalloy-C	Hot Rolled Steel (2)	Fabriod Sleeve
BRA-8	Grooved Single Lay (304) CRES	Hydraulic Motor inside submarine.	Drum Helix Follower	Not applicable.	UHMW Polyethylene Sleeve
BIAS	Grooved Aluminum (6061-T6) lagging, Hot Rolled Steel (2)	AC Motor (3) with planetary gearing one end and electromagnet disk brake on opposite.	Diamond Screw Hastalloy-C	Hot Rolled Steel (2)	Fabriod & UHMW poly. Sleeve.
VERSUS	Multi lay,(316) CRES	DC Motor conventional brake in air filled housing, cone drive reducer	Automatic Two Speed	CRES	Conventional ball reverse seal oil-filled
MAKAI	Multi lay, steel (Epoxy) paint finish)	AC Motor, gear reducer, mechanical brake (3)	None	Nodular cast iron (Epoxy paint)	Delrin Sleeve
MARK II	Multi lay, CRES	Electro hydraulic exposed, planetary reducer in drum.	None	CRES	Not available.
NEMO	Lebus grooved, multi lay,(316L) CRES	Battery, electro hydraulic, exposed 17-4-pn Gears	Lebus	(316L) CRES	Glass filled Teflon sleeve.
LOLITA	Double, pressure roller back tension Anodized Aluminum.	Battery, electro mechanical in air, non compensated.	None	Anodized Al.	Conventional sealed, steel ball
WEBS	Single, fleeting knives, pressure roller back tension, CRES	Battery, electro mechanical in air, non compensated.	None	CRES	Conventional sealed, steel ball

(3) Oil-filled pressure compensated housing

(1) Unless specified conventional direct tension

(2) Electrolysis-Nickel-plated (.001 to .0015 thick) Finished with Mono Seal Red Lead and Black Mono Seal.

3.2 CHAN

The CHAN system was originally designed for positioning a towed body several hundred feet away from a submersible. It was assembled in prototype form, tested in a circulating water channel, and taken to sea and tested aboard a surface vessel to determine its cable handling ability. The CHAN winch is shown in Figure 3-1. The CHAN program was cancelled before the winch was installed aboard a submersible and, therefore, data on underwater operation are non-existent. Several comments with regard to its design approach are appropriate however.

A deep-grooved, horizontally-mounted drum was used to store the cable. It was designed to handle and store a segmented faired cable as opposed to the bare cable design of the other underwater winch systems. The drum was fabricated from cast aluminum bronze which afforded the galvanized cable protection. All hardware and sheaves were made of stainless steel with the exception of bolts and shafting which were fabricated from monel. The supporting structure and gear housing were fabricated from medium grade steel, and impregnated bronze bearings were employed.

The winch was powered with an open-winding oil-filled ac motor (1725 rpm) in a pressure compensating housing. A conventional gear box was employed; the final reduction components were exposed to sea water and were fabricated from a nickel copper alloy. Since the winch was designed to be used with faired cable, storage was accomplished in a single lay on the drum. An acme screw-type level wind fabricated from K monel was employed. It incorporated a mechanical Gleason sheave and reel approach to obviate the requirement for sliprings to maintain electrical contact.

Since no data on the CHAN underwater operation are available, one can only conjecture as to what its performance would have been. Had the program been continued, there would have no doubt been many simplifications incorporated into the original prototype design such as a less complex approach

