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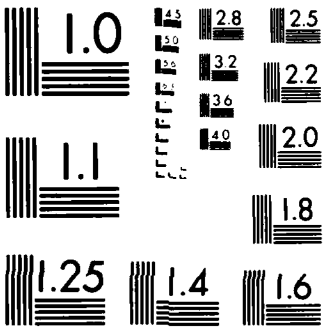
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Woods Hole Oceanographic Institution

WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

Improvement of Intermédiate Oceanographic Winches

by

H. O. Berteaux & R. G. Walden
Woods Hole Oceanographic Institution
L. W. Bonde & J. D. Bird
EG&G Washington Analytical Services Center, Inc.

March 1985

Technical Report

Prepared for the Office of Naval Research under Contract No. N00014-82-C-0019.

Approved for public release; distribution unlimited.

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Robert C. Spindel, Chairman
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ABSTRACT

The following is a report on the findings of a study conducted by the Woods Hole Oceanographic Institution to assess the needs and the means for improving the conventional intermediate winches used in the oceanographic community to lower profiling instruments (CTD for example).

Eight major U.S. oceanographic centers were visited to confirm community needs and common problem areas, and to survey existing lowering equipment and techniques. This information was used to develop a set of general requirements for an improved instrument lowering system. Recommended improvements included: compensation of wave induced ship motion, automation of casts, and capability for automatic tracking of oceanographic parameters.

A review is presented of additions or modifications which could meet these requirements. These options are compared and the system which offers the best potential for scientific usefulness, ease of fleet implementation and/or retro-fitting of existing equipment is described at the conceptual and general specifications level.

A plan for the design procurement, test and demonstration of a working prototype concludes the study.

ACKNOWLEDGEMENTS

The authors express their gratitude to the engineers, scientists, and marine personnel of the many oceanographic centers visited for their constructive comments and suggestions. We hope to have incorporated these in our report, and that the proposed winch meets their combined requirements for usefulness, innovation and practicality.

Discussions with J. G. Dessurault of Bedford Institute of Oceanography, Dartmouth, Nova Scotia and K. D. Saunders of NORDA, NSTL Station, MS, were extremely helpful.

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Appendix A "Heave and Roll Induced Sheave Vertical Displacement and Speed"

Appendix B "Power Requirements for Servocontrolled Winch"

1. INTRODUCTION

The Woods Hole Oceanographic Institution has recently completed a study of the needs and the means for improving the conventional intermediate winches used in the oceanographic community to lower profiling instrumentation (CTD instrument packages for example).

Steps followed in this study included site visits to eight major U. S. oceanographic centers to confirm community needs and common problem areas, and to systematically survey existing instrument lowering techniques and equipments. Based on this information preliminary requirements were outlined for a winch system which could best fit common user needs and shipboard facilities.

A review was then made of add on or stand alone options which could meet these requirements. These options were compared and the system with greatest potential for scientific usefulness and ease of fleet implementation was selected.

A set of specifications for this system was written. A plan for the design, procurement, test and demonstration of a working prototype, together with a cost estimate for the improved winch system development concluded the study.

2. BACKGROUND

Intermediate oceanographic winches are used to lower profiling instrumentation with remote sensing and telemetry capability. Users include oceanographers from all disciplines the majority of them being physical and chemical oceanographers. Intermediate winches are most frequently used to perform CTD casts (measurements of sea water conductivity, temperature and depth) and sea water sampling.

The loss at sea of at least twelve costly CTD instrument packages suffered by the oceanographic community, and the recurrent problem of signal losses due to cable conductor failures has prompted the Office of Naval Research to sponsor a comprehensive study of CTD instrument lowering mechanics. Results from this study have been published (Berteaux and Walden, 1984). The study did single out ship motion (heave, roll) as the major cause of instrument lowering cable damage. It also demonstrated how ship motion compensation would help reduce cable failures and would permit a much more efficient use of precious ship time.

Two principal mechanisms of cable damage were identified by the study. The first stems from the high dynamic loads sustained at the shipboard end of the cable while retrieving the instrument in a rough sea. As the ship heaves and rolls in the sea way (Figure 1), the inertia and drag forces imparted on the cable and attached instrumentation by the violent motion of the head sheave, considerably increase (up to 50%) the tension due to the winch steady pull. If the winch hauling speed could be regulated to produce a constant

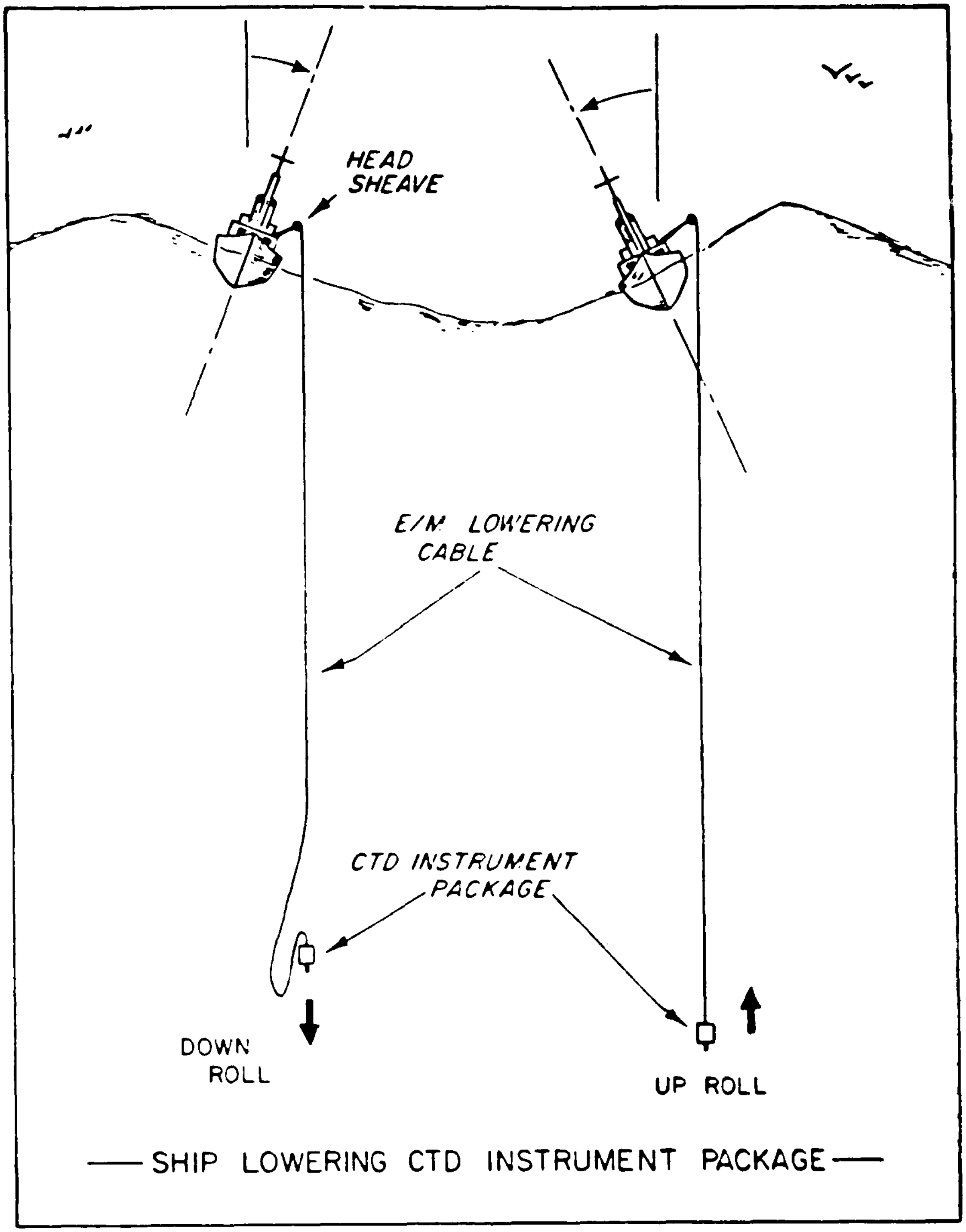

HEAD SHEAVE
E/M LOWERING CABLE
CTD INSTRUMENT PACKAGE
DOWN ROLL
UP ROLL
SHIP LOWERING CTD INSTRUMENT PACKAGE

Figure 1

speed of cable and instrument ascent, then inertia effects resulting from speed changes would be suppressed, as well as the substantial increase in drag due to upward sheave motion. The tension would be nearly constant, decreasing slowly as the cable is reeled in. High tension peaks due to wave induced forces would no longer be present.

The second recognized cause of cable damage is cable slackness followed by snap loads. This condition often occurs at the cable lower end while deploying the instrument in a rough sea way. Ship heave and down roll can force the head sheave to fall at a relatively large speed, thus greatly increasing the cable lowering speed. If the cable lowering speed exceeds the terminal velocity of the instrument-that is the maximum speed at which the instrument can free fall in the ocean - then the cable will override the instrument and will form a slack loop probably full of kinks. Cable and instrument will continue to fall until the next wave forces the sheave to move upwards again. The cable then rushes back to the surface, catches the free falling instrument and forces it to reverse its direction of motion in a fraction of a second. The kinked cable is then subjected to a severe snap load. The resulting damage can be cable rupture and loss of instrument, or conductor damage with loss of signal conductivity. If the winch payout rate could be regulated to prevent the actual cable lowering speed from exceeding the instrument terminal velocity then slack conditions, kinks, and snap loads would be eliminated.

3. SURVEY OF PROBLEM AREAS AND SCIENTIFIC NEEDS

In late 1983 and early 1984 a survey was conducted to confirm the frequency of occurrence and the severity of cable damage due to snap loads and fatigue, to inquire about other problems and the limits of present lowering techniques, and to assess the needs for improvements and new winch capabilities.

Oceanographic centers visited in this survey included: Oregon State University, University of Washington, Scripps Institution of Oceanography, Texas A & M University, University of Miami, Lamont-Doherty Geological Observatory, Woods Hole Oceanographic Institution and the University of Rhode Island. In each of the eight centers visited contacts were made with the scientific users of intermediate oceanographic winches and the marine personnel in charge of these winches. Site visits consisted of formal seminars followed by personal interviews. The highlights and conclusions of these visits are hereafter summarized.

Frequency of Use. Number and depth of casts vary. Some centers place emphasis on near shore studies, others explore the deep sea. Emphasis also shifts with time. Intensive winch use, with casts numbering in the hundreds, is typical. In most instances the bottom is the depth limit. Casts down to 6000 meters are not uncommon. Some casts (tow-yo) are performed with the ship underway at 2-3 knots.

Problem Areas

- Complete loss of instrument package. Fortunately infrequent, some 12 CTD losses over the last eight years or so. Causes include cable rupture due to snap loads, cable rupture due to cable unwinding, improper instrument attachment, two blocking. Two blocking occurs when the winch is not or cannot be stopped in time to prevent hauling the instrument up to the deployment sheave which results in cable rupture and loss of instrument.

- Loss of signals due to open or short circuits frequently at the cable lower end. Caused by wave induced ship motion. As previously explained, on a down roll the cable falls faster than the instrument can fall thus enabling the cable to become slack and kink. On the next up roll the kinked cable is pulled tight thus severely damaging the conductors. The cast must be interrupted, the instrument hauled back, the damaged end cut off and the instrument re-connected, and then re-lowered. Twelve hours of ship time loss is typical.

- System limitations. The present lowering technique is severely limited by weather conditions. Sea state 5 (20 knot winds, 10 foot waves) marks the end of CTD operations on most oceanographic vessels. In rough weather it becomes increasingly difficult to launch and recover the instrument package. Ship down roll considerably increases the speed of cable travel. Ship up roll increases cable tension at the shipboard end. The first effect limits the allowable payout rate. The second effect limits the allowable depth of cast.

- Deleterious effects on scientific data. Also often mentioned are the deleterious effects of instrument motion on scientific data: mixing of stratified layers, impossibility of studying fine scale structures, increased complexity of data reduction and premature tripping of water samplers.

