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FINAL REPORT

THE DESIGN AND CONSTRUCTION OF A TOWED MULTI-PORT WATER SAMPLING PROBE FOR 100 METER DEPTHS

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Clifford L. Winget
and
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TECHNICAL REPORT

Prepared for the U.S. Department of Commerce, National Oceanic and Atmospheric Administration under Contract NA79AA-D-0044.

WOODS HOLE, MASSACHUSETTS 02543

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Approved for Distribution *Earl E. Hays*
Earl E. Hays, Chairman
Department of Ocean Engineering

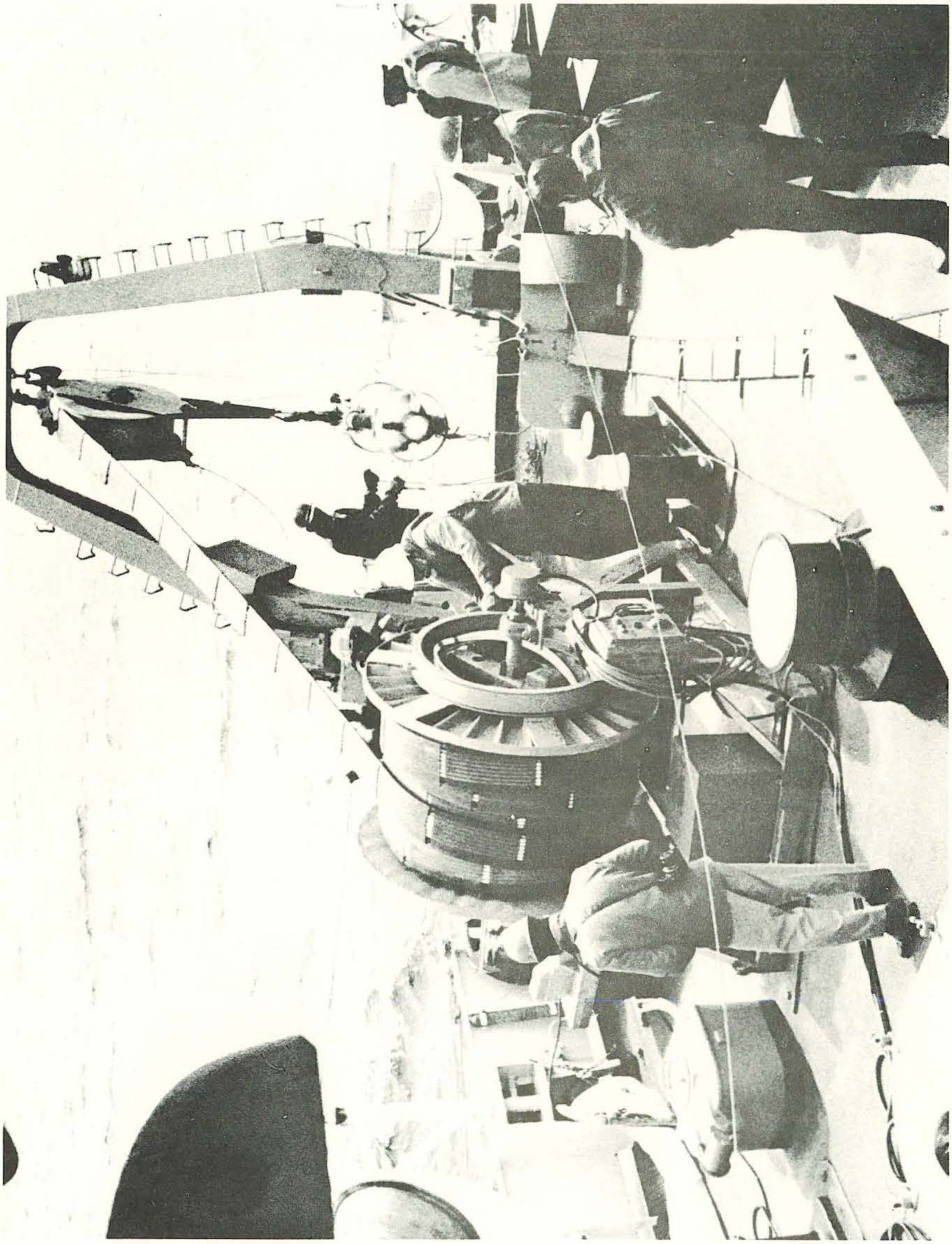


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd.)

Abstract

The experimental towed multi-port water sampler was designed to provide a shipboard science party with the capability of obtaining continuous water samples from the surface to a 100 meter depth. The device will simultaneously provide six samples spaced one meter apart in a vertical plane, while being towed by a surface support vessel at a forward speed of between two to three knots.

The device consists of a bottom fish containing six electric motors, each driving an individual pump. The six water samples are pumped to the surface using separate runs of TFE Teflon tubing. The tube is mounted in a pliant fairing that also houses the lifting cable, power leads, and instrumentation bundle. A drum winch is used to store a total of 150 meters of faired cable, and is capable of raising or lowering the fish while under way.

The sampler will provide a discharge flow rate of 5.6 liters per minute from each sample tube, while pumping through 150 meters of 12.7 mm bore tubing, against a 4.5 meter head. A depth sensor transducer within the fish provides a top-side readout of the actual operating depth of the fish, while a remote reading temperature sensor provides a continuous display of the water temperature.

Acknowledgements

The development of the six port underway sampling system was made possible by the United States Department of Commerce, National Oceanic and Atmospheric Administration under contract NA79AA-D-0044.

Recognition and appreciation are given to the various sections within the Woods Hole Oceanographic Institution, especially those who provided expertise and considerable patience in the areas of welding, machine shop fabrication, mechanical assembly, and final test of the device.

Specific thanks is also extended to Cindy Moor, Laurie Raymond Betsey Pratt, and Frank Medeiros for the numerous line drawings, system schematics, photographs, and artist concepts used throughout the report.

Special appreciation is also extended to Mrs. Ann Henry for her patience and expertise in assembling and typing the data contained in this publication, and to Mr. Moe Moniz of the Purchasing Department for his untiring efforts in obtaining a wide variety of components on short notice.

1.0. Discussion of the Problem and General Approach

This research effort was initiated to design, construct and demonstrate a system that would provide science personnel with the means of obtaining continuous selected water samples from any level beginning at the surface to a depth of 100 meters. The materials that are in direct contact with the water samples are fabricated of Teflon, ceramic, and polypropylene, to prevent introducing trace impurities into the water samples.

This report will cover in detail the preliminary design concepts, the prototype design, construction, weight, deployment and recovery characteristics, and will include a discussion on design improvements based on experience obtained during laboratory and sea trials.

The device is designed for use on a moderate size (130 feet or larger) oceanographic vessel of opportunity. It requires an 'A' frame and a source of 230 volt single-phase power. The fish weight is 680 Kg., while the gross weight of the winch with 150 meters of fairing wound on the drum is 1800 Kg.

Once deployed, the fish and its pumping system have an unlimited underwater endurance. The motor and pump assemblies are modified commercially available units built for continuous duty operation. They can be turned on or off at any time through the use of a power control console on the winch.

The water sampling system consists of an aluminum torpedo shaped housing or fish, that contains the pumps, motors, and fuse assemblies used to protect the electrical circuits. The fish is a watertight pressure-resistant assembly that is capable of operating at pressure depths in excess of the 100 meter operating level selected for this device.

The sampling flow to each pump is provided by a suction probe assembly constructed of individual TFE Teflon tubes. The tubes are mounted in a faired structure that maintains a fixed, one meter vertical separation between each successive inlet probe. The pump discharge is directed from the fish and to the surface vessel through six Teflon tubes contained in a chain of flexible polyurethane fairing flats. The discharge from the individual tubes can be obtained at a central distribution plate mounted on the shaft of the winch drum.

The winch is constructed of a reinforced wire cable drum that is chain driven through a gear box and electric motor. The motor controller provides a power-out, power-in, and a central-off position. A mechanical brake secures the drum, preventing creep during long tows.

A specially designed fiberglass reinforced sheave capable of passing the polyurethane fairing string is used to direct the 100 meter length of fairings over the side with a minimum of stress and mechanical distortion to the Teflon tubes. Figure 1 is an artist's concept of the device. Item 1 is the winch; item 2 a compressor; 3 illustrates the pliant fairings; 4 the water inlet tubes or pump suction ports; item 5 illustrates the discharge flow from the pumps returning top side; item 6 is the disconnect fairing; 7 is a remote reading temperature sensor; 8 is the landing skids and ballast weight to sink the fish; item 9 houses the pressure compensation regulator and pressure depth sensor.