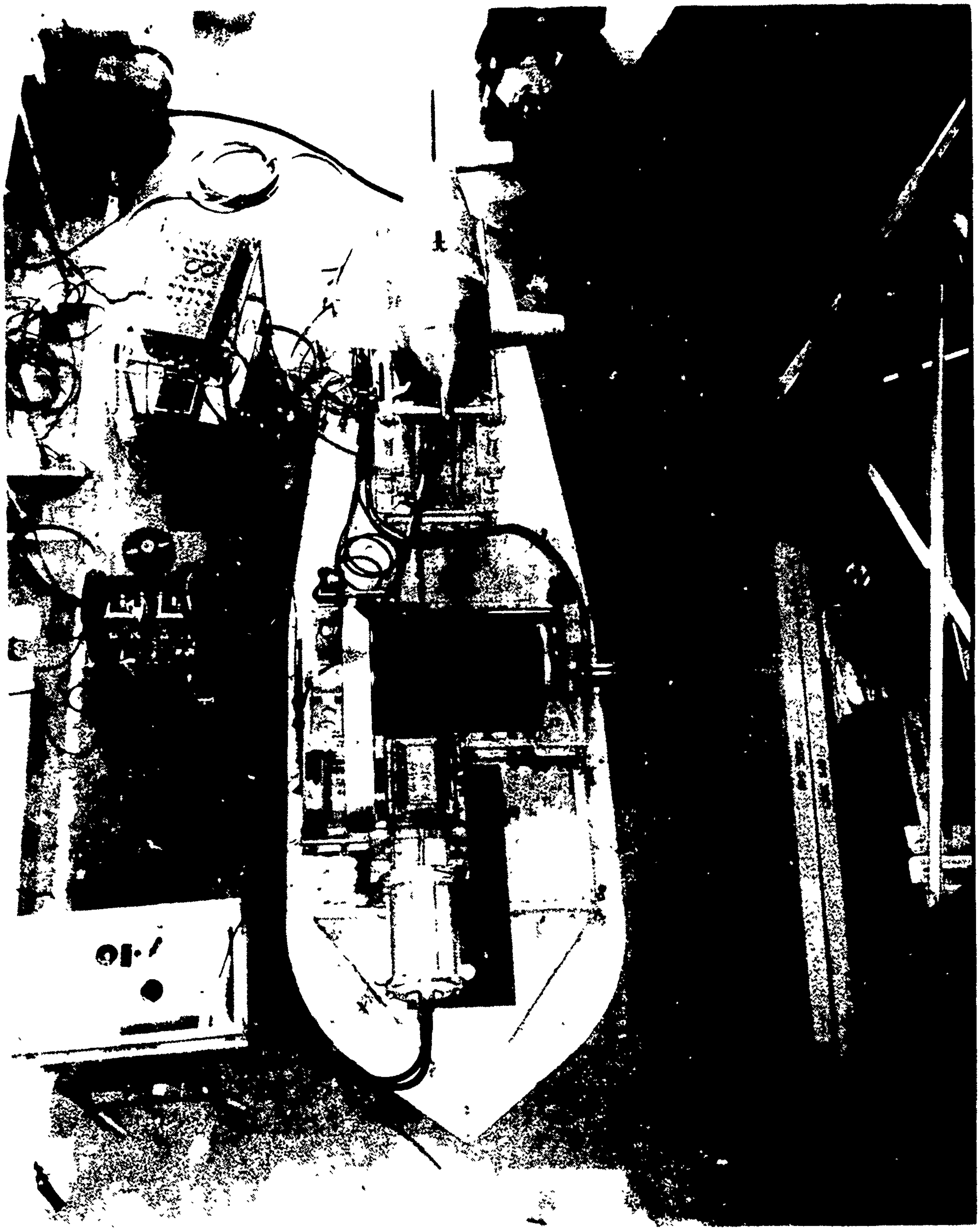

Figure 3-1. The CHAN Winch

to maintaining electrical continuity between the drum and the fixed cable function.

3.3 AN/BRA-27

The AN/BRA-27 winch was designed to control a submarine towed communications buoy. Positioning of the towed body is accomplished by in-hauling or paying out an electro-mechanical cable with a winch mounted to the submarine outside the pressure hull. The AN/BRA-27 winch was designed to be mounted on the after deck of the Guppy class submarines. Three prototypes were built, two of which were evaluated at-sea aboard a submarine. The laying up of the Guppy class submarines resulted in the termination of this developmental effort, so extended life operational data are not available.

The winch was a conventional direct tension single drum design. The drum was horizontally mounted and fabricated from corrosion resistant steel. The drum was surrounded with an aluminum cover, usually referred to as lagging, to protect the cable from galvanic corrosion.

The cable was stored in several layers on the drum, and a hastalloy-C diamond screw level wind mechanism was employed. A means to apply constant pressure was provided by a roller which, in conjunction with the level wind mechanism, maintained the position of the cable lays on the drum. The drum was torsionally spring mounted to allow approximately one full revolution to occur under increasing cable load to 2000 pounds before the mechanical stops were encountered.

The main frame served as the main structural element for the support of all components and attachment to the submarine hull and was fabricated from hot rolled steel, electrolysis nickel plated, and finished with mono seal red lead and black mono seal. All exposed hardware was fabricated from stainless steel, and Fabroid sleeve bearings were employed.

Conventional sliprings were used and were mounted in a waterproof housing equipped with a leak detector to provide a warning signal when water was present. This same housing was also equipped with a means for measuring cable scope paid out. The propulsion unit consisted of a 7-1/3 hp dc motor and speed reducer (21 rpm output) which were mounted within a hermetically sealed air-filled housing. A conventional double O-ring seal was used on the shaft to maintain the watertight integrity, and a leak detector was also incorporated. Final drum drive was through a chain and sprocket arrangement.

In testing, severe crevice corrosion problems were encountered with all stainless steel components. For example, the exposed stainless steel drive chain from the speed reducer output shaft to the drum failed due to crevice corrosion. It was replaced with a bronze chain which functioned satisfactorily.

3.4 AN/BRA-8

The AN/BRA-8 winch was also designed to control a submarine towed communications buoy. It is located partly in the stanchion stowage area, outboard of the submarine pressure hull, and partly in Auxiliary Machine Room No. 1, and is used for paying out, reeling in, and storing the tow cable. The components and their general arrangement are depicted in Figure 3-2.