Improvements and New Capabilities. Improvements and additional capabilities suggested or recommended during the survey included:

- Ways to reduce/suppress total instrument losses due to accidental cable failure, including human errors.

- Ways to reduce/suppress failures of cable conductors resulting in data losses and lengthy repairs.

- Shorter station time. Presently modest payout rates - typically 60 meters/minute (3.28 ft/sec) - are used to wishfully prevent cable slackness and snap loads from occurring. Typical terminal velocities of CTD instruments and of CTD lowering cable are 164 meters/minute (9 ft/sec) and 220 meters/minute (12 ft/sec). If the actual lowering speed could be regulated to a constant 120 meters/minute (6.56 ft/sec) then the time presently required to complete a cast would be cut in half.

- Methods or equipment to ease launching and retrieval of instrument packages in rough weather.

- Lowering of larger and heavier packages.

- To eliminate excessive cable tension fluctuations,
- To maintain payload at desirable position,
- To retain compatibility with ship capabilities and logistic constraints.

Each of these objectives can be examined to determine how to best quantify the system design parameters to meet the overall needs without imposing excessive complexity and cost on the system design.

Cable tension fluctuations can be both positive and negative. Obviously, cable tensions near the breaking strength of the cable are unacceptable. Excessively low cable tensions can also be destructive. Slack cables kink and "bird-cage" resulting in conductor damage and often cable breakage when the load is re-applied. It is important to note that tension fluctuations do not, by themselves, indicate a problem if the cable is not overloaded, or subjected to excessive slackness.

Payload position, on the other hand, is a far more sensitive parameter, when the quality of the data is considered. The system may be required to hold a constant depth, follow a depth-time profile, or track the profile of a measured parameter. A perfect constant tension system will do little to limit excessive position excursions.

6. DESIGN OPTIONS

Design Objectives. In numerous interviews with members of the oceanographic community, the requirement for an improved winch system arises from three basis needs:

- To reduce losses,
- To improve data quality, and
- To increase productivity.

Losses occur in many forms. Impact loadings cause damage to instruments, cables, and handling equipment. This results in loss of data, time, and possibly entire instrument packages. Violent motions of the instruments can degrade the quality of the data obtained (C.L. Trump, 1983). A system that can substantially reduce unwanted instrument motions can greatly improve the measurement capability. A system that can both reduce the unwanted motions and use real time instrumentation data to control the depth of the payload for profiling applications, would save a great deal of labor and time over present methods. Elevated sea states often shut down operations for days, greatly reducing the productivity of men and ships. A system that will permit operations in higher sea states could result in substantial increases in total productivity.

These needs can be satisfied by addressing several specific objectives that can be expressed in more quantitative terms. These include the following:

- Automatic two blocking preventer.
- Keyboard input for cast sequence programming.

Ancillary Equipment. Alarms, tension and line speed sensors, displays, brakes, level winds, etc.... are further described in Section 7.

Retrofitting. The possibility of providing motion compensation and automation to existing conventional winches by control/power modifications or by add on options is highly desirable.

Power. Line pull and speed of hauling determine the power requirements. A sensible upper limit of motion compensation should therefore be set. Hauling at a constant rate of two meters/sec a 1000 lb payload from a 6000 meter depth in sea state 5 appears to be a reasonable goal. As shown in Appendix B "Power Calculations", the power required at the drum would then be 150 hp maximum.

Size and Weight. Size and weight should be compatible with deck space available on one hand, and the desirable option of equipment transferability on the other hand. Winch base, power drive and winch controls could be a single assembly or mounted on two adjacent units. Preliminary size and weight requirements thus are:

- o Size: 3x4 meters of clear deck space for the winch. 2x3 meters of deck space for the power unit, within 5 meters of winch.

- o Weight: Winch and power supply 18,000 lbs maximum.

Control Options. Should include the following:

- o Manual only.
- o Preset constant rate of instrument travel, with full automatic compensation. Range of compensated speed: from 0 to $\pm$ 2 meter/sec. (0 $\pm$ 6.56 ft/sec).
- o Payout rate controllable from instrument end.
- o Guard length, length or depth within which automatic functions are locked out, say 50 meters from the surface.
- o Automatic slow down before of after guard length.

TABLE 1

Typical vertical head sheave displacements and speeds.

Horizontal Distance from Ship Centerline to Sheave = 22.5 ft

Vertical Distance from Mean Water Level to Sheave = 23.0 ft

RUN NO.	PERIOD (SEC)	ROLL AMP. (DEG)	HEAVE AMP. (FT)	MAX. DISPL. (FT)	MAX. VELOCITY (FT/SEC)	
					UP	DOWN
1	6	10	5	11.2	6.3	7.0
2	6	15	5	12.3	7.2	8.8
3	6	20	5	13.3	8.5	11.0
4	7	10	5	11.2	5.4	6.0
5	7	15	5	12.3	6.2	7.6
6	7	20	5	13.3	7.3	9.4
7	8	10	5	11.2	4.7	5.2
8	8	15	5	12.3	5.4	6.6
9	8	20	5	13.3	6.4	8.2

From these results a realistic upperboundary for motion compensation requirements could be set at:

Maximum amplitude of motion compensation = $\pm$ 7 ft

Maximum speed of compensation = $\pm$ 10 ft/sec

5. PRELIMINARY REQUIREMENTS

With the survey concluded, the next logical step was to formulate a preliminary set of improved winch system requirements. Obviously the first one is the introduction of automated, systematic motion compensation.

Motion Compensation. To gain an insight on the amount of motion compensation to provide, calculations of the head sheave vertical displacements and speeds were made using the approach outlined in Appendix A (Computation of heave and roll induced sheave vertical displacement and speed). Table 1 shows the results obtained for a sheave installed on the R/V OCEANUS, with a 10 ft. significant wave height (sea state 5) and several values of roll and period of ship response.

Cable. The winch should have a single drum. The drum should be capable of storing 10,000 meters of .322 inch diameter double armored electromechanical cable. Winch design will provide for ease of removal and replacement of full drum. Drum to incorporate standard Lebus grooving.

Payload. The lowered instrument package weight should not exceed 1000 lbs. when immersed in sea water.

Compensated Line Speed. The maximum compensated lowering/retrieving speed of the instrument package should be two meters/second (6.56 ft/sec.)

Conclusions. Present intermediate winch systems can provide a wide range of pull and speed combinations to satisfy most oceanographic needs in fair to moderate weather conditions. Limitations and problems introduced by wave motion cannot however be resolved by the existing equipment. Speed control remains essentially manual. Means of motion compensation are practically nonexistent. Gear boxes present in all systems reduce power efficiency and drastically increase system inertial response.

Ship Limitations. Specific deck space and weight limitations were not available, but a winch which could be installed in the area occupied by the new Markey winches would be satisfactory. Also a winch weighing in the 15,000 to 18,000 pound range could be accommodated.

Power take-off from the generators or main engines would have to be carefully studied for available space. Some ships could accommodate a power take off but most could not without some extensive modifications. Since most UNOLS ships are outfitted with an electrical outlet on the deck and have 2-300 kw generators, only one of which is required normally, an electric drive motor is preferred. This simplifies installation and makes a portable winch attractive.

The CTD overboarding equipment is usually designed for each specific ship's geometry. Several institutions expressed interest in improved equipment to prevent CDT pendulation during overboarding and retrieving. Also a two block preventer could prevent instrument losses.

Existing Motion Compensation Devices. A spring mounted sheave is rigged on some ships to minimize shock loads. One institution uses a spring restrained planetary gear arrangement to provide a one drum diameter length of cable payout when the load reaches a preset limit. Both of the systems absorb shock loads and do not compensate for motion. The simple spring system has been tried by several ships but is not widely used since it is limited to specific operating environments and complicates the rigging.

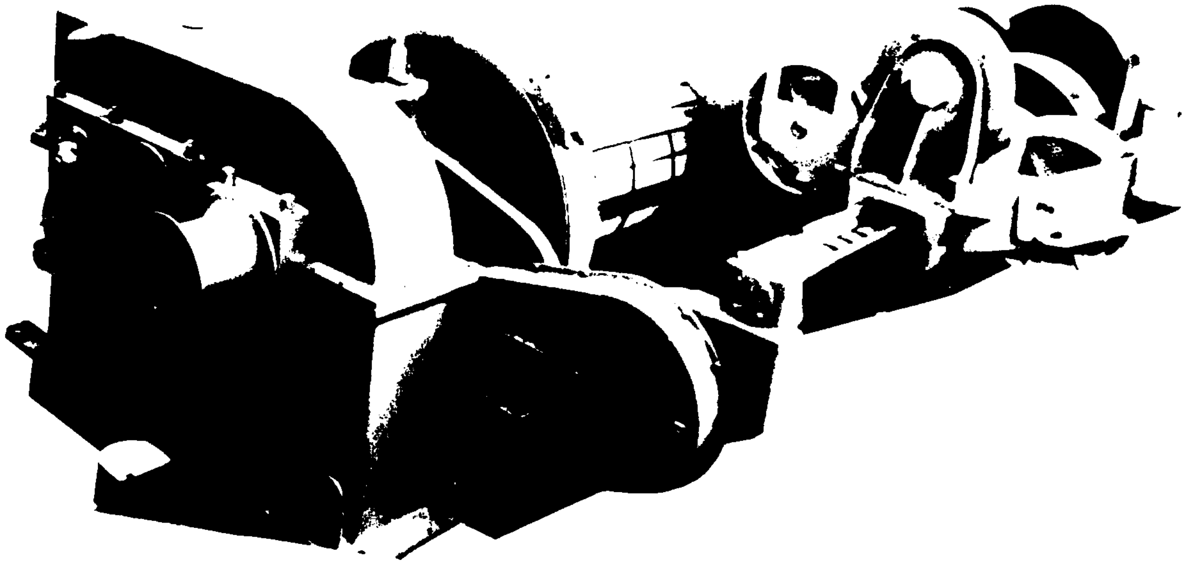


Figure 2 Markey-5 Winch

The winch drum is removable for ease of cable replacement. Its configuration is a follows:

Barrel Diameter	18 inches
Flange Diameter	44 inches
Distance between flanges	38 inches

This drum will hold 10,000 meters (32,000 ft) of .322 diameter cable with a flange margin.

The winch requires a 10 foot long 9 foot wide space for mounting to the deck with clear access all around to operate the fairlead (level wind) and drum clutches, capstan, drum brake, and gear range lever. The winch must be oriented to accommodate overboarding equipment and proper cable fairleading. The unit weighs between 15,000 and 16,000 pounds depending on the powering option selected.

A diamond screw level wind with vertical and horizontal rollers is used to properly align the cable on the drum. The level wind position can be adjusted by a clutch. The cable passes over three horizontal sheaves arranged to measure tension hydraulically (0-10,000 lbs), speed (0-300 m/min), and meters out (0-99,999 m) locally at the winch on two large dials. No alarms are provided for operator warning of meters out to prevent two blocking of an instrument or paying all the cable off the drum.

likes hydraulics and will continue using it on other winches. The community appears to be split with a preference based upon experience of personnel and equipment available.

Level Winds. Conventional diamond screw level winds are used by all institutions except one who uses a Lebus Fleet Angle Compensation system. Most used Lebus grooving on the barrel of the drum. A few institutions have difficulties in orderly spooling of cable on the drum indicating problems in level wind design, set-up, or dimensional changes of the drum on the support structure due to overloading. One institution indicated level wind failures when deep casts were made continuously for periods up to a week or two. Special care must be taken in level wind design and locating winch relative to overboarding equipment to minimize load on sheaves and rollers. This will minimize fatigue on the cable and wear on level wind.

New Markey 5 Winch. (See Figure 2) The new Markey winch with a 75 hp electric hydraulic drive has a performance range as follows:

High Pull Range: 9000 lbs on drum barrel layer
5200 lbs at midscope layer
at 210 ft/minute.