2.0. Mechanical Design Concept and Construction Details

The multi-port water sampling system design concept was to provide a continuous pumped sample of particulate laden water to a shipboard laboratory. The materials used in the construction, and in direct contact with

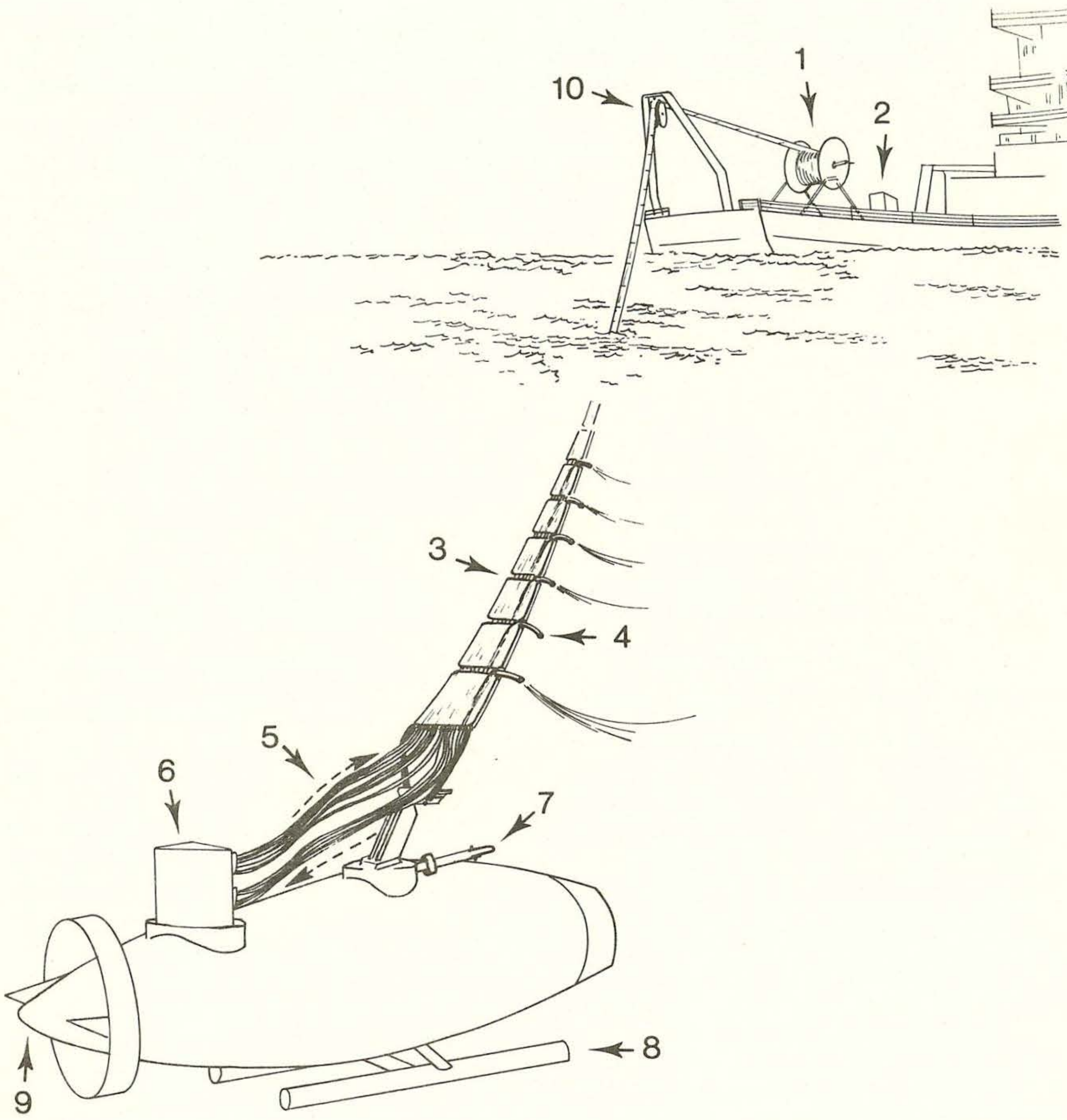


Figure 1. Artist Concept of Basic System

the individual water samples, will be of Teflon, or other acceptable material that will not introduce trace impurities into the water specimens.

2.1. Pump Containment Fish

The pump housing, or fish, was constructed from a modified section of a surplus Navy torpedo. Figure 2 provides a view of the main body of the fish including the structural double 'A' frame used as the lift and tow attachment point. The diameter of the fish at its largest point is 53.7 centimeters, while the total overall length, nose cone to tail cone, is 2.0 meters.

The fish is an aluminum casting capable of withstanding the pressure experienced at a 100 meter depth. It is, however, internally pressure balanced through the use of compressed air. The stabilizing tail cone and steering fins are locked in a "straight flight" position. They are not controllable from the surface. For the most part, existing holes or bosses were used to provide electrical and water sampling ports. Actual machining on the torpedo shell was held to a minimum.

2.2. Motor Driven Pump System

Six individual electrically powered centrifugal water pumps are used to sample the selected area of interest. The pump assembly was procured from the March Manufacturing Company. A model TE5C-MD was chosen for this application. Figure 3 illustrates the stacking arrangement used to mount the individual pump and motor assemblies within the fish housing.

Each pump is powered by a 1/4 horsepower electric motor, operating on 230 volt single phase 60 cycle power. They are individually fused such that the loss of one to five pumps does not prevent water sampling from continuing. Figure 4 is a view illustrating three pump heads with their