During the payout condition the buoyancy characteristic of the buoy, the hydrodynamic pressure on the buoy (a function of the submarine speed), and cable drag exert a pull on the tow cable, causing the drum assembly, drum drive shaft and thrust bearing, flexible coupling, and gear reducer to rotate as a unit. In this condition, the hydraulic motor functions as a pump, forcing the hydraulic fluid to flow through the piping and valves. Regulation of this fluid flow provides control of the cable payout. During the reel-in condition, the hydraulic motor functions as a motor, producing a mechanical torque which turns the drum assembly in a direction opposite to that required for payout, thereby causing the cable and buoy to be reeled in.

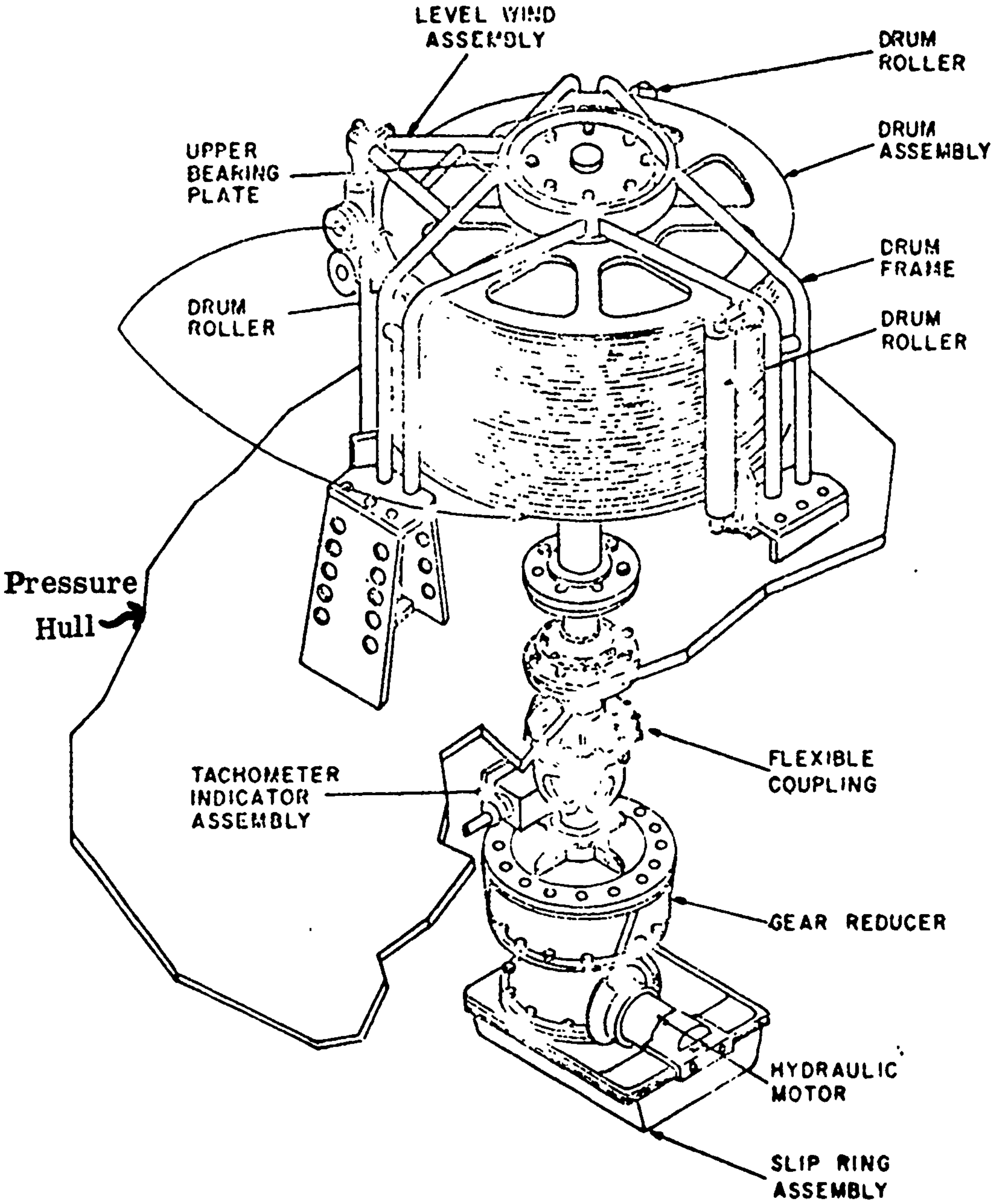

Figure 3-2. Major Components of the AN/BRA-8 Winch

When the buoy is secured in the buoy compartment, the major portion of the tow cable is wound on the drum assembly. The drum assembly consists of a AISI 304 stainless steel cylinder with a continuous helical groove machined on the periphery of the drum assembly; the tow cable is wound into the groove. The top and bottom diameters of the drum assembly are flanged to prevent the tow cable from slipping off. The drum assembly is approximately 39 inches high with a diameter of approximately 66 inches, turns at 8.7 rpm, and weighs approximately 3000 pounds. A strain connection is located on the flange of the drum assembly for termination of the armored cable, and from this point the four transmission lines are routed through a stainless steel braid sleeving to the pressure-sealed receptable fastened to the drum-drive shaft.