High Speed Range: 5600 lbs on drum barrel layer
3200 lbs at midscope layer
at 340 ft/minute.

4. CHARACTERISTICS OF PRESENT INTERMEDIATE OCEANOGRAPHIC WINCHES

The essential features of the intermediate winches presently installed on board the ships operated by the oceanographic centers surveyed are hereafter summarized.

Cable. Most institutions have adopted a .322 inch diameter, double armored, electromechanical cable except Oregon State University which still uses the 0.225 diameter cable. Some use a single large conductor and others prefer a three conductor cable for redundancy. The old Markey hydro winches held 6000 m (10,000 ft) of .225 cable and the Northernlines held 7000 m (23,000 ft) of .322 cable. The new Markey winches will hold 10,000 m of .322 cable.

Winches. Six of the eight institutions surveyed have replaced or will soon replace their hydro winches with a new ONR/NSF funded Markey-5 winch. This winch can be ordered with either a 50 or 75 horsepower AC or DC electric motor with a two speed range gear box. The DC motor is SCR controlled for speed regulation. The AC motor drives a hydraulic pump which provides hydraulic power to the hydraulic motor on the gear box. Winch speed is regulated by controlling the hydraulic fluid flow. The older hydro winches were primarily manufactured by Markey, Northernline, or Western Gear with hydraulic drives. Markey also furnished some winches with a DC electric drive with a Ward Leonard speed control system. Some institutions prefer the hydraulic systems and have few problems, while others are converting old hydraulically driven winches to SCR control for ease of maintenance. Five of the eight institutions surveyed are either using electric drives or converting. The other three are buying or rebuilding winches with hydraulic drives. One of the institutions converting

Conclusions. Contacts with eight major oceanographic institutions have been made with users of cable lowered instrument packages, and marine and technical personnel. Their problems were discussed, the advantages of motion compensation were explained and the community interest noted. Future and new uses for a "smart" winch were investigated, and the interest of ONR in providing a better tool was disseminated throughout the UNOLS membership.

The response of the community to modern motion compensation varies from keen interest to enthusiastic support. Regulating the winch payout rate to force the instrument package to travel at a smooth, constant and preset rate would suppress causes of cable slackness followed by snap loads, would reduce tension peaks, would permit deeper and faster casts, would increase the operational weather window, and would yield better scientific data. In short, it would lead to a more efficient use of ship time.

In addition to making life easier, there appears to be a need for automatically locking a cable lowered instrument with certain constant surfaces within the water column. Feedback from the cable lower end would be used to force the instrument to follow, for example, isotherms, isobars, isopycnals, isohalines and isolumes.

These improvements would make instrument lowering operations easier and safer. They would result in a more efficient use of ship time. Capabilities for increasing the scope of present experiments and of conducting new ones were also discussed. For example:

- Study of fine scale structures. Because of the up-down motion of the package during conventional lowerings, present CTD instruments are measuring mixed water each time they record a sample thus losing data about fine scale variations. With a constant velocity lowering rate each scan of data would be independent from the others and the CTD could measure higher frequencies in salt and temperature variables.

- Remote control of instrument package position. Feedback from the lowered instrument to control its location in the water column could open interesting possibilities. With a digital input to the winch, the depth, the direction of motion and the speed of instrument lowering could be controlled by variations in the physical parameters being recorded and/or calculated. For instance, one could monitor the 15°C isotherm along a ship's track by yo-yoing the CTD between 14.5 and 15.5°C. This could also be done for density levels by using the calculated density and boundary values, thus permitting the study of internal waves. One could control the speed of the packages to obtain a better match between sensors with different response times in areas of high gradients. One could "fly" the instrument package at a fixed altitude above the sea bottom.

- Keyboard input to program a cast sequence would certainly increase the winch usefulness and versatility.

To meet any of these objectives, the system must be able to reduce the unwanted, sea induced motions of the payload to acceptable levels. The range of acceptable depth variations will vary from one application to another, but $\pm$ 0.5 meter could provide adequate data quality with existing CTD's.

With these design objectives in mind, it is worthwhile to first examine the various motion compensation alternatives.

Compensation Alternatives. Motion compensating handling systems for shipboard applications can be categorized in at least two different ways. The first is a mechanical classification that is descriptive of the basic hardware utilized as the primary compensating element:

- Ram Tensioners (the term tensioner is retained here since these units were first commonly used in tensioning applications).
- Bobbing Booms, and
- Controllable Winches.

The second category is a control law classification that is based upon the primary input signal used in the compensation strategy. The two major strategies are:

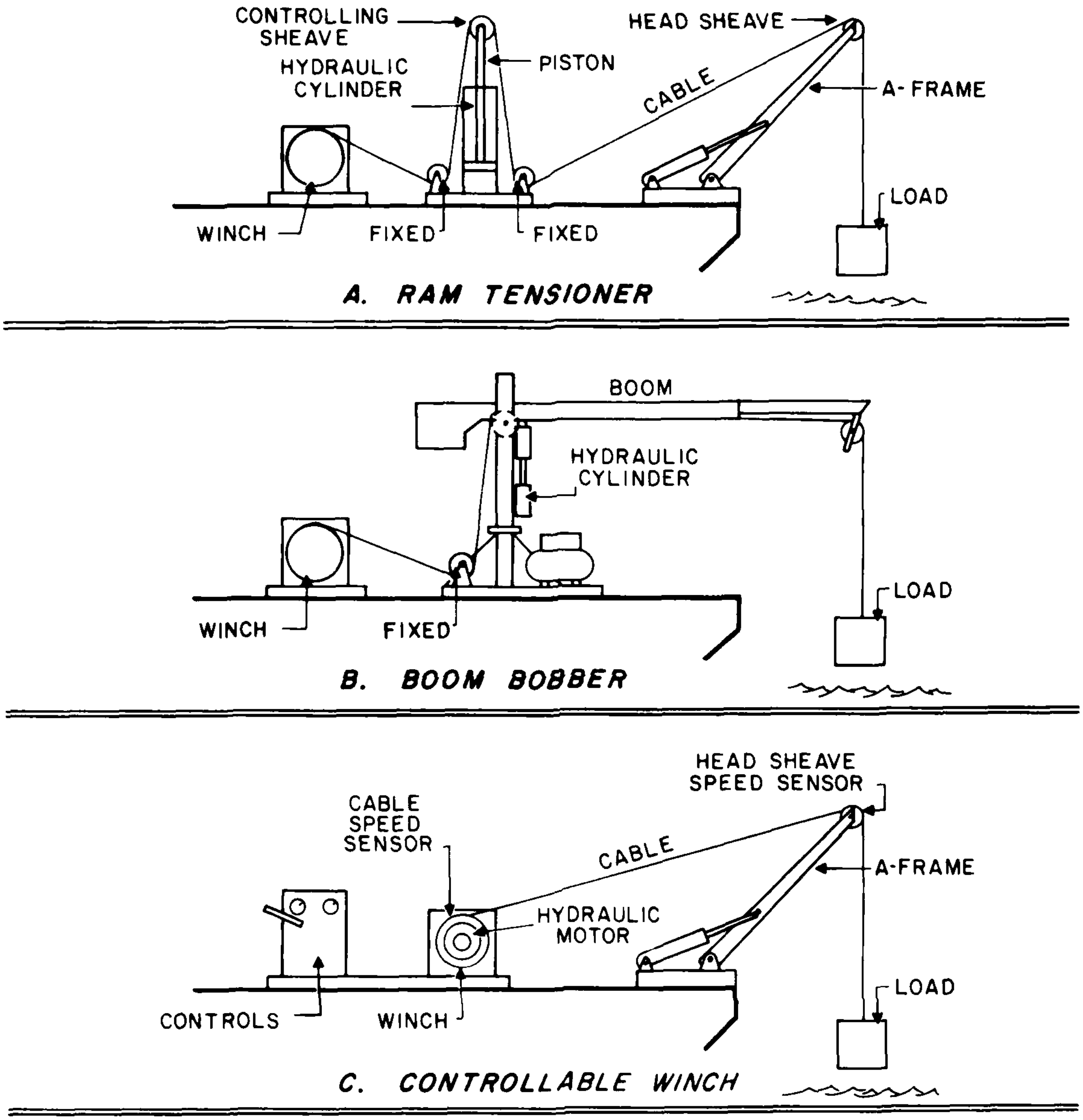
- Tension Activated, and
- Motion Activated.

This dual categorization leads to six distinct motion compensation techniques.

o	Tension Activated	Ram Tensioner
o	Tension Activated	Boom Bobber
o	Tension Activated	Controllable Winch
o	Motion Activated	Ram Tensioner
o	Motion Activated	Boom Bobber
o	Motion Activated	Controllable Winch

Two or more of these basic techniques can also be combined into more complicated systems where certain characteristics of each are desired. An example might be the high frequency response of a ram plus the larger amplitude capability of a controllable winch.

The three basic hardware approaches are shown schematically in Figure 3. In evaluating alternative hardware approaches, a number of parameters can be examined that will facilitate fair comparisons between approaches that differ significantly in their method of operation. These include total weight, deck space required, power consumption, complexity, cost, cable wear and fatigue during the compensation process, and frequency response. Most of these are fairly straight forward and self explanatory. Frequency response is an important control system parameter that is a complex function of several other parameters including torque available for control, effective inertia at the load, total system compliance and control actuator response. The effective inertia and system compliance define a natural frequency, above which it is difficult to achieve effective control response. The torque available is one



MOTION COMPENSATION HARDWARE ALTERNATIVES

Figure 3

measure of the limit on the rate at which the control can be applied to the system. The servocontrol activator can usually be chosen to have response characteristics above these other limits. The effective inertia of the system is an aggregate meaure of the inertias of all moving components reflected to a common point such as the drum or load. Reducing the effective inertia increases the natural resonant frequency and responds faster to limited applications of torque. Low effective system inertia is therefore one of the most important characteristics of the hardware that results in systems with better frequency response and wider overall band width.

The Ram Tensioner is a hydraulic cylinder with a sheave or sheaves attached at the end of the piston. The cylinder can be mounted in any orientation that permits the cable to be fair lead from the winch, around the ram sheaves and to the overboarding sheave. As the ram piston is extended the cable is hauled in at the overboarding sheave. Cable is payed out when the piston is retracted. By making multiple passes around the ram sheaves, the cable compensation amplitude can be several times the piston stroke. Ram tensioners have a relatively low effective inertia, however they have fixed maximum amplitude, and subject the cable to relatively high wear and fatigue.

The Boom Bobber is a cantilevered arm free to pivot at one end with an overboarding sheave fixed at the other end and a hydraulic cylinder located somewhere along its length to support the weight of the arm and the cable suspended payload. As the piston is extended or retracted, the overboarding sheave is raised and lowered respectively. Boom bobbers have a relatively high effective inertia due to the required mass of the moving boom structure and therefore have poor frequency response in servocontrolled applications. Like the ram tensioner, they also have limited compensation amplitude. With careful reeving, however, cable wear can be held to a minimum.

Controllable winches are mechanically the simplest of the three approaches since, presumably, a winch is required in the system for normal cable handling. Winches have medium to low effective inertia depending upon the particular design. Since the effective inertia of the drive motors at the winch drum is increased by the drive gear ratio squared, high speed motor drives generally have higher effective inertias than slower speed, direct drive motors. A major advantage of the controllable winch is that the amplitude of compensation is limited only by the length of the suspension cable. Cable wear with a compensating winch is moderate, when compared to the ram tensioner and the boom bobber.

Current literature tends to group motion compensation strategies as either "Active" or "Passive". This may be an unfortunate choice of terms. Active systems are thought of as ones that add energy while passive systems do not. Active systems are thought of as possessing feedback elements while passive systems do not. For these reasons, passive systems are considered to be inherently stable, but this may not always be the case. If a passive system has a spring-mass resonance near the peak of the ship motion spectrum, responses can grow uncontrollably.