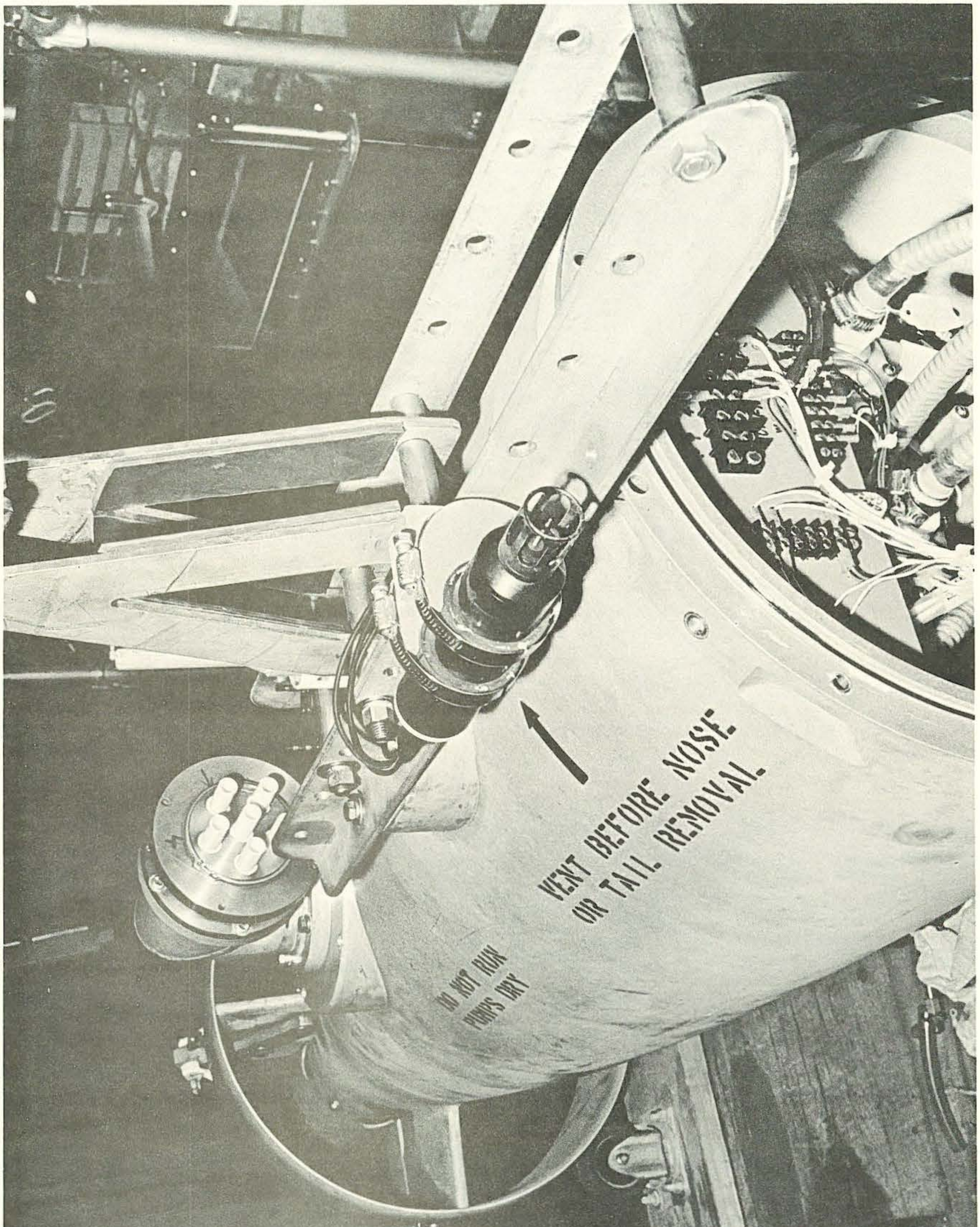


Figure 2. Pump Containment Fish

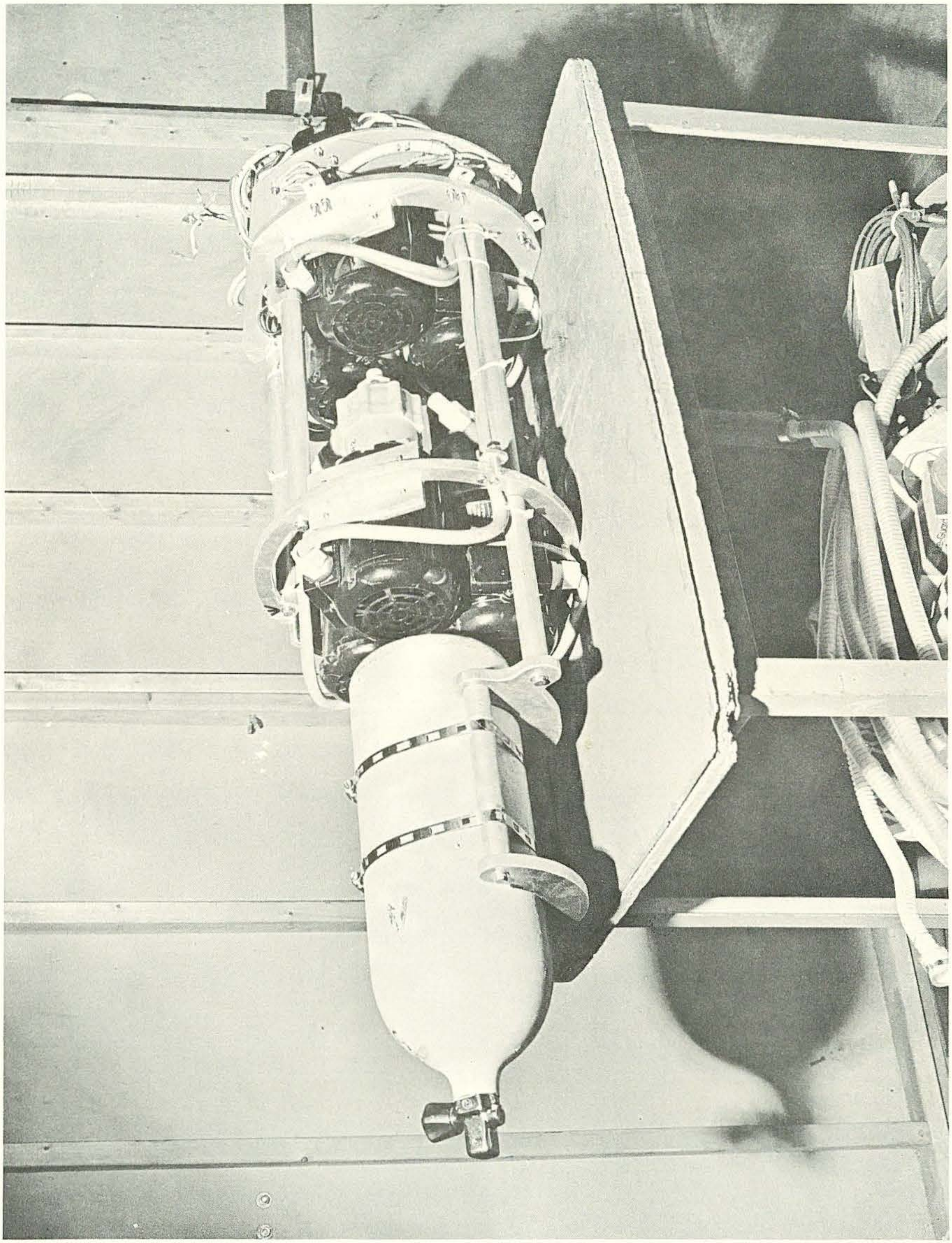


Figure 3. Motor Driven Pump Stack

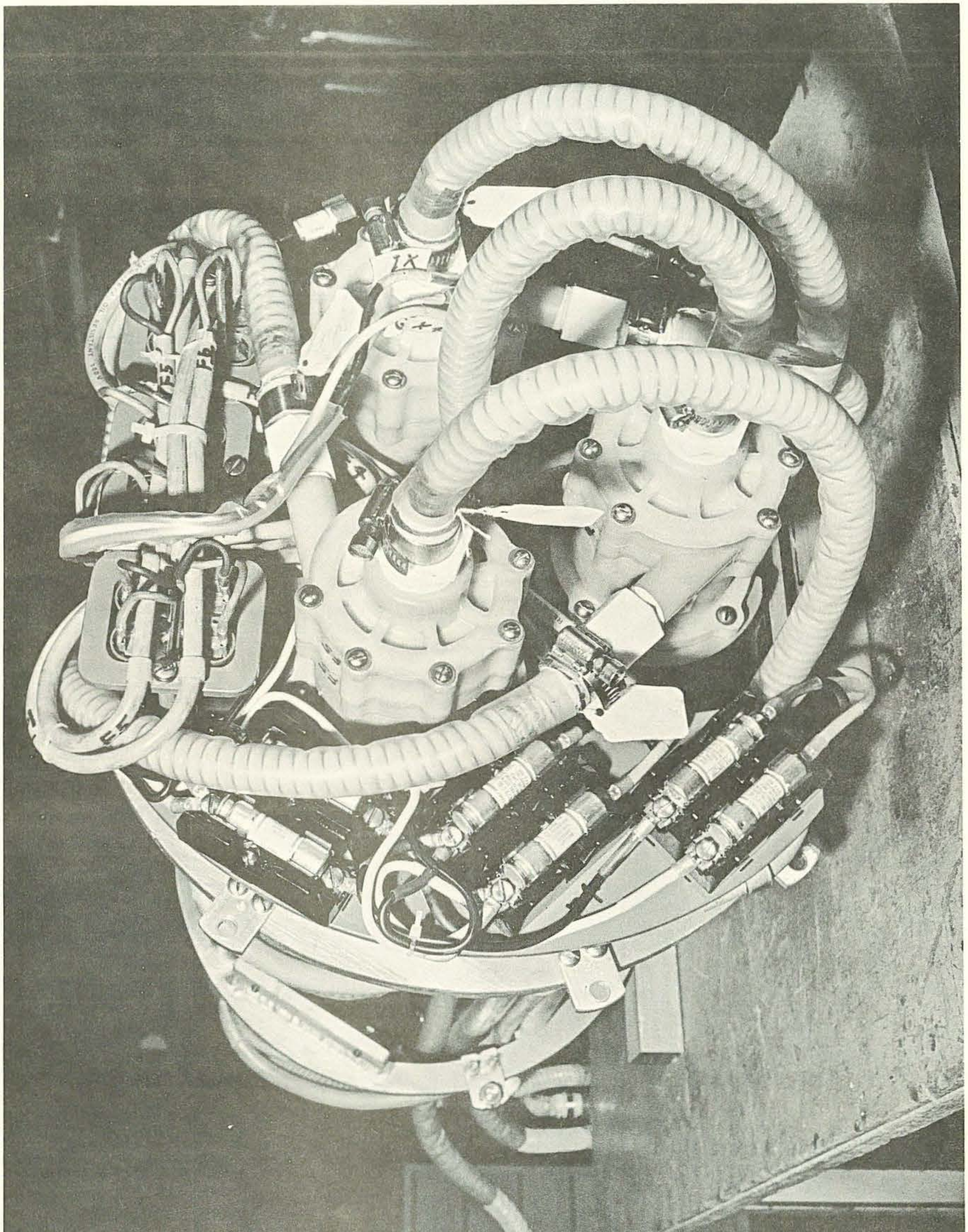


Figure 4. Pump Head and Fuse Block Assembly

associated piping, and the fuse block assemblies used to both protect and isolate the individual pump systems. The motors are high torque capacitor start devices. In order to reduce the overall physical size of the motor, the capacitors were removed and remounted across the upper front of the pump cage. This modification reduced the overall diameter of the pump cage, and eliminated a tubing run interference point.

Each pump is capable of free discharging 60.5 L/minute at a one foot head. When coupled to 150 meters of 12.7 mm ID Teflon tube, the drag or friction that is induced to the pumped fluid reduces the pumping rate at the discharge end to 5.6 L/minute.

The pump and motor assemblies are commercial off-the-shelf devices, and are capable of continuous duty. The pump impeller is magnetically coupled to the drive motor eliminating all wearing seals. The impeller and pump body are polypropylene, while the impeller spindle and thrust washers are porcelain. The front face Viton 'O' ring was replaced with a FEP Teflon encapsulated Viton ring procured from the A.W. Chesterton Company. The convoluted 19 mm ID tube used to direct the fluid flow through the individual pumps are TFE Teflon. The tube to pump adapters are fabricated of TFE Teflon, and all pipe threads are sealed with Teflon ribbon tape. The use of a flexible tubing was mandatory due to the space limitations and pipe runs within the system. The tube was procured from the Penn Tube Plastics Company.

When operating at the rated depth of 100 meters, the pump housing and head, the magnet barrier cup and the flexible tubes, are directly exposed to an internal pressure of sufficient magnitude to cause a possible rupture of the system. The pressure experienced by the pumps and tubing is equivalent to 9.6 atmospheres. To prevent a catastrophic failure of this type, with total flooding of the fish, a pressure compensation system was installed.

2.3. Pressure Compensation System

The pressure compensation system to be described will automatically maintain the inside of the fish at a level that balances the external sea water pressure regardless of the depth.

The design parameters for the compensation system required simplicity, simple recharging, damping out wave action and ship's roll, with sufficient pneumatic charge to provide at least a 24 hour mission. The basic components for the system were a scuba storage tank and regulator, and a vent and over pressure relief valve. Figure 5 illustrates the basic system. The scuba tank is mounted within the fish, and is attached to the motor rack as shown in Figure 3.

In operation, the 2200 psi G air charge in the scuba tank is reduced to 150 psi by the first stage regulator. It is directed to the inlet of the second stage, where its flow is controlled by the pressure sensing diaphragm. The diaphragm has been modified to desensitize it to wave action and ships' roll. The pressure sensing side of the diaphragm does not feel pressure changes directly; the oil-filled bladder experiences the pressure change first, forces oil through the adjustable orifice, applying the increase slowly. The fixed orifice in the down stream side of the regulator, applies a back pressure to the bottom side of the diaphragm, helping to reduce the free flow of air into the fish.