The drum frame is used to retain the upper drum bearing and to support three drum rollers. The rollers are placed in a position to prevent overlapping of the tow cable. The frame is a tripod assembly straddling the drum assembly and bolted to a foundation welded to the pressure hull. The frame and roller weigh approximately 3000 pounds. The drum assembly is supported by the drum-drive shaft located below it. An upper sleeve bearing guides the stub shaft connected to the top of the drum assembly. Three resilient-surfaced rollers hold the tow cable in the drum assembly helical grooves under conditions of low cable tension.

The drum drive shaft is hollow, providing a conduit to feed the four transmission lines from the drum assembly tow cable receptacle to the slip ring assembly. The shaft also supports the lower portion of the drum assembly. Another function of the shaft is to transmit torque from the gear reducer through the thrust bearing, to the drum assembly. The thrust bearing is a self-aligning antifriction-type bearing and is used to support the drum-drive shaft. Mounted inside the hull, the thrust bearing absorbs the full thrust load of the drum assembly weight and sea water pressure.

During reel-out and reel-in sequences, the level wind functions to guide the tow cable on or off the helical grooves on the drum assembly. A guide shaft is mounted alongside the drum close to the tangency point of the tow cable. The level wind assembly rides this post, guided by delrin bearings mounted on the top and bottom of the level wind assembly. Rollers mounted on the level wind assembly engage the helix on the drum. Two rollers mounted on the main body trap the cable between them and guide the cable into the drum grooves.

This equipment has been in operation over an extended time period, and two lessons can be learned:

1. AISI 304 stainless steel is unacceptable for this type of application due to its susceptibility to crevice corrosion and its inability to repel various types of marine growth.

2. The original leaded bronze sleeve bearings proved to be unsatisfactory in extended use and were replaced with ultra high molecular weight polyethylene sleeves which functioned well.

3.5 BIAS

The BIAS winch is quite similar in design approach to the AN/BRA-27. A prototype unit has been built and is presently undergoing sea trials. Preliminary results indicate satisfactory operation after several test days at sea. The winch assembly is mounted in a flooded area outboard the pressure hull. Figure 3-3 shows the major components of the winch assembly.

The grooved cable drum is fabricated of nickel plated mild steel with 6061-T6 aluminum lagging and has a system of internal spring-type shock absorbers to minimize the transmission of shock loads to the tow cable. A hastalloy-C diamond screw level-wind attachment on the drum ensures that the cable is wound on the drum in an orderly manner to prevent cable tangles during reeling and unreeling. Extensive use of monel has been incorporated in this system design to overcome the corrosion problems experienced in the AN/BRA-27 system.