Consider the following block diagram (Figure 4) for a system which monitors cable tensions and hauls in or pays out in proportion to the difference between measured tension and a preset desired tension (T_0).

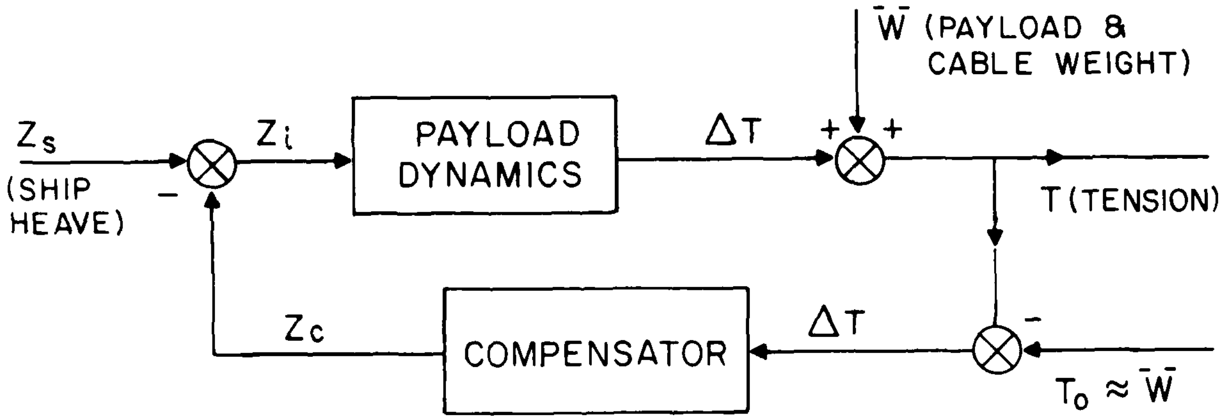
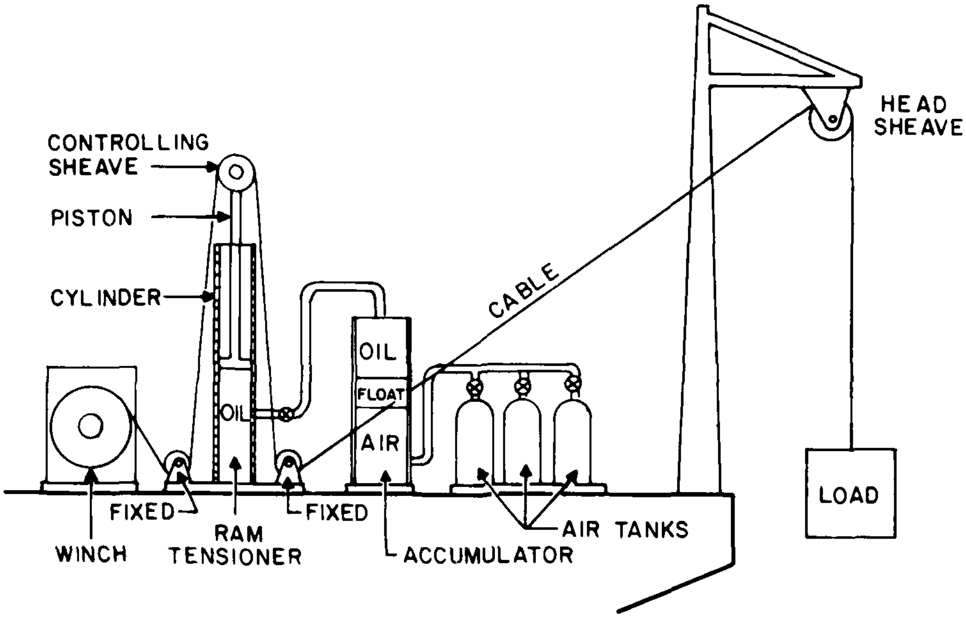

W̄ (PAYLOAD & CABLE WEIGHT)
Zs
(SHIP HEAVE)
–
Zi
PAYLOAD DYNAMICS
ΔT
+
+
T (TENSION)
Zc
COMPENSATOR
ΔT
–
To ≈ W̄

Figure 4

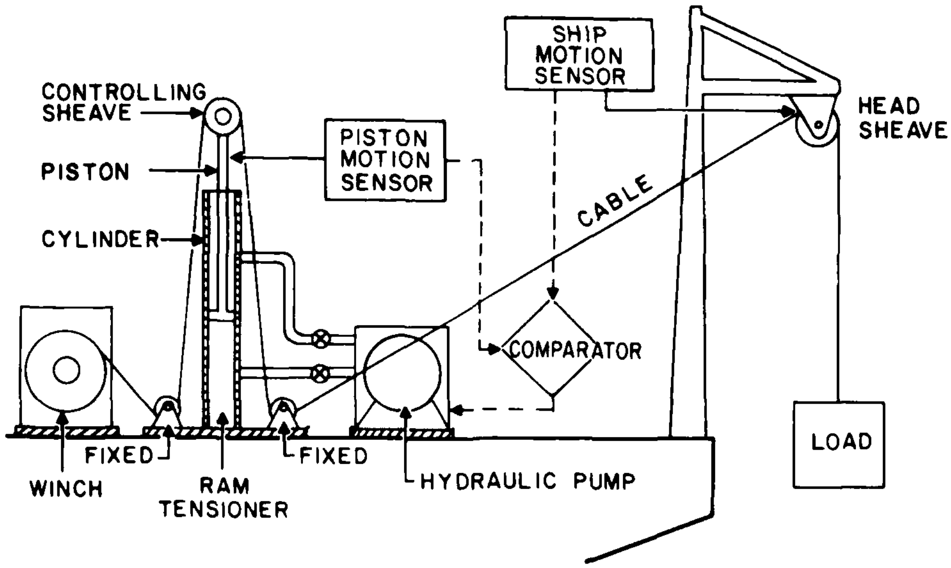
A variety of complex feedback strategies could be proposed but a simple proportional arrangement meets the requirements of this example. It contains all of the elements one would expect to find in an active system. It is, however, the block diagram of an overboarding sheave suspended on a spring. Other systems which are basically classified as passive, such as boom bobbers, often contain rather complex servo-control systems to maintain nominal tension bias to compensate for a changing suspended load such as increasing cable length. For these reasons, the more appropriate and less ambiguous grouping of "Tension Activated" and "Motion Activated" compensation system is proposed here.

A third category must also be considered. These are "Tension-limiting" devices such as shock absorbers and slip clutches. They are, however, probably best categorized as a subset of Tension activated devices although they do little or nothing during normal operations and only begin to function during overload conditions to serve, much in the capacity of an electrical fuse, to prevent the cable from breaking under excessive overloads.

Tension activated systems respond to changes in wire rope tension by hauling in or paying out the line in such a manner as to reduce these loads. The most common examples of this type of system are boom bobbers and ram tensioners supported by hydraulic accumulators (Figure 5.a). There are some basic characteristics associated with tension activated systems. They exhibit an effective spring constant which is in series with the spring-mass system of the cable and payload. In order to minimize the change in tension for a given ship displacement, this effective spring constant must be relatively low. The



5a TENSION ACTIVATED RAM TENSIONER (PASSIVE)



5b MOTION ACTIVATED RAM TENSIONER (ACTIVE)

Figure 5

natural frequency of the cable-payload system is generally above the significant heave spectrum of the ships, except for very deep casts. The addition of another spring often aggravates the problem by moving the system's natural resonant frequency nearer to the ship's heave frequency. The solution to this dilemma is to provide some damping (a natural by-product of hydraulic oil moving through piping and accumulators) and to soften the spring sufficiently to lower the natural frequency below the ship's range of significant heave energy. The resulting soft spring constant provides poor position control, since small changes in tension result in large displacements.

Tension activated systems actually do very little to directly control the position of the payload. Some researchers have experienced reductions in motion of payloads with properly tuned tension activated systems, but this was primarily due to damping and a shift in the systems natural resonance away from the predominant frequency of the ship motion energy. The primary function of tension activated systems is to reduce the magnitude of tension fluctuations in the suspension cable. For this purpose, they are relatively effective.

Motion activated systems, on the other hand, deal with the problem at its source. If the upper end of the suspension cable can be held stationary in inertial space, the unwanted energy cannot be transmitted to the payload. This point is particularly well made by Clifford L. Trump in his paper, "Effects of Ship's Roll on the Quality of Precision CTD Data" (Reference 1). Motion activated systems, however, do not utilize the rather easily monitored tension input. Measurement of the vertical motion of the suspension point requires elaborate instrumentation. For this reason, motion activated systems generally have more complex servocontrol elements and multiple feedback loops. System stability becomes more of a concern when high gains are used to provide the required frequency response and accuracy.

Evaluation of Alternatives. The ability of the two basic control strategies to meet the three main system objectives is summarized in the table below.

TABLE II

	Tension Activated	Motion Activated
Minimize Tension Fluctuations	Good	Good
Maintain Desired Position	Poor	Good
Meet Logistic Constraints	Acceptable	Acceptable

It is assumed that both strategies can be designed to meet the ship capabilities and the logistic constraints, although neither stands out particularly over the other in this area. Both strategies will effectively minimize tension fluctuations, but only motion activated systems will effectively control the position of the payload. For this reason, it is felt that only motion activated systems should be pursued in this effort.

There are three basic hardware implementations of the motion activated control strategy: It appears that any of the approaches could be designed to meet the three basic objectives. Examination of specific constraints and other system measures of effectiveness is necessary to identify a preferred approach. A general, qualitative rating is provided for each alternative as it relates to specific performance criteria (Table III).

Of the three, the controllable winch exhibits advantages in several areas. The low space and weight requirements, the unlimited compensation amplitude and good potential for profiling applications combined with the least overall system complexity make it the most attractive alternative.

The boom bobber appears to be the least attractive of the three. The high weight and deck space requirements, low frequency response, limited stroke and its inability to perform profiling applications without additional winch controls practically rule it out as a viable alternative for CTD handling systems. The boom bobber is really best suited in the tension activated systems where its high inertia coupled with a soft pneumatic spring can effectively isolate the suspended load from extreme tension fluctuations.

The ram tensioner (Figure 5-b), although not as attractive or as versatile as the controllable winch, appears to exhibit some noteworthy features. Although stroke limited like the boom bobber, it only adds slightly to the space and weight requirements of the winch alone. As a result of its low effective inertia, it has the highest frequency response potential of the three control elements. To meet the profiling and programmed cast requirements would require a dual control of the winch and the ram. Ship motion could be eliminated at the ram and the slower profiling requirements could be accommo-

TABLE III

Rating of motion compensation alternatives.

SYSTEM PERFORMANCE CRITERIA	RAM TENSIONER	BOOM BOBBER	CONTROLLABLE WINCH
Total Weight	Moderate	High	Low
Deck Space	Moderate	High	Low
Power Required	Average	Average	Average
Frequency Response	High	Low	Moderate
Compensation Amplitued	Limited	Limited	Unlimited
Cable Wear & Fatigue	High	Low	Moderate
Profiling Capacity	Poor	Poor	Good
System Complexity	High	High	Moderate
System Cost	High	High	Moderate

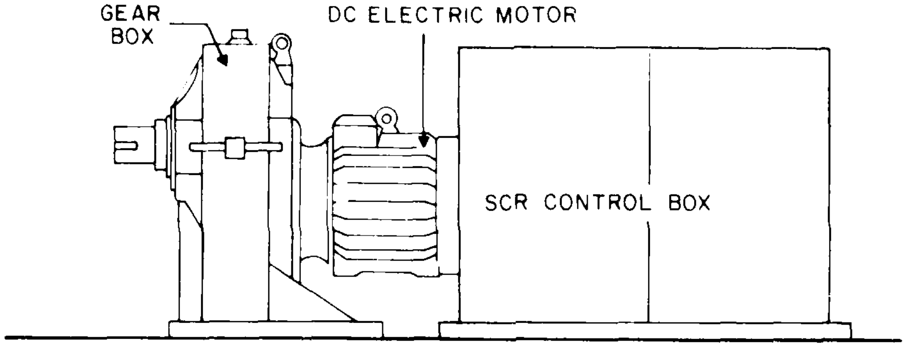
dated by a relatively simple winch control. However, the added complexity and the additional cable wear associated with the multiple moving sheaves make this approach less attractive than the controllable winch alone.