On ascent, the over pressure vent valve opens, continuously venting the fish housing until it reaches a level that is approximately 8.5 psi above ambient. The modified regulator and oil filled sensing bladder are

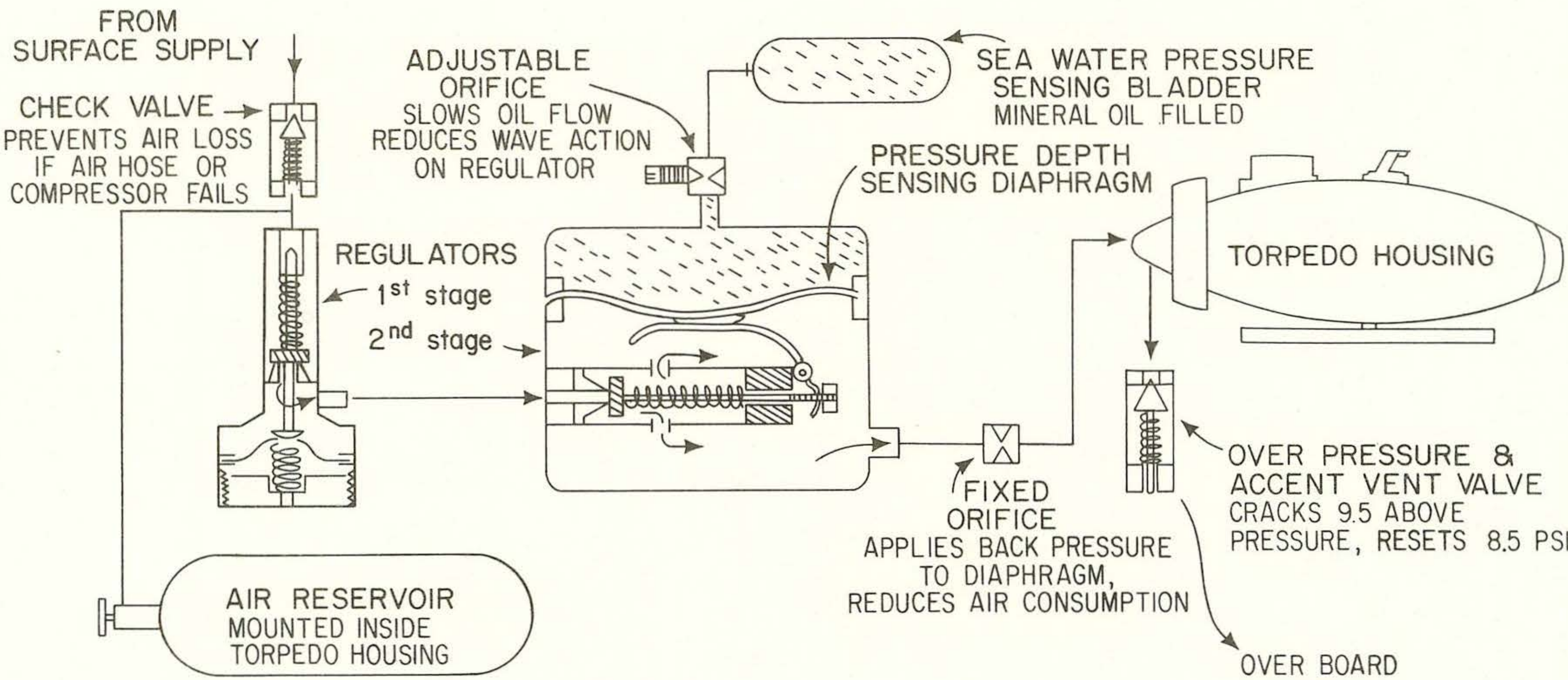


Figure 5. Pressure Compensation System Schematic

located in a free flooding fiberglass tail cone. Figure 6 illustrates the assembly mounted on the tail cone closure plate.

2.4. Water Sample Distribution System

Figure 7 illustrates the water flow through the entire system, beginning with the sample first entering the suction port, continuing through the centrifugal pumps, then being discharged at the exit disconnect at the top of the fish. Both inlet and discharge ports are of identical construction. A typical assembly is illustrated in Figure 8. It is a machined stainless steel shell with a threaded jam nut. A spanner wrench is used to secure the nut, assuring a tight, leak-free system. The primary purpose of the disconnect is to provide a means of separating the fish from the fairing and transfer tubes, allowing greater flexibility during maintenance and transportation.

The internal construction features are illustrated in the exploded view shown in Figures 9 and 10. The assembly consists of a six port inner ring of TFE Teflon, Teflon tube inserts, and Teflon coated 'O' rings. The squeeze exerted by the jam nut provides the compression force necessary to seal the disconnect against sample leakage or infiltration of external water. When installed on the fish, the disconnect also becomes a water barrier seal, preventing outside sea water from entering the fish. The design of the disconnect exposes the sample to Teflon components only; there are no metallic parts to contaminate the sample.

2.5. Transfer Tubes and Fairings

As the sample continues through the system, it is directed into the tube distribution bundle shown in Figure 11. The TFE Teflon tubes are extruded material, somewhat stiff, with a minimum allowable bend radius. The