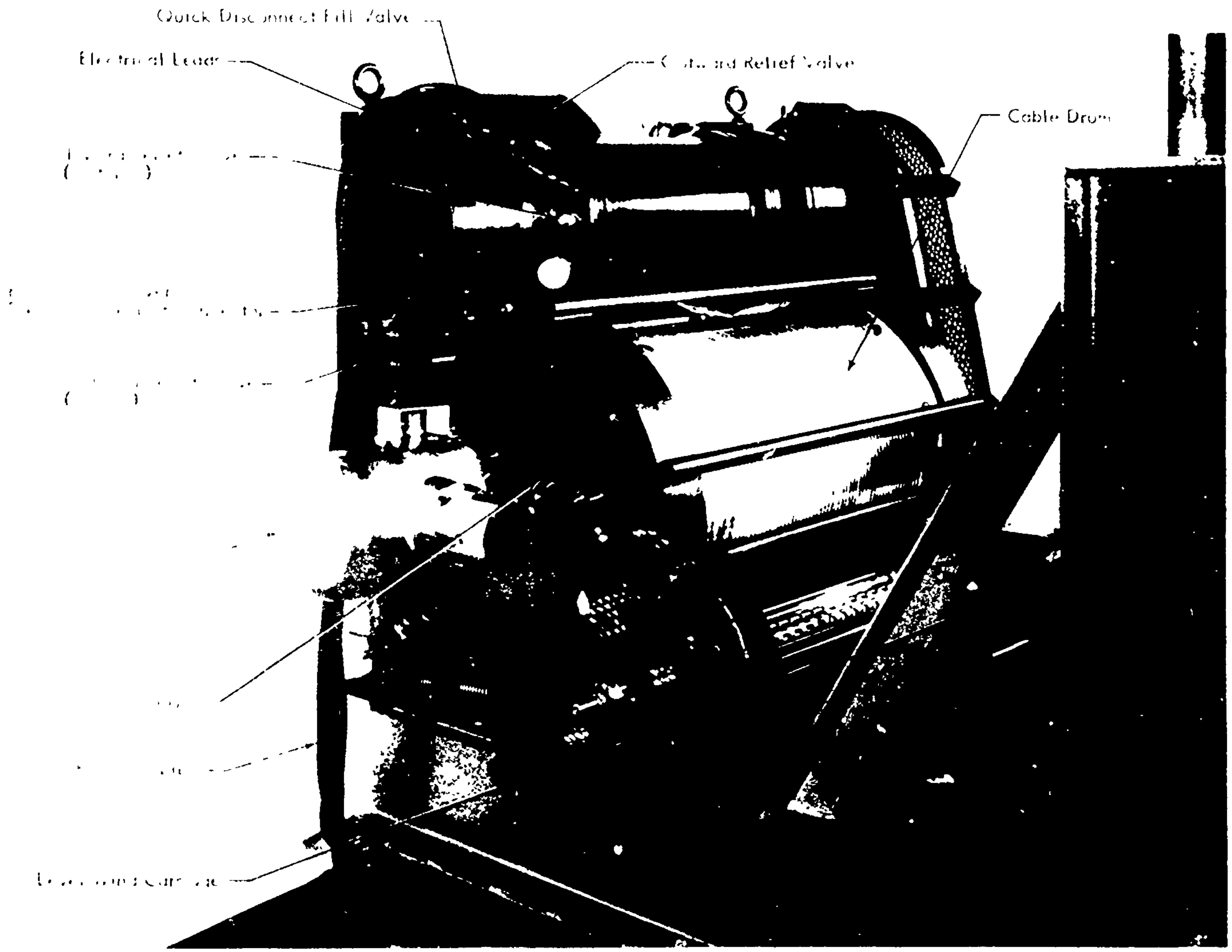

Figure 3-3. Bias Winch Assembly, Left View

The winch is powered by a two-speed, bidirectional, 400-volt ac motor which is mounted in an oil-filled waterproof housing. Also in the housing are an electromagnetic disc brake, a motor housing flooding sensor and a speed-reducing gear assembly. At low speed, the motor reducer has a 8-1/2 horsepower rating (9.5 rpm) that moves the buoy at a speed of 50 feet/minute; at high speed, the motor has a 26 horsepower rating (27 rpm) that moves the buoy at a speed of 150 feet/minute.

The slipring assembly is mounted in a waterproof housing located on the left end of the cable drum shaft (see Figure 3-3). The assembly consists of 10 sliprings used to make electrical connections to conductors in the tow cable and for the flooding sensors in the motor housing.

3.6 VERSUS

The VERSUS winch was designed to handle and store a hydrophone array aboard a submarine. The array comprised 1000 feet of 0.95-inch cable with 2-1/4 inch diameter by 32-inch long hydrophones on 32-foot centers. The tow cable was also 0.95-inch diameter and 2000 feet long.

The drum is large enough to accommodate the rigid hydrophones of the array and is fabricated from AISI 316 stainless steel. A rather complex level wind mechanism is required to accommodate both the cable and the larger diameter hydrophones in an orderly fashion. It is a mechanical level wind with a two-speed drive to allow for speed changes required by the different diameters. Speed change is accomplished automatically upon signal from a sensor which detects the presence of a hydrophone.

The hardware and fittings are fabricated out of monel and corrosion-resistant steel. Oil-filled conventional ball bearings with reverse seals were employed.

Power is supplied by a dc motor contained in a hermetically sealed air-filled housing. A cone drive speed reducer is employed, and a conventional mechanical brake is used. Conventional sliprings were utilized.

Due to the classified nature of this project, no information is available about the operational use of this winch. A check with the supplier revealed that no service calls had been required in the past eight plus years since it was developed.

3.7 MAKAI RANGE

Two winches were designed and built to assist in the placement of the habitat on the ocean floor and to raise and lower the Emergency Transport Capsule at the Makai Range. These winches have been installed for just under a year, and all reports indicate satisfactory operation.

The winch is a direct tension, single drum design. The drum, which stores the cable in multiple lays, is fabricated out of mild steel and is protected with an epoxy paint finish. No level wind mechanism is required since the fleet angle is quite small. The frame is fabricated from nodular cast iron and also protected with an epoxy paint coating. Delrin sleeve bearings are used.

The winch is powered by an open-winding, oil-filled 1-1/2 hp ac motor mounted on the load brake housing. The power drive to the drum is accomplished through a one-step fluid filled, pressure compensated gear reduction and flexible coupling inside the gear housing, and through the reducer unit. A mechanical load brake holds the load when the power is off. Both the motor and gear housing are oil-filled and separately pressure compensated by a rolling diaphram. Leakage is indicated by the position of a T-indicator on top of the gear housing. An O-ring teflon boot-type seal is used on the output shaft. Since only mechanical cable is handled, no sliprings are required.