To conclude, the design options which could provide motion compensation and servocontrolled profiling within the requirements envelope previously defined appear to be, in order of preference:

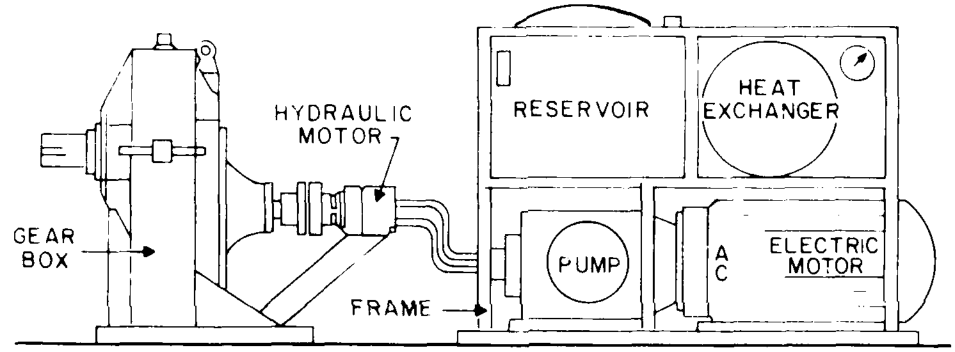
1. New winch, specifically designed for motion activated controllability (both wave action and instrument feedback).
2. Existing winch, modified (power and controls) for motion controllability as above.
3. Existing winch, modified for servocontrolled profiling, augmented by a motion controllable (active) ram device.

Winch Drive Options. The three drive options commonly encountered on shipboard installed winches are depicted in Figure 6. These options are:

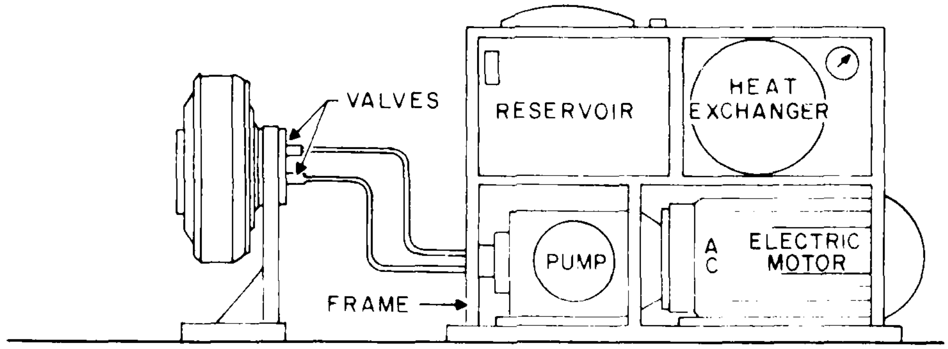
- o Electric motor and gear box.
- o Hydrostatic transmission with a high speed hydraulic motor and gear box.
- o Hydrostatic transmission with a low speed high torque hydraulic motor for direct drive.



ELECTRIC MOTOR WITH GEAR BOX



HIGH SPEED HYDRAULIC MOTOR WITH GEAR BOX & HYDROSTATIC TRANSMISSION



LOW SPEED HIGH TORQUE HYDRAULIC MOTOR & HYDROSTATIC TRANSMISSION

Figure 6

capability throughout the water column. When used with the motion compensation option - as the case should be most of the time - the signals from the cable lower end shall be superimposed on the basic motion reduction signals to provide an integrated system command. Components of the remote control option include:

- Keyboard computer input terminal.
- Microcomputer with storage device (floppy disk).
- Software package to allow operator input.
- Electronic interface for remote signal processing and integration into winch control system.

Remote sensors (pressure, conductivity, temperature, light etc....) are not part of this specification.

(e) Guard Length. If activated this control option shall automatically interrupt any and all automatic functions - except two blocking prevention - and immediately restore manual control as soon as the cable end reaches and/or remains in a prescribed "guarded" depth range. The guard length should be continuously adjustable from 10 to 100 meters. A provision shall be made for the winch to automatically slow down when the package reaches the guard length. If not activated, manual control shall be automatically restored when the package is 10 meters from the head sheave. In all cases manual control shall prevail as long as the package remains within 10 meters from the head sheave.

- Computer keyboard to input desired compensated rate of profiling instrument travel (0 to $\pm$ 2 meters/sec).
- Electronics package to read, condition, compare, amplify sensor signals and provide required control voltage to pump servo strokers.

(c) Keyboard Input. When in the keyboard input mode the line payout (or hoist) is automatically program controlled. Typical keyboard input shall consist in a series of lowering and hauling commands specifying number and depth of stops, time at stops, and speed of lowering of hauling between stops.

Depth shall be sensed either by length of cable out, or by pressure measurements from the lowered instrument. The keyboard input control mode shall be available with or without motion compensation.

As a minimum the components of the keyboard input control unit should include:

- Line speed sensors.
- Line out (meters out) sensors.
- Computer keyboard for program input.
- Electronics package to read, condition, compare speed and depth signals with programmed input and provide control voltage to pump servo strokers and/or brake as appropriate.

(d) Remote Feedback. The remote feedback control option enables the winch to be controlled by measurements made at the remote end of the cable. This control option shall provide a station keeping and/or a tracking exercise the desired options. The manual control station located near the winch will enable the winch manual control, and the guard length and two blocking preventer options. The remote control station, located below deck in a sheltered environment, will enable the automatic control of the winch.

7.4.1 Control Options.

(a) Manual Control. When in the manual control mode, the winch is solely controlled by the operator. When activated, the manual control mode immediately overrides any and all automatic control modes, except two blocking prevention. Manual control will be exercised with the help of a lever. Pushing the lever away from the operator should result in line payout. Pulling in should result in line retrieval. Speed of line payout and hauling should be linearly proportional to the displacement from the neutral position. Upon hand release the lever should automatically return to neutral.

(b) Motion Compensation. When in the motion compensation mode the line speed is constantly and automatically adjusted to provide a smooth and constant rate of instrument travel. The prime objective of the motion compensation control unit is to identify the vertical component of motion of the overboarding sheave and to provide a suitable command to the winch to cancel this motion. As a minimum the components of the motion compensation unit should include:

- Head sheave motion sensors.
- Line speed sensors.

the pressures on the hydraulic input ports and applying a slight positive pressure to the motor case, the drive pistons can be fully retracted from the cam ring, presenting no resistance to the free wheeling of the winch drum.

An alternative to this complete free wheeling is the possibility of recirculating the oil within the motor by opening a path across the hydrostatic loop. This approach will not permit payout speeds as high as the complete free wheeling technique, although the load can be reacquired by the hydrostatic transmission without the need to bring the load to a complete halt with the brake. Both methods have been used effectively in a variety of winch applications.

7.3.6 Slip Rings. A slip ring assembly with a minimum of two circuits shall be provided to provide continuity between the EM cable and the data terminal.

7.3.7 Automatic Level Wind. The automatic level wind shall provide a travel rate of the fair lead which accurately matches the Lebus shell groove pitch. Provisions should be made for fair lead occasional repositioning and for the possibility of adjusting the fair lead timing for cable diameters other than 0.322 in.

7.4 Control Requirements.

Winch operators should have the following control options available: manual only, automatic motion compensation, keyboard input, remote feedback, guard length, and two blocking preventer. Two control stations shall be provided to

7.3.3 Winch Construction. The winch shall be of steel construction, designed for heavy duty and long life. Bearings should be antifriction and sealed. The frame, of welded construction, shall support the winch components. The frame should be free of pockets where water can collect. Lifting eyes an hold down bolt sockets should be provided. All exterior surfaces should be sandblasted, coated with inorganic zinc, and top coat painted.

7.3.4 Brakes. The winch should have automatic and manual brakes.

Automatic Brake. An electrically or hydraulically released brake should be provided to stop the winch drum. The brake shall automatically release when the manual control is off neutral position or when automatic control is active. The brake shall set automatically when the manual control is returned to neutral, when the automatic control stops, when alarms, guard length, and stop options (two blocking preventer) are actuated, or whenever a loss of electrical or hydraulic power occurs.

Manual Brake. The winch shall be equipped with a separate manually operated heavy duty lined band brake or pawl.

Brake Holding Power. Both manual and automatic brakes should be capable of maintaining 150 percent of rated load on a full drum without slippage.

7.3.5 Free Wheeling. An inherent feature of the low speed, high torque hydraulic motor design is the ability to easily free wheel the winch drum without the need for bulky or costly clutching mechanisms. By reducing

Line Speed. The required maximum line speed is $\pm$ 16 ft/sec ($\pm$5 meters/second). It should be continuously and smoothly adjustable in both directions.

Acceleration. The winch should be capable of providing at least 0.3 g acceleration at any layer and load, up to a maximum load herein specified.

Rated Load. At mid-drum layer (5000 meters out) the winch should pull a rated load of 5000 lbs. This load represents the weight of the cable and attached payload, combined with hydrodynamic drag. The winch should be capable of producing the rated pull at all speeds up to the specified maximum speed. It should be capable of producing 150 percent of the rated load at speeds less than the maximum speed. The Duty winch should be capable of both intermittent and continuous operation up to 72 hours without overheating or component degradation.

7.3.2 Drum. The drum shall have a holding capacity for 10,000 meters of 0.322 in. diameter EM cable. At least one inch of flange shall remain uncovered with 10,000 meters of cable spooled on the drum. The drum core and flanges shall have sufficient strength to safely withstand the pressure forces due to cable tension. Provisions should be made for easy connection of the inner wrap to the slip ring assembly. The full drum shall be readily removable from the winch. The drum should be fitted with a Lebus grooved shell, with pitch to suit the 0.32 in. diameter cable. The shell should be removable to allow replacement with shells pitched for other cable diameters. Drum barrel to be 18 inches in diameter.

The hydrostatic transmission is an effective approach in winch applications, since the swashplate control loop is substantially de-coupled from the hook load, resulting in control systems that are robust in the sense that their resonant characteristics are insensitive to load.

7.2.3 Low Speed High Torque (LSHT) Motor. Standard low speed high torque, direct drive, hydraulic winch motors such as the Hagglund 43 series have the required torque and speed to meet the requirements of the servocontrolled winch (paragraph 7.3.1).

Inasmuch as retrofitting the Markey 5 winches is desirable, at least two drive approaches should be considered.

The first is to replace the existing gear-box and motor with the direct drive LSHT motor. The LSHT motor will be connected to the winch input power shaft with the help of a standard motor-to-shaft adaptor set. The existing winch clutch and drum release mechanism will still be usable as is.

The second option is to direct drive the free end of the drum, and relocate the slip rings. In this option the existing Markey winch drive components could be used as a back-up.