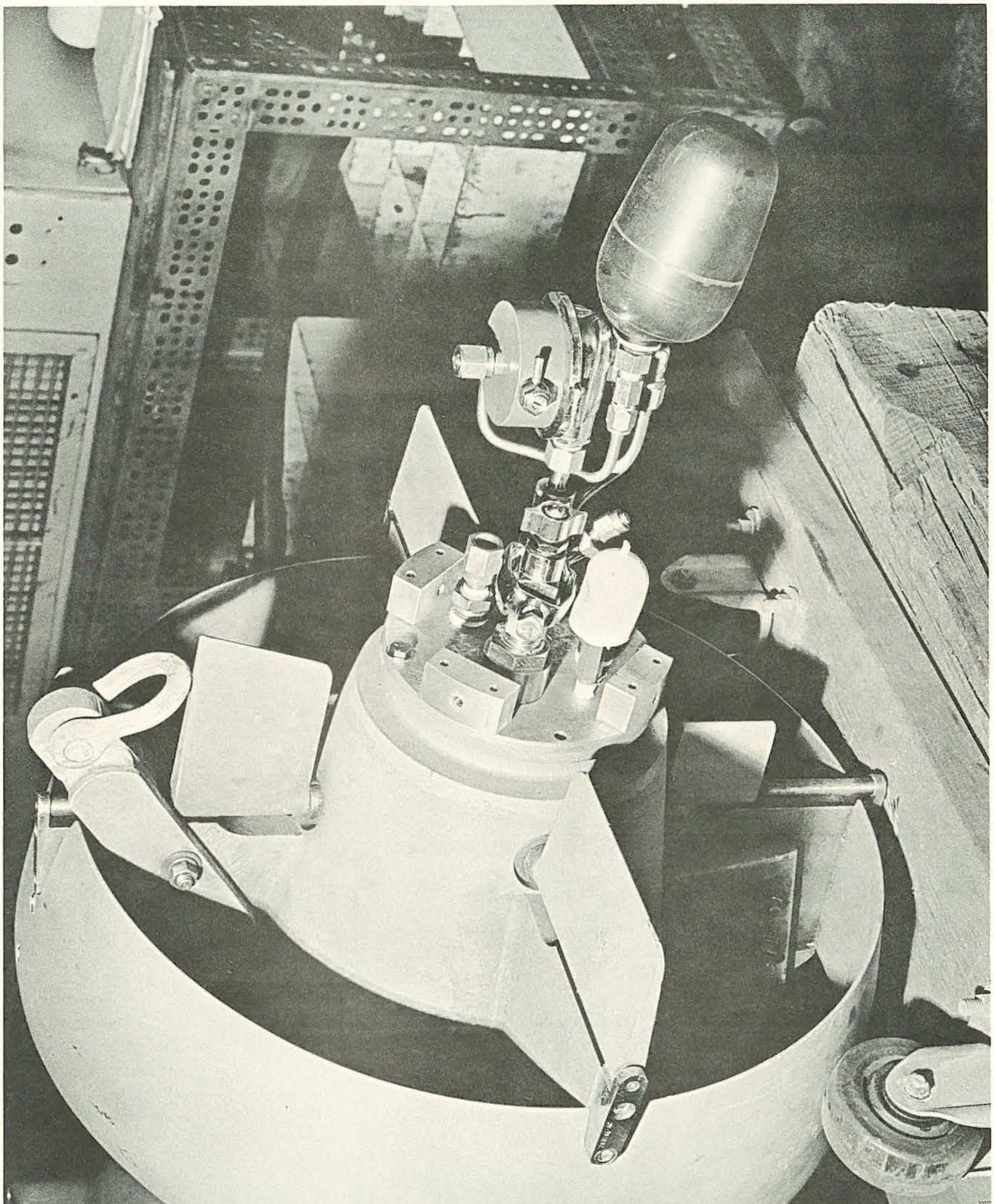


Figure 6. Pressure Compensation Regulator and Sensing Bladder

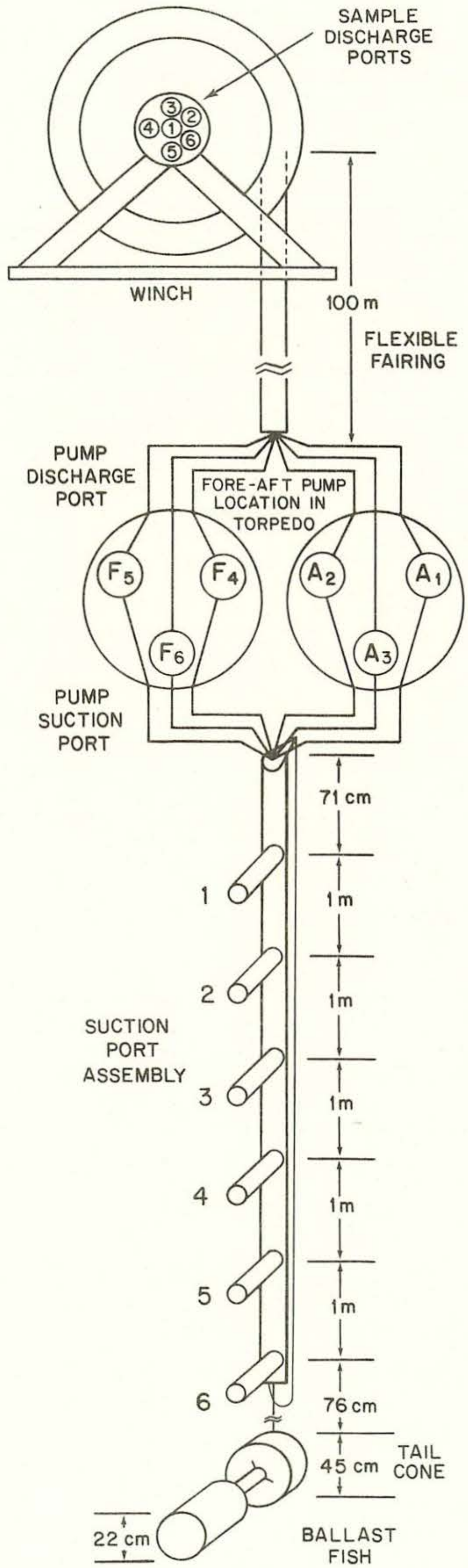


Figure 7. Water Sample Distribution Schematic

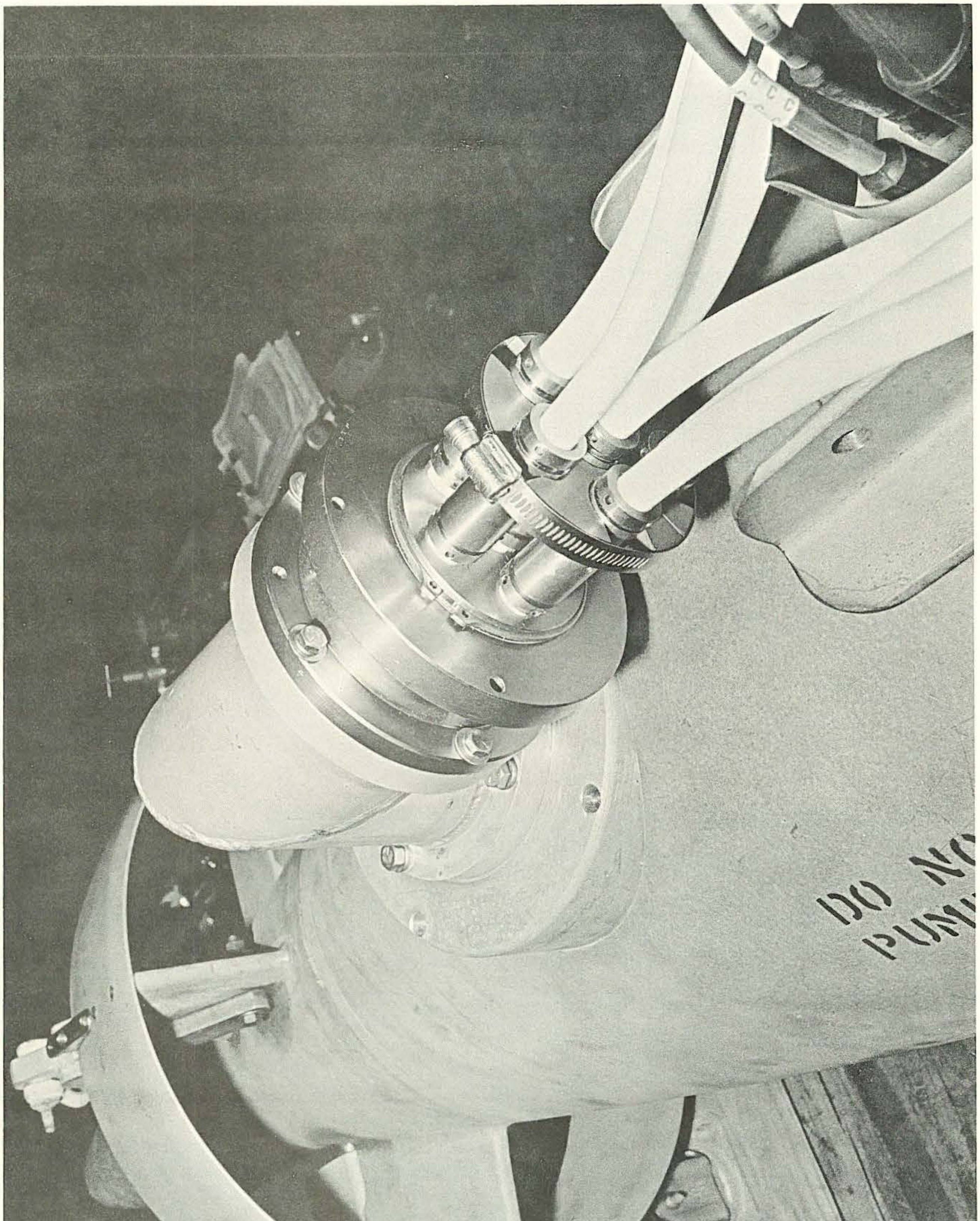


Figure 8. Water Pump Discharge Manifold Connector

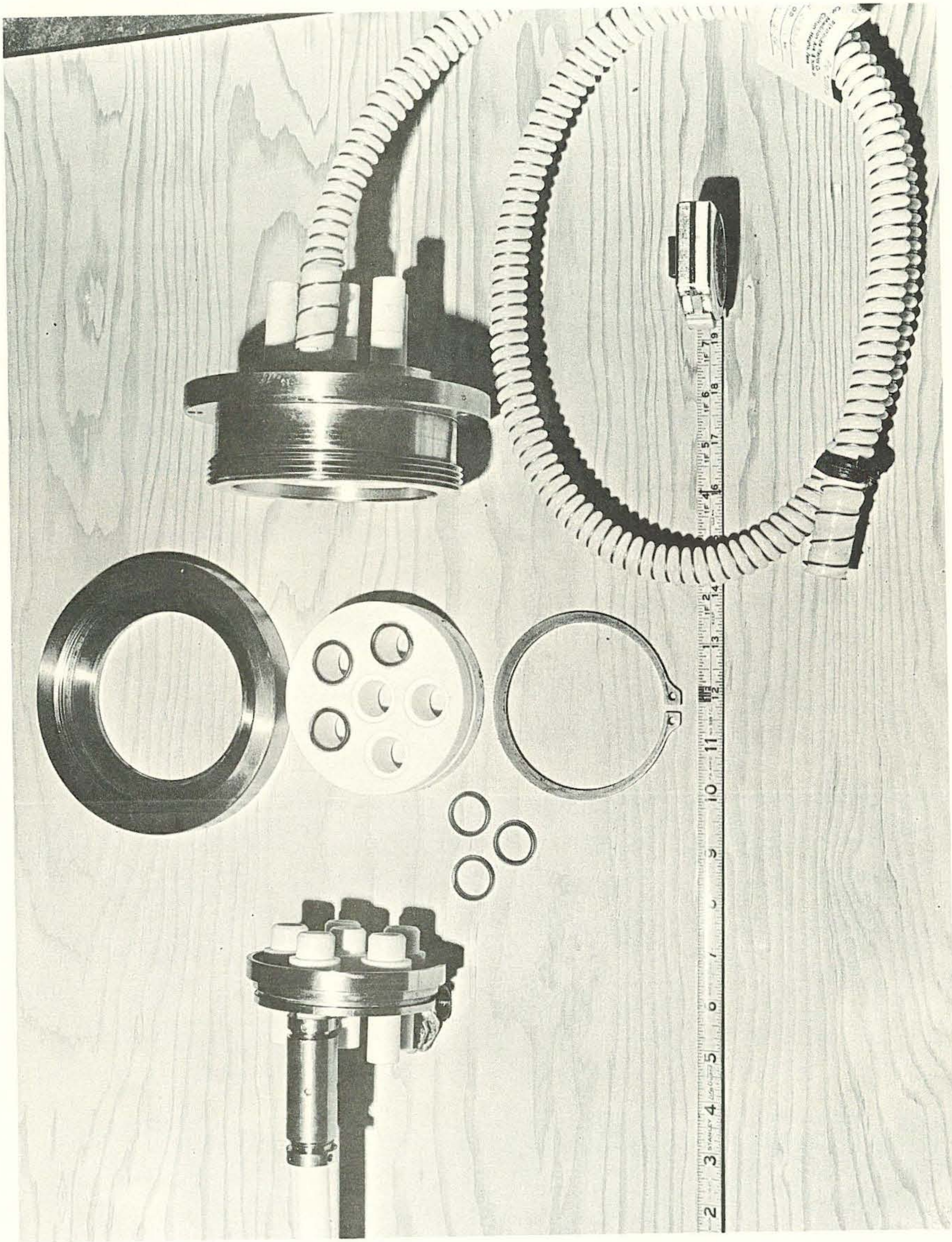


Figure 9. Exploded View of Disconnect Port

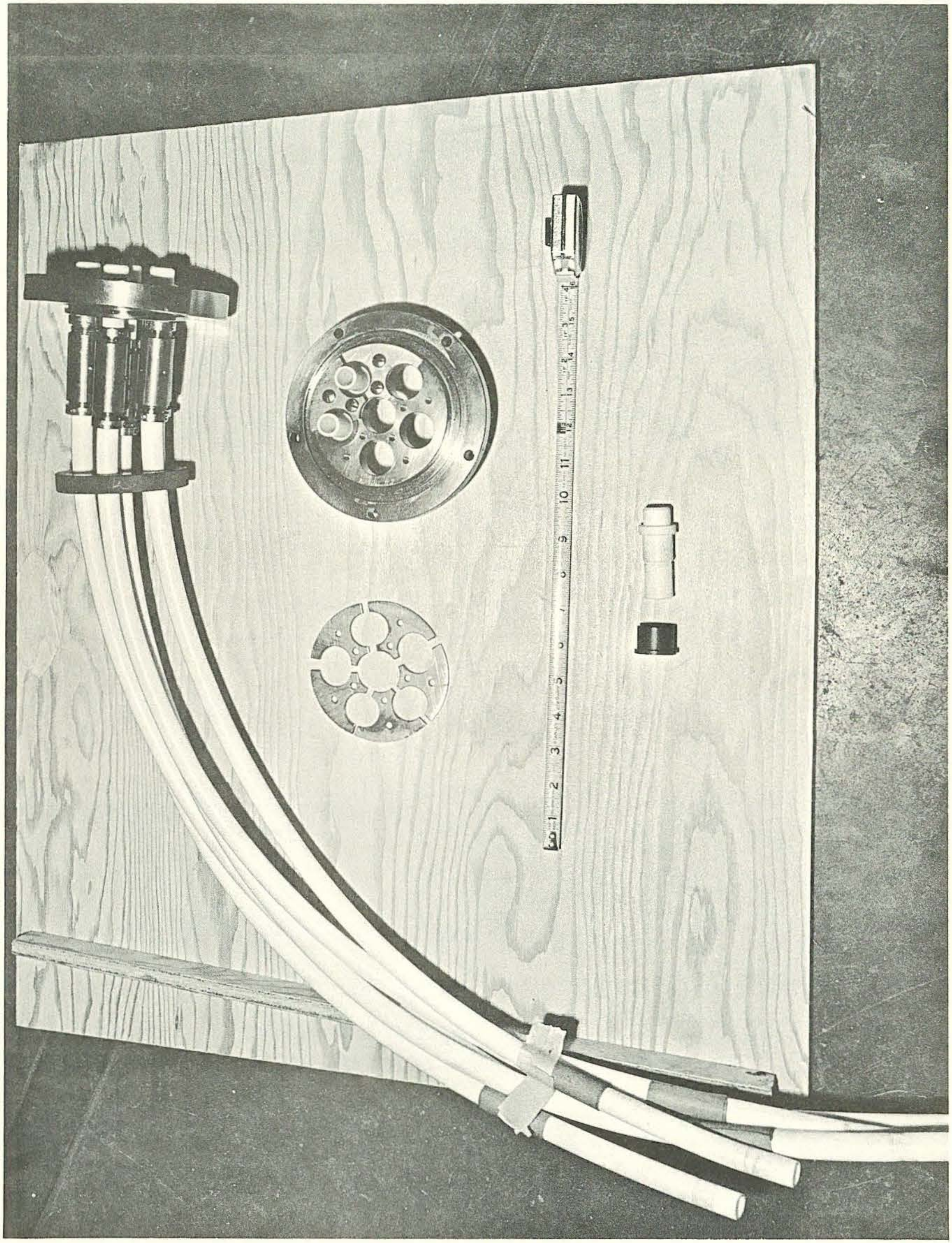


Figure 10. Disconnect Jam Nut Assembly

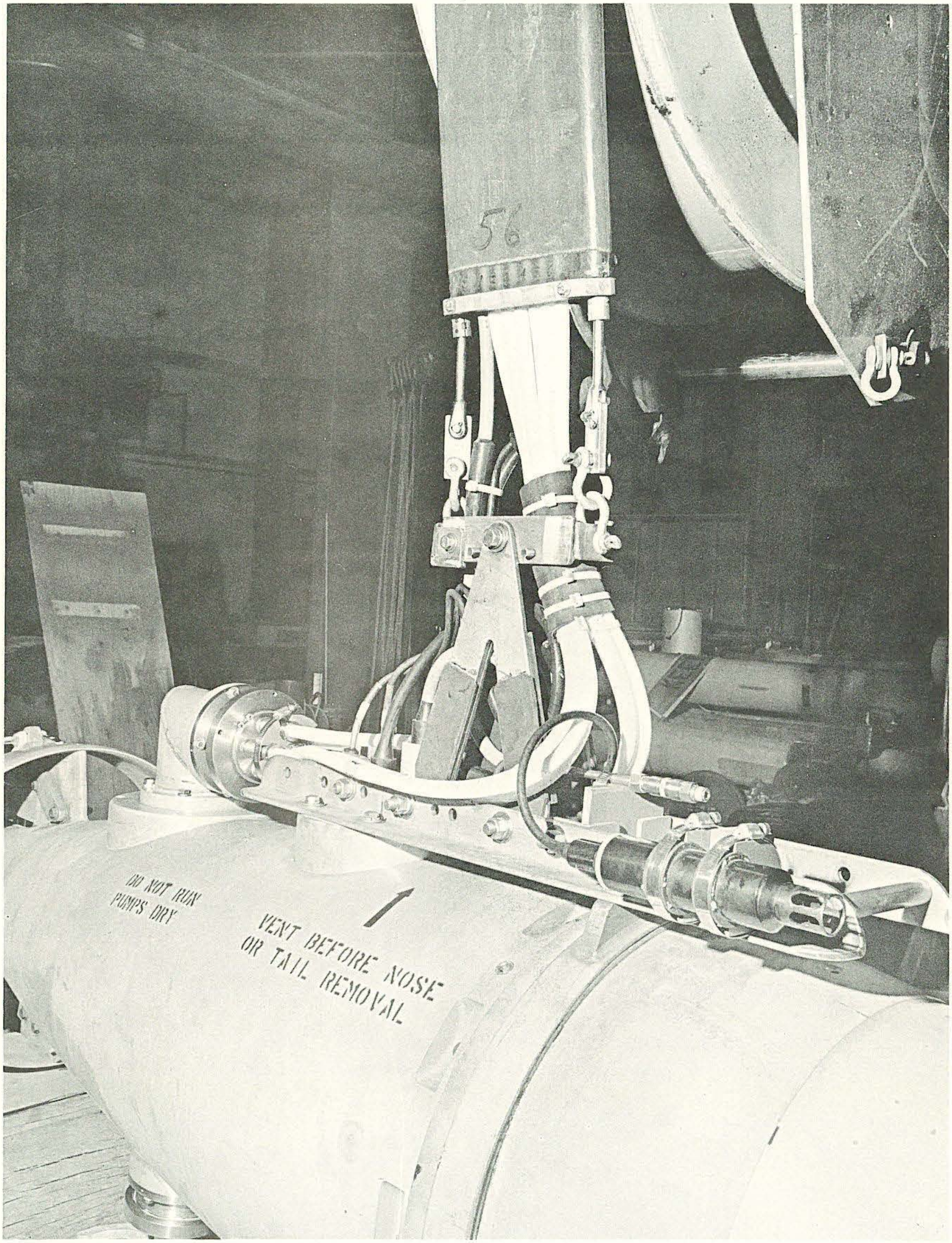


Figure 11. Transfer Tube Distribution Bundle

bend illustrated in the photograph is close to its minimum allowable, although if a heat gun is carefully applied, a slightly tighter radius may be obtained without excessive flattening of the tube.

As shown in the photograph, the tow bar can pivot around the central mounting bolts at the top of the 'A' frame. This provides the fish with sufficient flexibility to assume its most streamlined position, regardless of the catenary taken by the towed fairing string. Without the strain relief loops shown in the photograph, the tubes might be damaged or pulled out of the disconnect assembly by rocking of the tow bar. As a precautionary measure, two pins have been welded to the 'A' frame to restrict the maximum excursion of the tow bar assembly.

The Teflon transfer tubes pass through polyurethane fairings as illustrated in Figure 12. The fairings were fabricated by Astronautics Inc., Marlboro, Massachusetts. They are 23 cm wide, 46 cm long, and 5 cm thick, with a mass of 2-3 Kg. A total of 10 holes are molded into the fairing. The two extreme outboard holes are used to contain the two 6 mm 7 x 19 stainless steel strength cables. The remaining eight passages house the six Teflon transfer tubes, one 3-wire number 12 power cable, and the instrumentation cable.

The pliant fairing serves several purposes. It performs as a protective sheath to mechanically prevent tubing kinks during excursions over the 'A' frame deployment sheave, as illustrated in Figure 13. By design, its semi-flexible nature allows it to conform to the drum shape as successive layers are wound. It constrains the tubes and cables in an orderly position, easing the rewind effort during recovery. It also serves to remove the compressive or crush load on the Teflon tubes that are wound as the bottom layers on the drum.