3.8 MARK II DEEP DIVING SYSTEM WINCH

This winch was designed to be attached beneath the personnel transfer capsule for controlling its vertical position in the water column. Six of these units were manufactured, two of which were successfully used in the SEALAB III program.

The winch is a conventional direct tension, single drum design. The cable is stored in multiple layers on the drum; the very small fleet angles experienced did not necessitate the inclusion of a mechanical level wind to ensure orderly spooling of the cable. Stainless steel was used throughout the winch. All piping was fabricated from Schedule 40 stainless steel with flat-face O-ring-type fittings welded on each end for ease in assembly and disassembly.

The winch can provide a constant nominal tension of 750 pounds and maintain this tension within a given margin by appropriate payout or reel-in Primarily due to this constant tension requirement, an electro-hydraulic drive was selected. Initial power is supplied by a 5 hp open-winding, water-filled ac motor which is coupled directly to a constant displacement, dual hydraulic gear pump. Solenoid-operated directional control valves direct flow to a hydraulic gear motor housed in the winch drum. The gear motor, driving through a planetary gear reduction, provides the required torque to rotate the drum. The sump side of the hydraulic system and all large cavities in the winch are pressurized with oil to produce an internal pressure equal to environmental pressure plus 10 psig. This positive outward pressure differential ensures that any leakage will be outward, and will not allow sea water into these winch cavities.

3.9 NEMO

The Navy Experimental Manned Observatory (NEMO) has the capability of using an underwater winch for positioning this manned submersible in the water column. This unit is used to deploy or retrieve an anchor via a cable. Once the anchor has been set, the submersible positioning can be be controlled by reeling in or paying out cable. The winch has been in use for over two years during which time it has successfully controlled approximately 250 dives. During this period special attention has been paid to preventive maintenance including washing down the unit with fresh water after each dive.

The grooved drum is manufactured from AISI 316L stainless steel as is the main frame. Corrosion-resistant steel is also used for the miscellaneous hardware and fittings. A Lebus-type level wind is used to allow orderly spooling of the cable in multiple layers for storage.

A battery-powered pressure compensated 1-1/4 hp motor submerged in the hydraulic reservoir drives the drum via a hydraulic pump, motor and gearing combination. AISI 316L stainless steel has been successfully used throughout the unit except for the gear train. The exposed gear train was manufactured from 17-4-Ph. This special material was used due to the hardness requirements. Glass-filled teflon sleeve bearings were employed throughout the design and have functioned satisfactorily once properly aligned. Since the cable is mechanical only, no sliprings are required.

3.10 LOLITA

As a part of the LOLITA sonobuoy system, a winch is employed to haul the buoy down to depth once the anchor has bottomed. Since operating life is short (depth is adjusted only once) and the device is expendable, cost considerations were paramount in the design.

A double-drum capstan-type indirect drive winch design was chosen to deliver the cable to a fixed basket for storage. A pressure roller is utilized to provide back tension. Anodized aluminum is used throughout as the construction material. Conventional sealed steel ball bearings are employed.

A sea water battery-powered dc motor hermetically sealed in an air-filled housing is used for the propulsion unit. Due to the classified nature of its application, limited test data are available; however, indications from developers reveal satisfactory operation.

3.11 WEBS

As in the case of the LOLITA winch, the WEBS winch was also a haul-down device used to control a buoy depth.

The original design of this unit employed a single drum capstan with fleeting knives and a pressure roller for generating the required tension. Storage of the cable upon exit from the capstan was accomplished by a rotatable basket. Rotation of the basket was to be accomplished solely by virtue of the cable stiffness.

Corrosion-resistant steel was used throughout; conventional sealed steel ball bearings were employed. The unit was driven by a battery-powered 4-1/2 hp 50-volt dc encapsulated motor. The motor capsulation technique proved to be a problem, as did the wire rope characteristics. The assumed friction coefficients employed in the design proved to be too high, and therefore the unit was unable to develop the tractive force required. This allowed the cable to slip. Also, the cable was stiffer than expected which caused the rotatable basket storage technique not to work well. Subsequently, this unit was redesigned along the LOLITA approach.

Due to the space constraints which necessitated small diameter drums, wire tangles were experienced in the limited operation in which this unit was employed.

Section 4

DESIGN CONSIDERATIONS

4.1 GENERAL

Certain lessons can be learned from underwater winch developments to date. Considered in light of the requirements and performance specifications, critical design features arise which must be accounted for in any new developmental program. The requirements for deep ocean (10,000 to 20,000 feet) installation and long unattended operational life (10 years) necessitate allowances for high ambient pressure, corrosion in low velocity flow, fouling, foreign particle intrusion, and general salt incrustation.