7.3 Winch Requirements

7.3.1 Winch Performance.

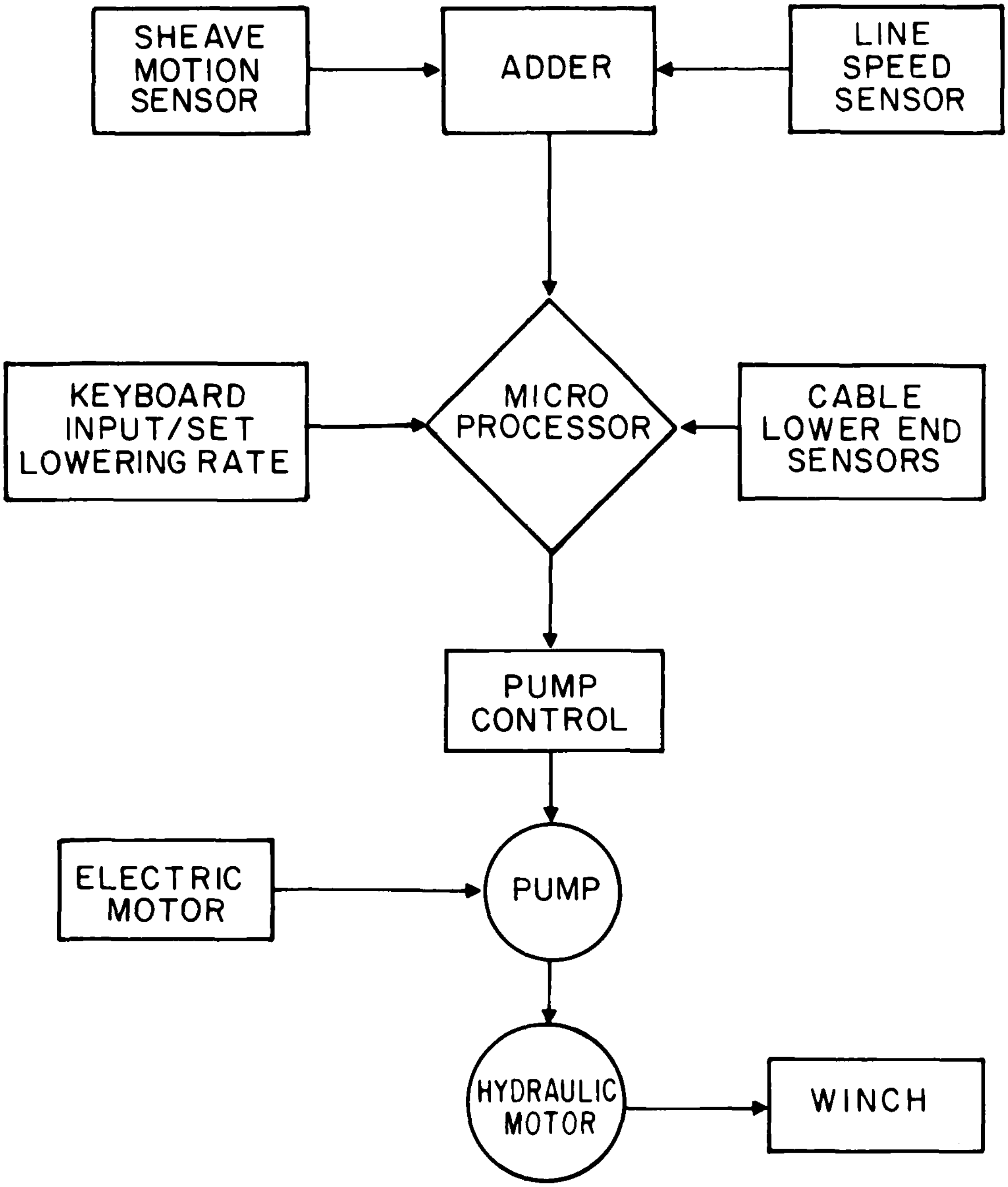
7.1.4 Power. The winch shall operate on ship's power, 440 VAC, 60 Hertz, three phase.

7.1.5 Weight and Deck Space Requirements. The winch weight should not exceed 6000 kgs (13,200 lbs), including the weight of the stored cable and the weight of the hydraulic motor. The power unit weight should be less than 5000 kgs (11,000 lbs). Maximum clear deck space required is 3 x 4 meters for the winch and 3 x 2 meters for the power supply located within 10 meters from the winch.

7.2 Electro-Hydraulic Drive Requirements

7.2.1 Electrical Motor. A 150 horsepower, 1800 rpm, squirrel cage, electric motor will be used as prime mover for the winch system. The motor will operate on 440 VAC, 60 Hertz, three phase ship's power.

7.2.2 Hydrostatic Pump. The hydraulic power required by the winch will be provided by one or more variable displacement, axial piston, hydraulic pumps like the series 20 Sundstrand pumps. These can be connected directly to the winch in a closed hydrostatic loop so that winch speed is directly controlled by the pump swashplate angle. The swashplate angle, in turn, can be electronically positioned by a servo valve like the Moog series 63 pump stroker.



SERVOCONTROLLED WINCH - WORKING PRINCIPLE

Figure 8

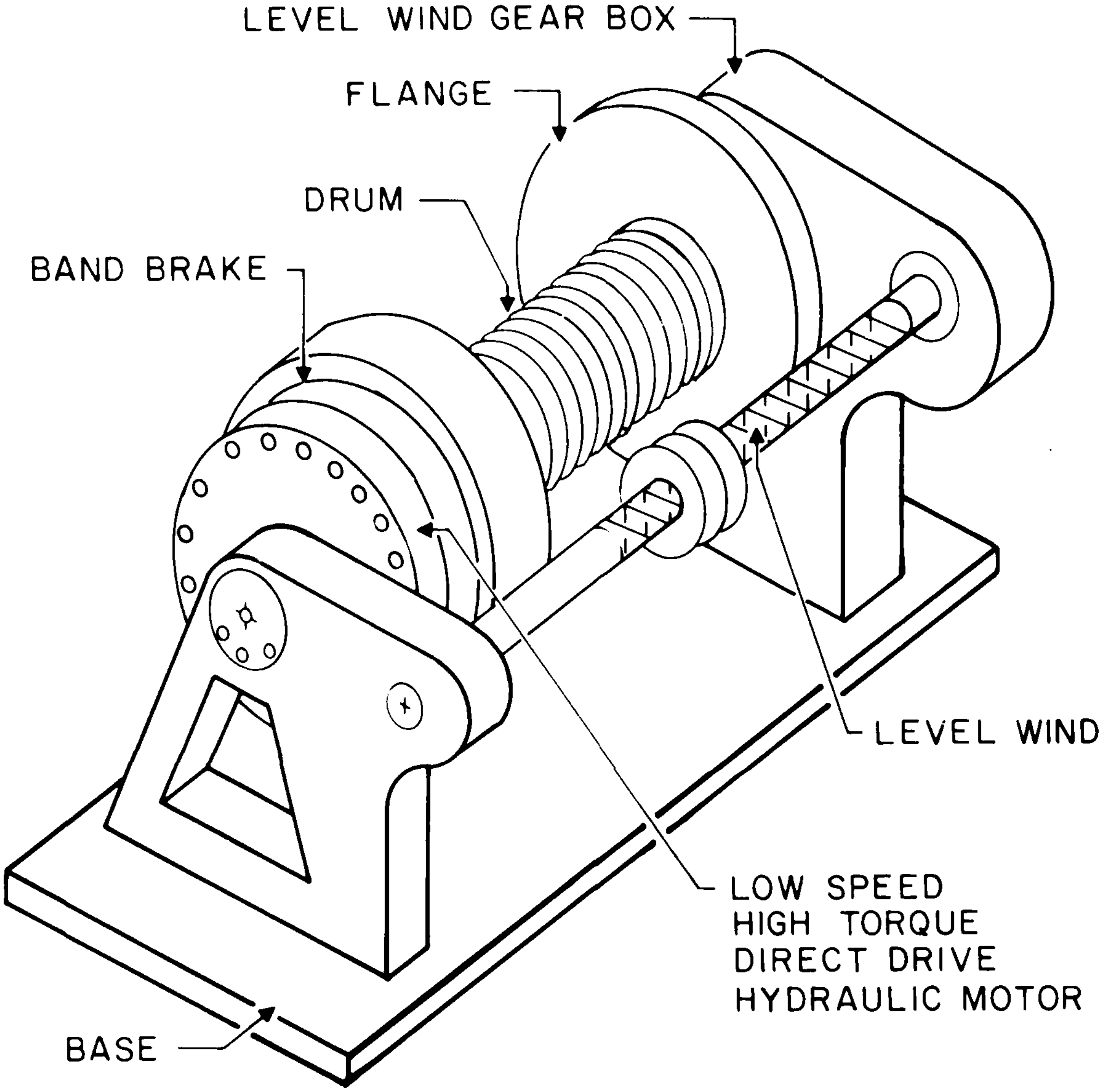
7.1.2 <u>Working Principles.</u> By controlled rotation of the drum, the winch will automatically decouple the lowered instrumentation from wave induced ship motion. To achieve this goal a desired lowering rate, commensurate with the prevailing sea state and the intrinsic compensation/power limits of the winch will be selected by the operator.

Shipboard sensors will detect/compute the actual motion of the outboard lowering sheave with respect to an inertial frame of reference. Sensors will also monitor the instantaneous rate of cable payout (line speed). Sheave motion and payout rate will then be computer added and compared to the preset lowering rate. The error will then be used as feedback to control the output of the variable displacement pump, increasing, stopping or reversing the flow of oil to the hydraulic motor as required.

In addition to compensating for wave induced motion, the winch will also be controllable by keyboard program input and by measurements made at the cable lowered end. A manual override feature will permit instantaneous interruption of all automated controls, and will restore immediate manual operator control.

A schematic representation of the working principles is shown in Figure 8.

7.1.3 <u>Environmental Conditions</u>. The winch must be designed and constructed for installation on the weather deck of oceanographic vessels, normally unprotected from the marine environment. Components shall not become inoperative due to corrosion and/or exposure to freezing temperatures.



WINCH ASSEMBLY

Figure 7

7. IMPROVED WINCH SPECIFICATIONS

Preliminary components and performance specifications for an improved, retrofittable, single drum winch with fully automated motion compensation and servocontrolled profiling options are hereafter outlined.

7.1 General

7.1.1 Winch Description. A motion controllable, electro-hydraulically driven winch is retained as the best practical option.

The winch system is made of three distinct parts: the power unit, the winch, and the winch controls. The power unit includes the electrical motor (prime mover), the variable discplacement, axial piston, pump(s), and the hydraulic support components: reservoir, filters, valves, heat exchangers, etc. All components of the power unit will be assembled on one single frame.

Winch components include winch base, low speed high torque hydraulic motor drum, shaft and bearings, brakes, level wind and slip rings. The hydraulic motor will be directly attached to the drum and assembled on one single frame with the other winch components adjacent to the power unit (Figure 7).

Winch controls include motion and cable payout sensors. winch status monitoring sensors, command selectors, microprocessor, hydraulic servo-controls, alarms, and displays of monitored parameters.

This option results in a compact, easily controllable, highly efficient energy transferring system that allows a large degree of freedom of components assembly and good operating flexibility.

Hydraulic transmissions can be driven by a diesel or electric motor. Since most ships can provide the electric power required, using an electric motor as the prime mover appears to be simpler and more practical.

Performance criteria specific to a servocontrolled motion compensation winch include:

- o Ability to reverse direction of rotation easily and continuously.
- o Stepless smooth speed control.
- o Wide speed range.
- o Good low speed response.
- o Good starting performance under load.
- o Ability to hold a load stationary for periods of time without damage to the drive system.
- o Fast response to control input, i.e. low inertia.
- o Ability to automatically limit torque.
- o Allow the prime mover to operate at constant rotational speed in one direction while providing a bi-directional, continuously variable output.
- o High overall efficiency.

When examining these performance criteria, a hydraulic hydrostatic transmission driven by an electric motor and powering a low speed high torque hydraulic motor appears to be the optimum winch drive. This drive system would be free of gear train, which reduces inertia and increases efficiency.

(f) Two Blocking Preventer. This control option prevents the instrument package from hitting or "two blocking" the head sheave during retrieval and possible deployment operations. When activated this control option shall automatically stop the winch whenever the package reaches a distance of one meter away from the outboarding sheave. The automatic brake should be then engaged. It shall disengage only if cable payout is resumed.

7.4.2 Control Stations.

(a) Manual Control Station. The manual control station is located near the winch. It shall provide shelter and protection for the operator, and a clear, unobstructed view of the winch and the overboarding sheave. The control station shall house such switches, readouts, controls and electronic circuitry for complete manual control of the winch and for exercising the two blocking preventer and the guard length control options. As a minimum the following features shall be included.