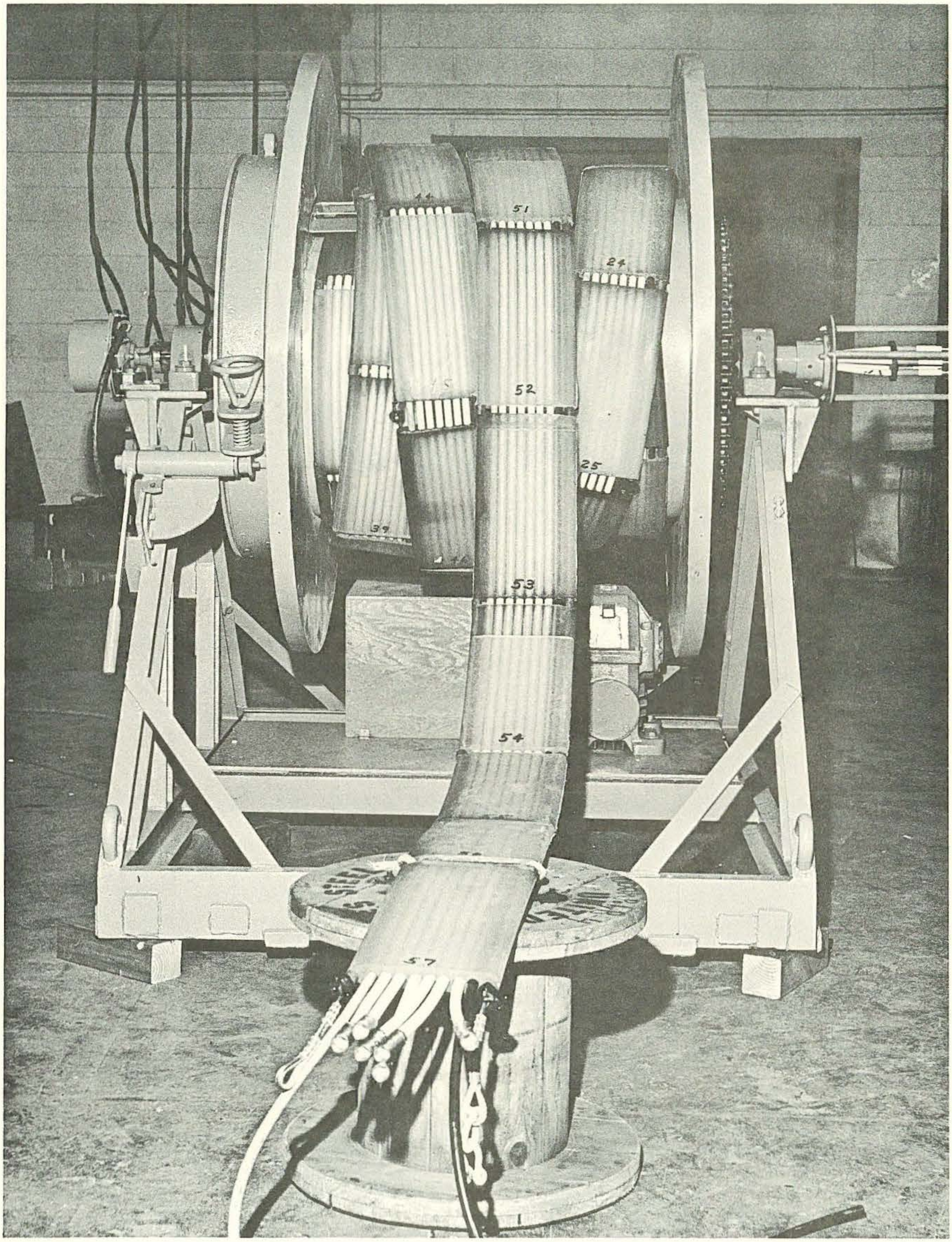


Figure 12. Polyurethane Fairing Assemblies

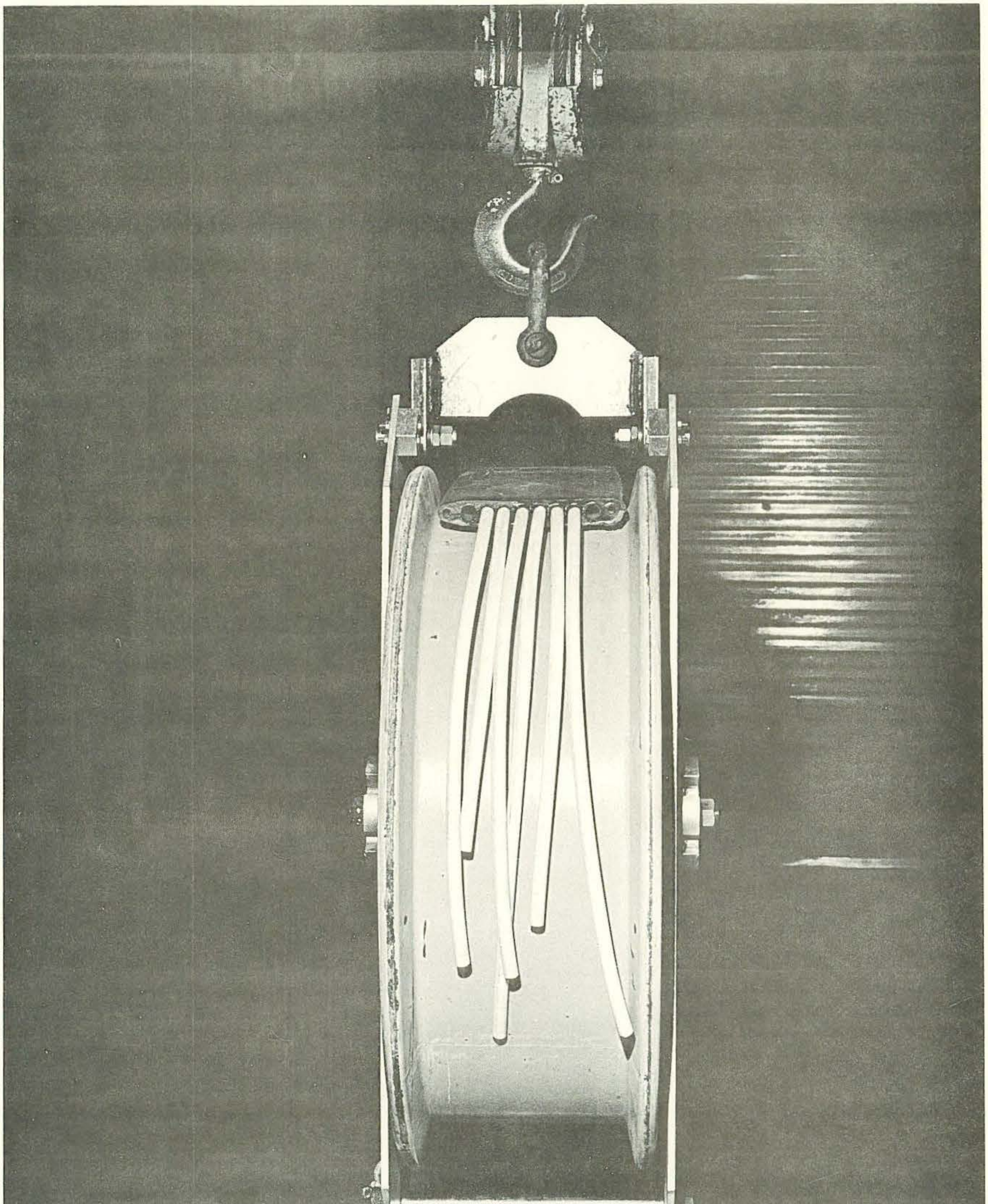


Figure 13. 'A' Frame Deployment Sheave

2.6. Transfer Tube Coupling Assembly

The 15 mm OD x 12 mm ID transfer tubes were procured from Chemplast Inc., Maynard, Massachusetts. At the time of conception of this program, this vendor was the only known supplier that could provide random 30 meter lengths of extruded TFE Teflon tube. As a result of this, some means was required to couple individual sections into the required 150 meter length. Commercial suppliers were reviewed for a usable assembly having the following characteristics:

1. low profile (no bulky nuts or packing glands);
2. all wetted parts of TFE Teflon;
3. high tubing pull-out forces;
4. Teflon 'O' ring seals;
5. corrosion resistant strength material;
6. sized to fit 15 mm OD tube.

While several vendors met the material and seal requirements, none were able to satisfy the total list of essential requisites. An in-house design provided the coupling illustrated in Figure 14.

Referring to the cross sectional drawing in Figure 15, the outer shell #1, is a threaded 25 mm OD stainless steel tube. The two gland nuts #2, are machined from 25 mm OD stainless steel stock, and have 4° taper (8° included angle) on the inside bore. The Teflon spacer sleeve #3, has a 45° angle machined on both ends. Two stainless steel spacer rings #4, and two Teflon 'O' rings #5, are used to seal the wetted parts area. The two split tapered cones #6 fit around the Teflon tube; they are wedged by the taper in the threaded gland nuts. As the nuts are tightened, they compress the split cones against the spacer rings, which in turn compress the Teflon 'O' ring into the 45° angle at both ends of the Teflon sleeve.