The intended application requires handling of moderate size cables (1/2 to 1-1/2 inch diameter) in lengths up to 1000 feet. History suggests that a direct tension conventional drum approach is warranted. It will be the most compact in size and weight and the least complex overall. The possibility of cable slippage and the intricate mechanisms, together with their serious lubrication, sealing and fouling design problems, which are inherent in indirect tension devices, are obviated. The special considerations that led the LOLITA and WEBS winch designers to choose indirect tension winches are not present here, and the developmental problems that plagued these programs (especially WEBS) should teach that such approaches are not desirable unless absolutely necessary. Within the overall approach of a conventional direct tension winch, each functional component must be carefully considered in the light of its intended application and experience gained to date. In the following paragraphs each functional winch component will be discussed in this regard.

4.2 DRUM

The diameter of the drum will be established primarily by the cable size and type and, to a lesser extent, by the intended use or duty cycle. Selecting the drum width will require a trade-off among the number of layers of cable, the level winding approach, and the geometric envelope requirements. The greater the number of layers of cable, the more the chance of cable burying or fouling on the drum. The outer circumference of the drum should be grooved since grooving prevents cable flattening under load, thereby prolonging cable life. The grooving material must be compatible with the cable since they are in direct contact. The cable will likely be galvanized or aluminized. If the candidate grooving material cannot withstand the hoop stress from the cable loading, it would have to be separate from the drum. Aluminum lagging over a higher strength core was popular in the designs reviewed in Section 3. Cable burying and/or fouling were not reported by users of any of these equipments.

It must be kept in mind that none of the previously developed underwater winches had a ten-year unattended life as a design goal. They were either short life (as in the case of LOLITA and WEBS) or regularly accessable for inspection and repair. The use of aluminum liners over nickel-plated steel might not be successful for very long periods of submergance since any scratches in the protective plating would create a susceptability to very rapid, uneven corrosion.

4.3 LEVEL WIND

In all likelihood only very small fleeting angles will be encountered in the intended installation; therefore, mechanical level wind devices will not be required in order to ensure proper spooling of the cable on the drum. All three types of level wind devices used on the winches reviewed in Section 3 functioned satisfactorily, and should the designer wish to incorporate a mechanical level wind at the depths under consideration, no problems should be experienced due to the high ambient pressure. However, mineral deposits and marine growth could inhibit these type devices.

4.4 POWER DRIVE

All of the winches reviewed were powered by an electric motor with the exception of the AN/BRA-8 which receives power from the submarine hydraulic system. Some drive the drum through reducers and chains, while others drive hydraulic pumps which in turn drive hydraulic motors and reducers.

Early designs employed direct-current motors due to their favorable performance characteristics for many undersea applications and particularly good variable speed control with a battery supply. Because the basic design requires the use of commutator bars and brushes, dc submersible motors are generally built as open-winding, oil-filled units. Brush wear was very rapid in early submerged dc motors and frequent maintenance was required. Improvements in materials and design techniques have allowed dc motors to reach unattended lives of over 1000 hours operation.

The ac motors are designed with squirrel cage rotors, and have been built in all three basic submersible motor types. Maintenance is reduced since brushes are not required. Submersible ac electric motors are particularly good in continuous duty applications. Through extensive application in the oil well industry, ac motors have attained a high state of development.

Ambient sealed, air-filled motor housings have been used but suffered from the necessity for high pressure differential rotating shaft seals, heat dissipation and condensation problems. Through the use of oil-filled motor housings, complete pressure equalization with the deepest part of the ocean (the surrounding environment), lubrication, and corrosion inhibiting for the rotating parts, and a circulating heat transfer medium are all attained.

In order to attain pressure equalization, a bellows or diaphram-type device is required on the housing. This will allow for compressibility or contraction of the internal fluid due to the ambient pressure or temperature respectively, thereby maintaining pressure equalization. By spring-loading this device, a slight positive internal pressure can be maintained. This will preclude water intrusion in the event of seal seepage, and ensure that any leakage will be outward.

The power output from an electric motor is characteristically high rpm and low torque. The requirements of the traction drum are just the opposite, low rpm and high torque. The conversion can be accomplished in several ways.

Direct gear and chain combination drives have been employed with mixed results. For example, in the early AN/BRA-27 design a stainless steel drive chain was used. In service, crevice corrosion was so severe that the chain fell from its sprocket. Bronze and monel chains have proven most satisfactory in the limited experience gathered to date. Cone drives and planetary gear sets have also been used satisfactorily. Both sea water exposed and pressure compensated gear drives have performed well over the relatively short duty cycles required.

Electro-hydraulic drives were used on three of the winches reviewed. All seemed to function well. They are very attractive when very large speed reduction is necessary or when maintaining constant tension is a requirement. Such approaches also offer the possibility of eliminating electro-mechanical brakes by incorporating a hydraulic brake or pump energy dissipation scheme.