Manual/Automatic Switch. This switch controls whether the winch shall operate in a manual mode or an automatic mode outside of the guard length.

Winch On/Off Switch. This switch shall start/stop the electric motor, provided the control lever is in neutral and the manual/automatic switch is in the manual position.

Control Lever. This shall permit the manual operation of the winch as previously described and provided the manual/automatic switch is in the manual mode.

Guard Length Switch. The guard length shall be set with the help of a dial knob. It shall be actuated by an on/off switch.

Two Blocking Preventer, On/Off Switch. This switch will engage/disengage the two blocking prevention option previously described.

Readouts.

- Line out. This readout shall display, in meters, the total amount of cable payed out. Resolution shall be to the nearest meter. A zero reset shall be provided.
- Line speed. This readout shall display, in meters/minute, the rate of line payout or retrieval. Resolution shall be to the nearest meter/minute. An indication of cable travel direction (in or out) should be provided.
- Line tension. Line tension shall be measured and displayed in pounds. Tension range shall be from 0 to 10,000 lbs. Accuracy shall be 1% of full scale. A zero reset shall be provided.

All readouts shall be digital. Displays should easily be readable in daylight or night. Digits shall be no less than one inch in size.

Alarms. Visual and audible alarms shall be provided at the control station to alert the operator to the following conditions:

o Only 20 wraps are left on the drum. This should also restore manual control.

o The instrument is a 100 meters from the surface and coming up.

o The instrument is at 10 meters from the surface and coming up. This should restore manual control.

o Tension reaches a preset level.

(b) Remote Control Station. The remote control station is located below decks, in a sheltered environment. It shall house such switches, controls, keyboard, processors, and electronics as necessary to permit remote/automatic control of the winch when and only when the manual/automatic switch of the manual control station panel is on the automatic position.

Selection of control options previously described and modes of operation should be entered by computer interactive mode, with keyboard input and screen display. A highly visible indicator should be turned on whenever the winch is under automatic control.

A manual operation switch should be provided to pass winch control back to manual. When switched back to manual, the winch control lever shall automatically be rest to neutral thus causing the automatic brake to engage.

Thereafter manual control will resume. The remote control station shall be equipped with readouts and alarms similar to those found in the winch manual control station.

8. DEVELOPMENT PLAN.

The plan for developing the improved winch system previously described, follows the traditional engineering management steps of analysis, design, procurement, assembly, tests, demonstration, documentation and transfer of the finished prototype. The development effort is anticipated to span two years.

Development Plan.

Analysis. Analyses with a bearing on components and subsystem design must be performed at the very start of the winch prototype development program. This analytical effort should focus on the following topics:

- Ship Dynamics. Using a linear (or linearized) model, establish the response spectrum of the head sheave motion for different sea ways and location of sheave. Make statistical predictions of averages such as mean, RMS, significant ... and of expected maxima.

- Cable dynamics. Use the results of the ship dynamics analysis to investigate with the help of a linearized payload/cable mode, the frequency response of the payload. Determine natural and damped periods of system oscillations. Make statistical predictions of averages and maxima.

- Motion compensation. Use results of the ship and cable dynamic analyses as a basis to quantify the upper and lower limits of motion compensation (no more, no less than....), and thus to firm down the power requirements.

- Control analysis. This analysis will address the crucial question of how to use the signals from remote and shipboard mounted sensors to best control the winch. Topics relevant to this analysis include sensor/selection and comparison, feedback and control options, gain, phase, frequency response of candidate control systems, development of software and algorithms, considerations on deadband, drift, hunt and fail-safe operation and finally writing a general specification for the required control system.

<u>Design</u>. The design phase consists of the rational selection of system components based on analytical results and program overall objectives. Retrofitting being an important option, winch power and control components should be designed to properly interface with a basic Markey-5 winch. The design phase should end with mechanical drawings, electrical schematics, and detailed specifications as necessary to fabricate/procure all basic system components.

<u>Procurement and Fabrication</u>. Following the design phase, commercially available components should be procured. These include the electrical motor and starting circuitry, the hydraulic hydrostatic transmission, the low seed high torque hydraulic motor, the basic Markey-5 winch and certain electronic components such as sheave motion and line speed sensors, microprocessor, servo amplifiers etc... The fabrication of mechanical and electronic components which need to be modified, adapted or built from scratch should also take place at this time.

<u>Assembly</u>. The three major subsystems: power transmission unit, winch and controls should be shipped to a central location for system assembly and land based testing. The electric motor should be aligned and frame mounted on the

hydraulic hydrostatic transmission frame, probably best done by the supplier of the power transmission unit. The hydraulic motor should be coupled to the winch and hydraulically connected to the hydrostatic transmission unit. Both manual and remote control stations should be assembled and wired to their respective input/output terminals.

Testing. A detailed and progressive test outline should be written as winch assembly proceeds. Some of the projected tests will best be done in the laboratory, prior to ship installation of the winch system. Included in this category is the evaluation of most, if not all, control options. The actual vertical motion of a sheave moving sinusoidally on a circular arc could be sensed and used to control the direction and rate of rotation of winch drum. This could be repeated over a representative frequency band. The actual motion compensation response of the winch system to sinusoidal input could thus be measured and optimized. Remote sensor and keyboard input capabilities should also be evaluated with and without ship motion compensation. Performance of winch status monitoring sensors (line speed, line out, line tension) and disbplays, of guard length sensors, of alarms, of two blocking preventer, of automatic brake and fail-safe features should also be tested in the lab. After satisfactory system lab tests, the winch should be disassembled, shipped, and installed on board an oceanographic vessel.

Demonstration. Winch acceptance tests and actual performance evaluation and demonstration should be performed at sea. Most of the winch mechanical acceptance tests do not involve long lengths of cable, and therefore they could be conducted in relatively shallow, protected waters. These tests could include: line speed tests, no load tests, rated load tests, overload test, brake tests, alarms and two blocking tests.

Two offshore, deep water trials should be contemplated, with time allowed between the two for system debugging and improvement. The purpose of these sea trials would be to verify the proper operation of the winch system under actual conditions of use and to demonstrate its capabilities. Instrumentation and techniques previously developed could be used to obtain pressure and tension records from a special CTD instrument package (Reference #3). Records would be obtained in both the compensated (controlled) and the non-compensated modes of winch operation. Pressure records would evidence the reduction of instrument vertical excursions when keeping station and the degree of steadiness in lowering and hauling speeds. Tension records obtained at the cable lower end should show the suppression of cable slackness and snap loads.

The tension at the sheave should also be monitored. Measurements of sheave vertical speed and cable line speed would be readily available from the control system instrumentation. The tension record should reveal how effective speed regulation is in suppressing the peak loads introduced by dynamic effects. Sheave speed and line speed measurements would be helpful in assessing the overall system response.

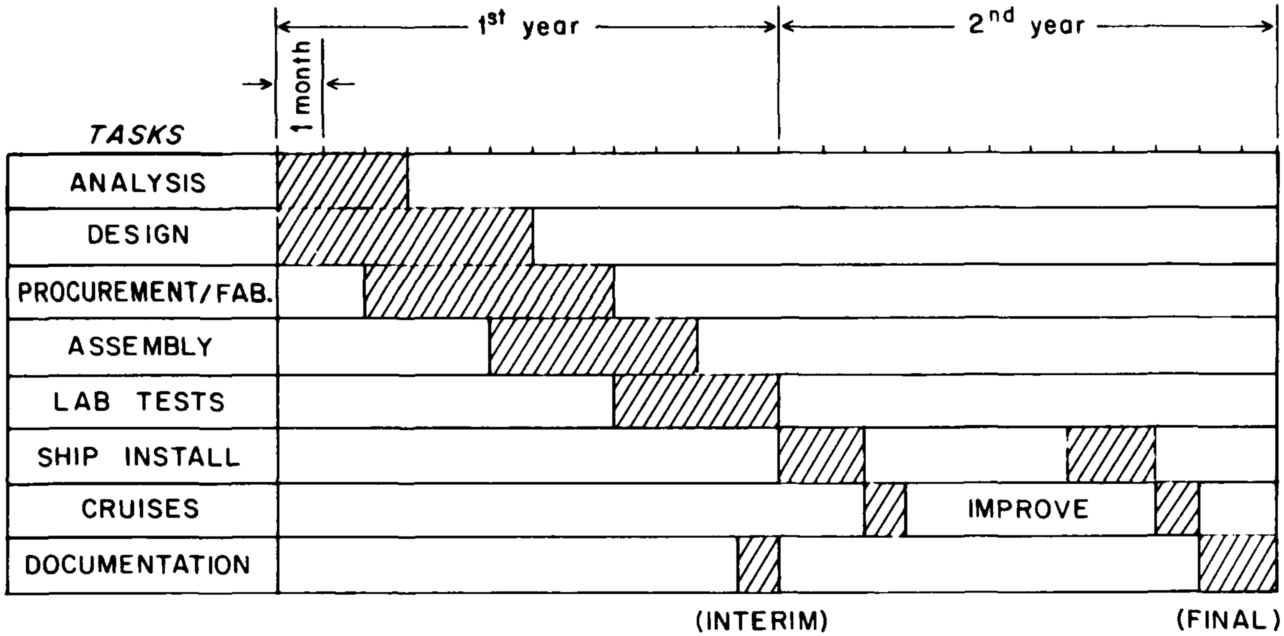
Response of the system to keyboard inputs and in the programmed mode should also be tested. Control of the system in response to pressure measurements taken at the CTD end should be fully evaluated.

Documentation/Transfer. Data obtained from the trials at sea should be processed and studied. A formal paper, describing the winch system and its performance at sea could be written and published in an oceanographic journal.

The winch system should be fully documented with operational manuals, blueprints, hydraulic and electrical schematics.

At the end of the two years development program the winch could be assigned to a UNOLS research vessel and its use shared by a group of users (NECOR for example) on a time/availability basis. Alternatively the winch could be transferred to an operational group actively involved in the acquisition of profiling data such as the CTD group of the Woods Hole Oceanographic Institution. In either case, the engineers/technicians who would operate/maintain the servocontrolled winch system in the long run should be incorporated in the development program at an early stage.

Schedule. A two year schedule for the development plan is shown in Figure 9.



SERVOCONTROLLED WINCH DEVELOPMENT SCHEDULE

Figure 9

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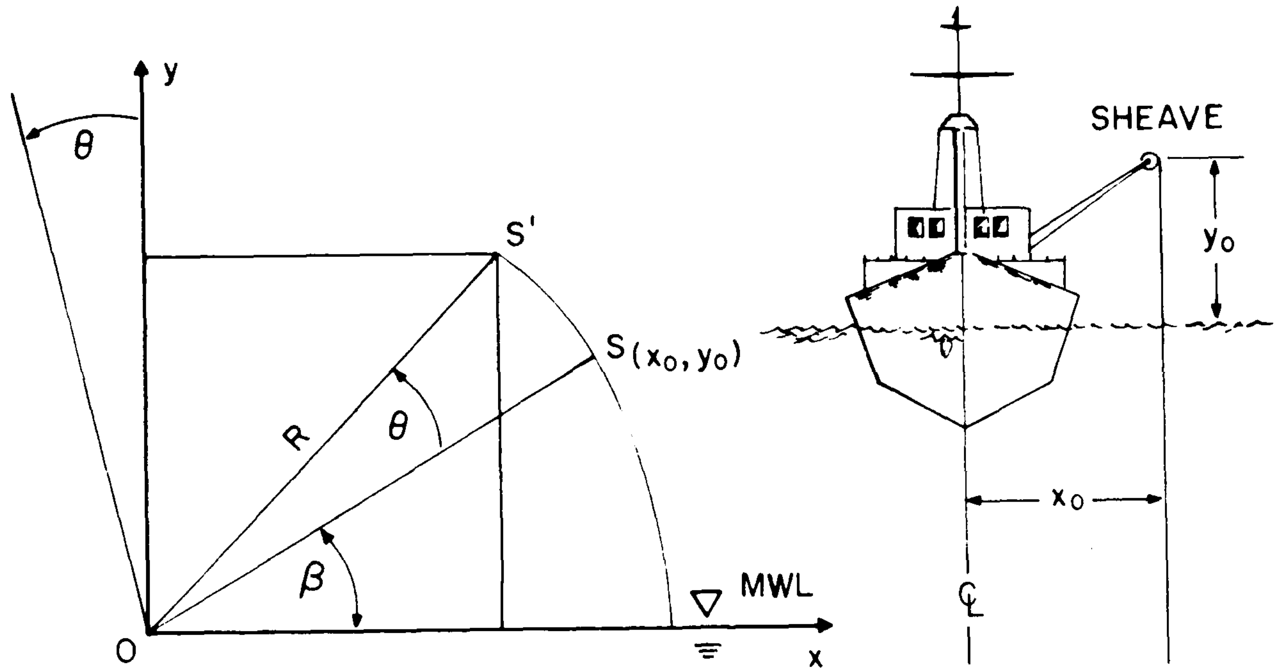
APPENDIX A

Title: Heave and Roll Induced Sheave Vertical Displacement and Speed

1. ROLL



Considering Roll Only (no heave)...)