4.5 SENSORS

Line speed, scope, and tension sensors have been successfully employed on the submarine communication winches by using gear driven rotary potentiometers and load cells. For the intended application, line speed and tension may not be required, but it will be desirable to know the scope paid out or reeled in. Scope could be determined as in the past, or drum revolutions could be counted electromagnetically. This would only require the mounting of a number (based upon the required accuracy) of hermetically sealed reed switches on the fixed structure adjacent to the drum, and a magnet on the drum. As the drum rotates, closures of the switches can be sensed and counted. Knowing the drum diameter, scope can be calculated. This approach has been used successfully for both speed and scope measuring devices.

4.6 WINCH FRAME AND HARDWARE

The primary design factors involved in the winch frame and associated hardware are concerned with material selection. Deep submersion for prolonged periods involves many physical, chemical and biological processes which affect, to some degree, the deterioration of most substances.

The seas are anything but predictably alike. Since corrosion is inextricably bound up in the chemistry of oxygen transfer from water to substance, the oxygen content of the water at specified depths affects corrosion rates profoundly. Currents tend to scrub off protective marine growth from the surface and thus render the surface increasingly vulnerable to corrosion. Further accelerating the corrosion process, the current also provides added oxygen along the face of the specimen.

Ordinary construction steels, alloy steels and high-strength low-alloy steels can be used for deep sea applications where the strength-to-weight and buoyancy-to-weight ratios are not vital factors. Because of the predictably uniform corrosion rate, the life of a structure fabricated of these steels is also predictable. The corrosion factor thus becomes a primary design element in undersea construction.

Stainless steels fare badly at all depths over long immersions. Aluminum alloys, with their high strength-to-weight and high buoyancy-to-weight ratios, are suitable for short-time, constant immersion. Aluminum alloy structures must embody preventive measures in their design to decrease the possibility of pitting and crevice corrosion. Such systems extend the useful life of aluminum alloy structures.

If strength and weight are not major considerations, copper alloys which are not susceptible to dezincification and dealuminification are suitable for deep sea application. Their corrosion, too, occurs uniformly. Some nickel base alloys, with their low strength-to-weight ratios, moderate strength and excellent resistance to corrosion, are quite suitable for general deep ocean use. Titanium alloys are generally excellent where maximum corrosion resistance and high strength-to-weight ratios are the deciding factors. There is virtually no information on susceptibility of welded alloys to stress corrosion cracking.

Recently information has become available on materials exposed to deep ocean environments for extended periods of time. Several interesting observations have been made. At 6000-foot depths, ordinary steel lasts far longer than it does at the surface. The same holds true of copper-based alloys. Aluminum alloys, on the other hand, fair worse than at the surface; stainless steel which pits severely in sea water takes the same kind of punishment at 6000 feet as it does close to the surface.

Marine fouling of specimens has been found to be less at 6000 feet than in shallower waters. Hydroids and slime films have been found on the surfaces of recovered samples, but typical fouling organisms such as barnacles, sea squirts, and bryozoans have not been attached to any of the materials recovered from 6000-foot depths. The slime covering has yet to be evaluated fully in terms of its effect either to increase or to inhibit the corrosion process.

The current trend towards providing long term protection against corrosion and fouling is towards the use of copper nickel alloys. 90-10 copper nickel needs no coatings or cathodic protection. The 70-30 copper nickel alloy is stronger and offers almost as much resistance to fouling as the 90-10 alloy.

Particular attention needs to be paid to areas where there is contact between dissimilar materials, but galvanic series data are readily available. Attention also needs to be given to areas in the design where water may be entrained because of the completely different corrosion environment that is thereby created.

4.7 SLIPRINGS

In the ten winches reviewed, only CHAN, AN/BRA-27, AN/BRA-8, BIAS and VERSUS handled an electromechanical cable which necessitated a slipring type device to maintain electrical continuity between the rotating drum and the fixed cable junction. Conventional sliprings mounted in a waterproof, oil-filled pressure compensating housing were employed successfully. However, recent developments in mercury wetted contacts, flat ribbon cables, and disk or platter rings are attractive for new designs where packaging envelope or low noise requirements are severe. For the intended application, a slipring may not be required since the cable to be handled may only be a strength member; however, if this should change, the incorporation of such a device does not present any major problem.

Section 5

CONCLUSIONS

Based upon available information, no underwater winches have been or are in development which can meet the requirements for deep ocean installation and a ten-year unattended operational life. The developments surveyed in the effort were by and large successful for their intended missions, which indicates that advancements in the state-of-the-art can be accomplished with minimum risk.

For the application under consideration, the major problem will be the ten-year unattended operational life, not the high ambient pressures. In order to maximize the probability of overcoming this problem, a well thought out design based upon a direct tension, conventional drum, enclosing a pressure compensated drive approach, and incorporating physics of failure and increased hazard analysis would be required.