Say 0 = Center of roll.

assumed to be at intersection of ship ℄ and plane of calm water (MWL = mean water line).

S = Position of sheave when ship is on an even keel.

coordinates of S are X_o (ft)

and Y_o (ft)

OS = Distance from center of roll to sheave

$$OS = R = \sqrt{X_o^2 + Y_o^2} \quad \text{(ft)}$$

θ = Angle of roll, positive as shown.

$$\theta = \theta_o \sin \frac{2\pi t}{T} \qquad (1)$$

T = period of roll (sec)

θ_o = roll amplitude

Using equation (1) yields the initial condition

$$\theta = 0 \qquad t = 0$$

The fixed angle β is given by

$$\beta = \tan^{-1}\frac{y_o}{x_o}$$

As the ship rolls the point S moves to S'.

The vertical distance y from the sheave to the water is then

$$y = R\sin(\beta + \theta)$$

or

$$y = R\sin\left(\beta + \theta_o \sin\frac{2\pi}{T}t\right) \qquad (2)$$

The vertical sheave speed is found by differentiating (2) with respect to time, i.e.:

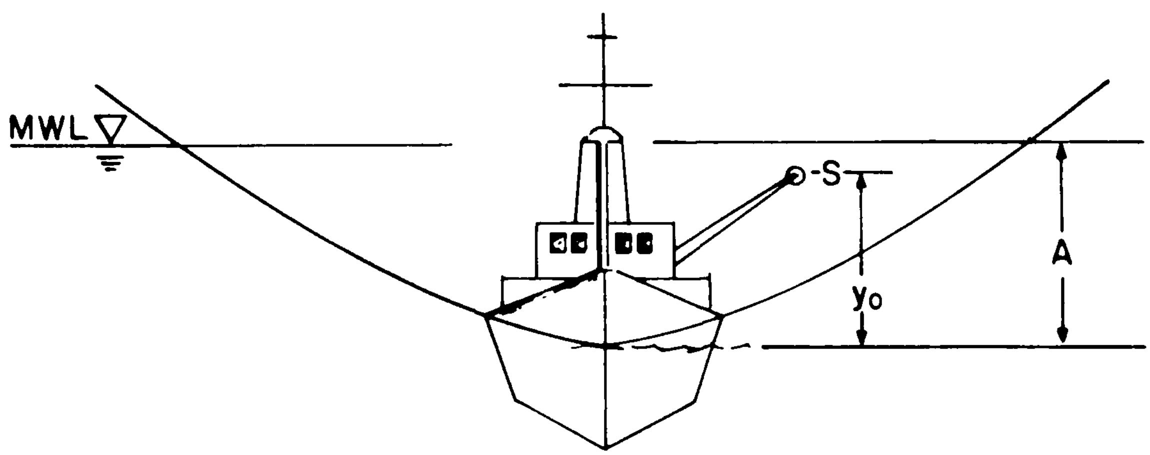
$$V = \frac{dy}{dt} = R\cos\left(\beta + \theta_o \sin\frac{2\pi t}{T}\right)\frac{2\pi\theta_o}{T}\cos\frac{2\pi t}{T} \qquad (3)$$

2. <u>HEAVE</u> Considering next heave motion only (no roll).

As a wave of amplitude A and period T passes by, the ship and therefore points O and S move vertically up and down.

If the ship lies in a trough at time $t = 0$ as shown below, then the equation of motion of point O is given by

$$z = -A\cos\frac{2\pi t}{T}$$



The equation of vertical motion of point S is then

$$y = y_0 + z$$

or

$$y = y_0 - A\cos\frac{2\pi t}{T} \qquad (4)$$

The speed of the sheave is obtained by differentiating (4) with respect to time, i.e.:

$$V = \frac{dy}{dt} = \frac{2\pi A}{T}\sin\frac{2\pi t}{T} \qquad (5)$$

3. HEAVE and ROLL Now let us combine Heave and Roll.

Under steady state conditions the ship roll will have the same period as the exciting wave. Assuming the initial condition depicted on Page 4

i.e. ship roll $= 0$ at time $t = 0$

and ship in a trough at time $t = 0$

Then.....

.he vertical displacement y of the sheave from the still water level will be given by

$$y = z + R\sin(\beta + \theta)$$

all terms as previously defined.

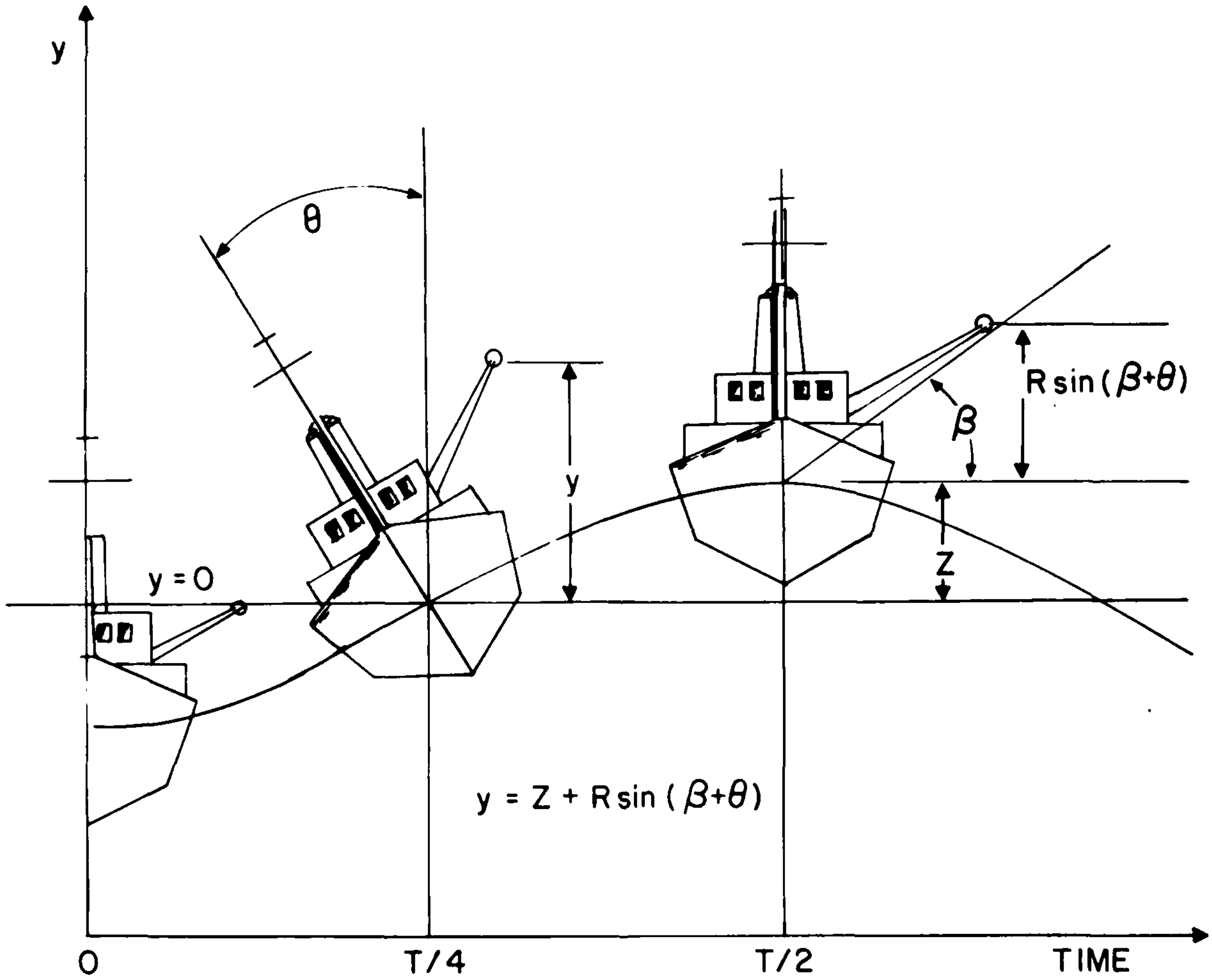
Explicitly:

$$y = -A\cos\frac{2\pi t}{T} + R\sin\left(\beta + \theta_0\sin\frac{2\pi t}{T}\right) \qquad (6)$$

Again differtiating (6) with respect to time yields the expression of the sheave vertical speed, i.e.

$$V = \frac{dy}{dt} = \frac{2\pi A}{T}\sin\frac{2\pi t}{T} + R\cos\left(\beta + \theta_0\sin\frac{2\pi t}{T}\right)\frac{2\pi\theta_0}{T}\cos\frac{2\pi t}{T} \qquad (7)$$

Different initial conditions would produce different equation..



COMBINING HEAVE AND ROLL

APPENDIX B

Title: Power Required for Servocontrolled Winch

Given:

- Speed compensated to ± 10 ft/sec of vertical sheave speed.
- Constant, regulated hauling speed = 120 meters/minute
  = 2 m/sec
  = 2x 3.28, say 6.5 ft/sec

Assume:

Cable out = 6000 meters. Diameter = .322. Weight = .137 lb/ft in sea water.

Immersed weight of instrument = 1000 lbs.

Cable strength = 9000 lbs.

Then:

- Instantaneous required line speed = 10+6.5 = 16.5 ft/sec
- Weight of immersed cable:

  6000 x 3.28 x .137 = 2696 lbs
- Total weight = 2696 + 1000 = 3696 lbs.
- Cable drag

  $$0.01 \times \frac{.322}{12} \times 6000 \times 3.28 \times 6.5 \times 6.5 = 701 \text{ lbs}$$
- Instrument drag. Assumed area = 10 sq.ft.

  1.2 x 10 x 6.5 x 6.5 = 507 lbs.
- Tension at the drum

  3696 + 701 + 507 = 4904 lbs say 5000 lbs.
- Power at the drum = $\frac{\text{Tension x line speed}}{550}$ hp

  $$\frac{5000 \times 16.5}{550} = \underline{150} \text{ hp } \underline{\text{max}}$$

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16. Abstract (Limit: 200 words)

The following is a report on the findings of a study conducted by the Woods Hole Oceanographic Institution to assess the needs and the means for improving the conventional intermediate winches used in the oceanographic community to lower profiling instruments (CTD for example).

Eight major U.S. oceanographic centers were visited to confirm community needs and common problem areas, and to survey existing lowering equipment and techniques. This information was used to develop a set of general requirements for an improved instrument lowering system. Recommended improvements included: compensation of wave induced ship motion, automation of casts, and capability for automatic tracking of oceanographic parameters.

A review is presented of additions or modifications which could meet these requirements. These options are compared and the system which offers the best potential for scientific usefulness, ease of fleet implementation and/or retrofitting of existing equipment is described at the conceptual and general specifications level.

A plan for the design procurement, test and demonstrations of a working prototype concludes the study.

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