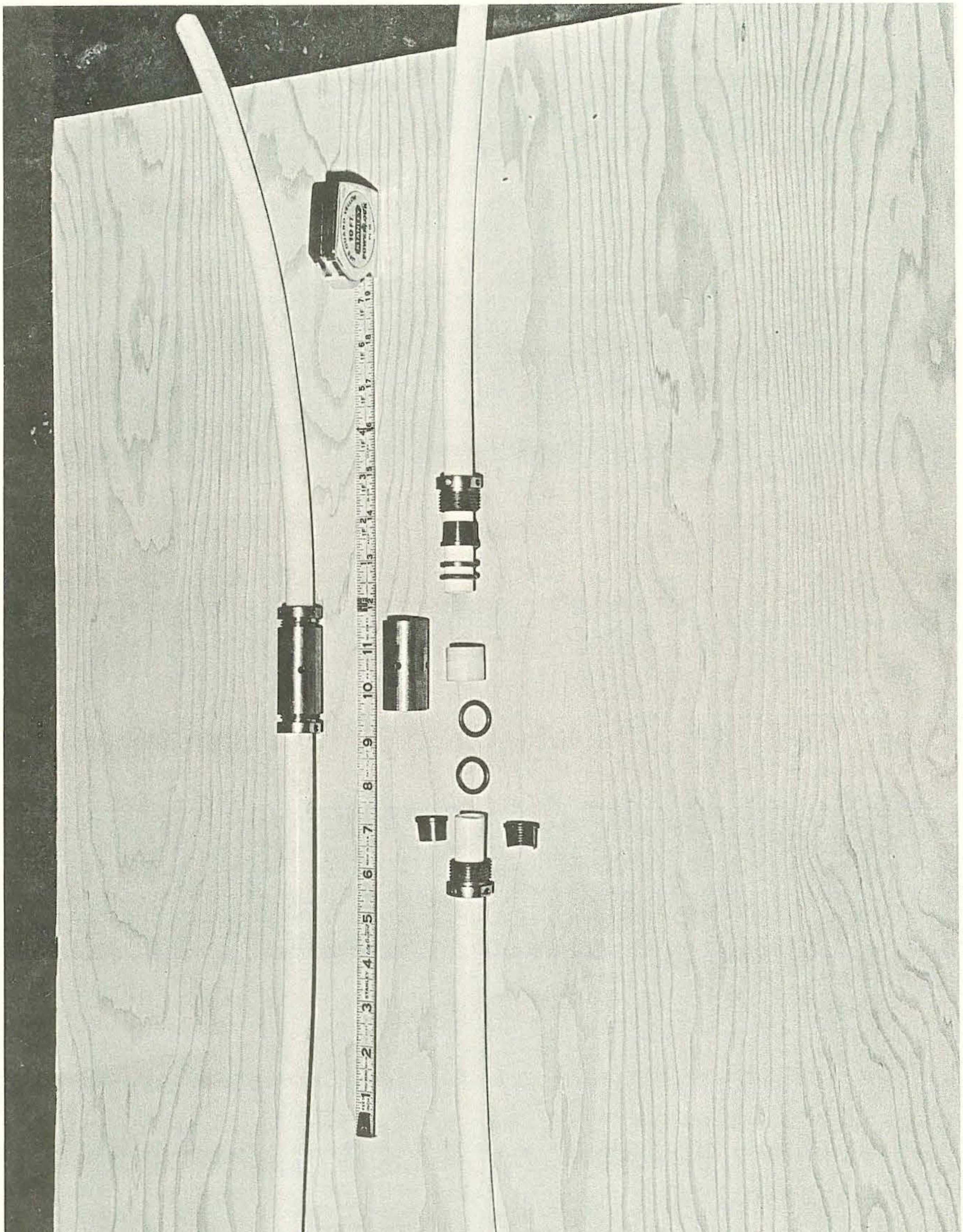
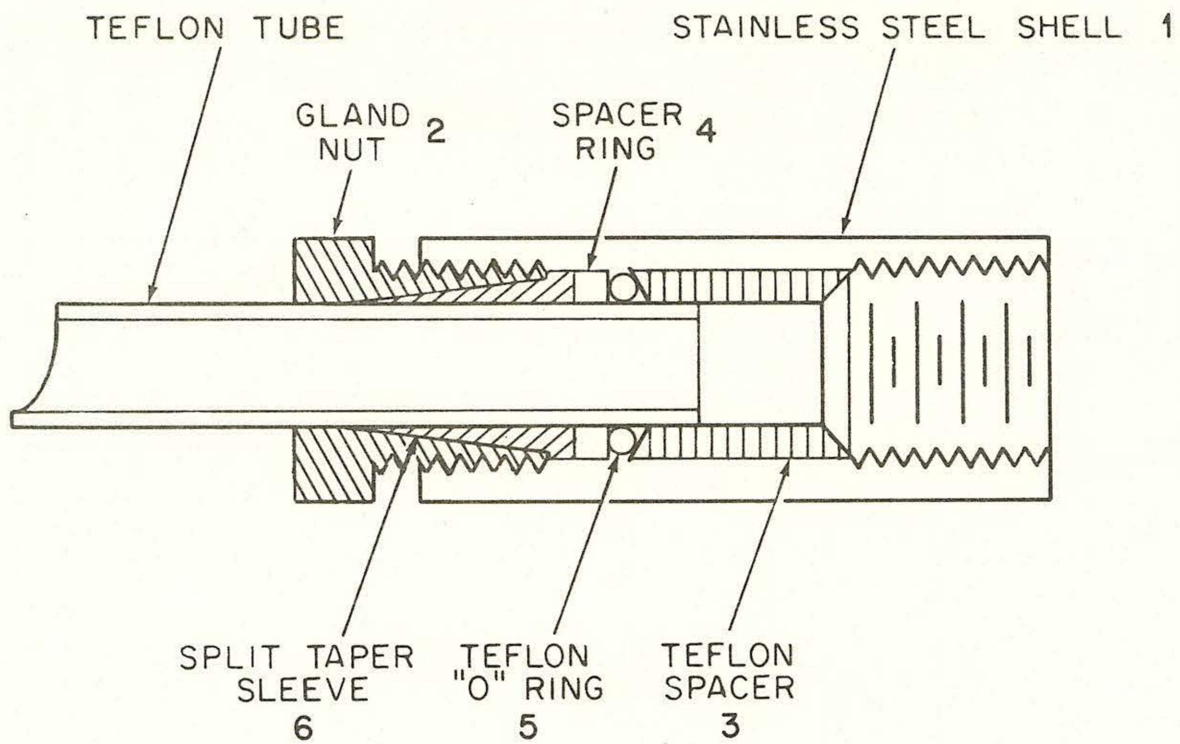


Figure 14. Transfer Tube Coupling



SHELL 1" OD x 2" LONG
    BORE .828"
    THREAD 7/8 — 14 DEEP
GLAND NUTS 1" OD x 1/2" LONG
    THREAD 7/8 - 14 DEEP
    ID TAPER 4° (8° INCLUDED ANGLE TO .735 DIAM. AT LARGE END)
    DRILL THRU WITH 41/64 DRILL
    DRILL 4 EQUALLY SPACED .128 DIAM. HOLES FOR SPANNER WRENCH
TEFLON SLEEVE .823 OD x .750 LONG, .635 ID, 45° ANGLE AT ENDS
SPACER RINGS .823 OD x .125 THICK, .635 ID
SPLIT RINGS, LENZ MFG. CO., DAYTON OHIO P/N 165-10

Figure 15. Cross Section of Transfer Tube Coupling Assembly

A course thread on the ID of the split cones tend to bite into the OD of the Teflon tube mechanically restraining the tube from pulling out when placed under elevated tensile loads. A small spanner wrench used in conjunction with a straight 3 mm pin are the only tools required to assemble or disassemble the coupling. In an emergency, two pins will suffice.

2.7. Electrical Circuitry and Instrumentation

2.7.1. Depth Sensing

A pressure sensing transducer located within the fish provides a deck side readout of the true depth of the water sampling system. It is mounted on the tail cone closure plate illustrated in Figure 16. The sensing diaphragm is of corrosion resistant material and could be used directly in sea water without any short term detrimental effects. The sampling system, however, is exposed to a wide variety of chemical and biological waste materials, and, in the interest of transducer longevity, it was decided to sense outside depth pressure through an oil filled transfer barrier. The method does not add to the system complexity, consisting only of the small oil filled silicone bladder shown in Figure 17. The pressure transducer is a model 204, manufactured by Setra Systems, Natick, Massachusetts.

2.7.2. Temperature Sensing

A temperature sensing device is mounted at the nose of the fish in a location that provides an uninterrupted flow of water around the sensor. It is a model SBE-3, manufactured by Sea Bird Electronics, Mercer Island, Washington. It is shown at the lower right side, at the nose of the fish illustrated in Figure 11.

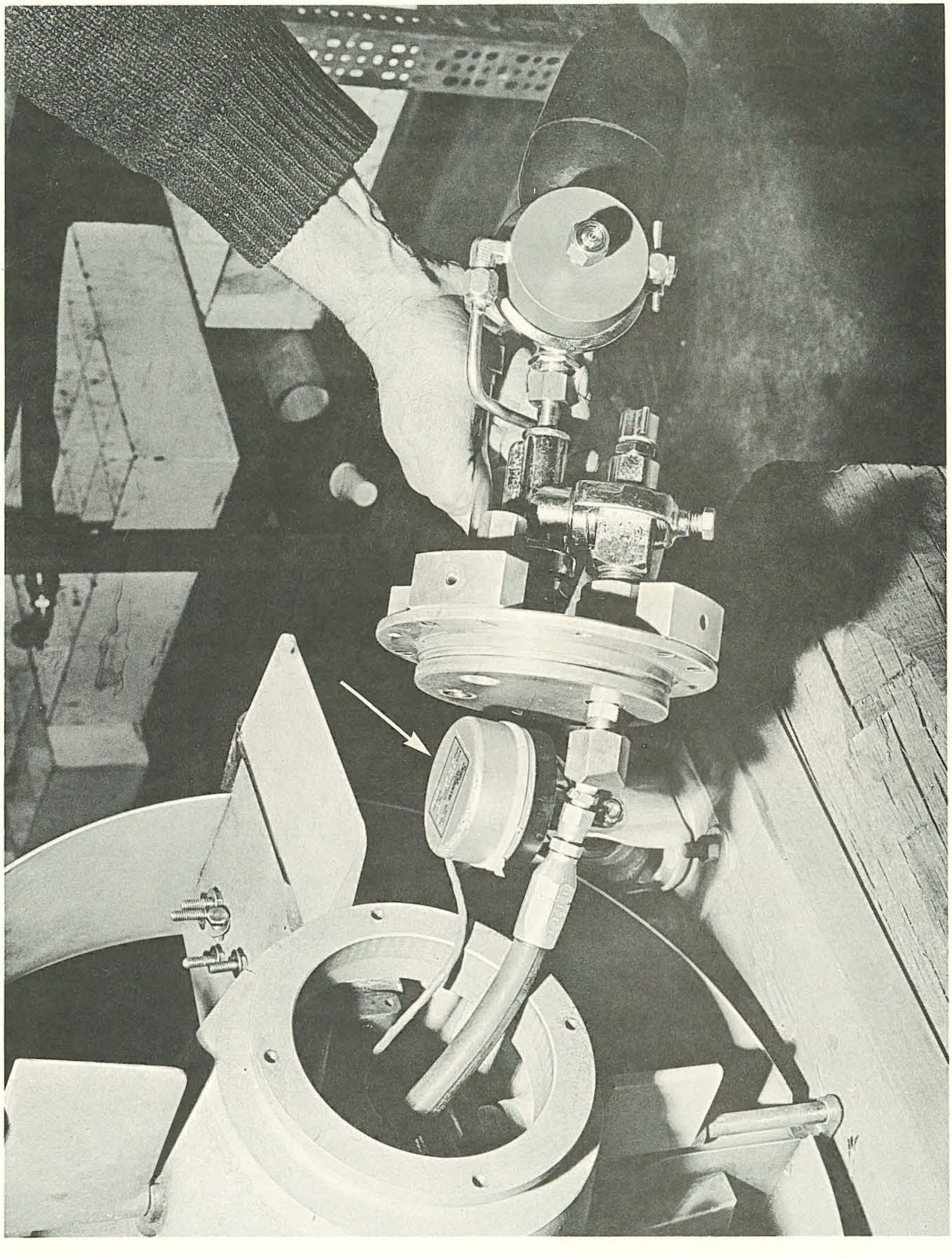


Figure 16. Pressure Sensing Depth Transducer

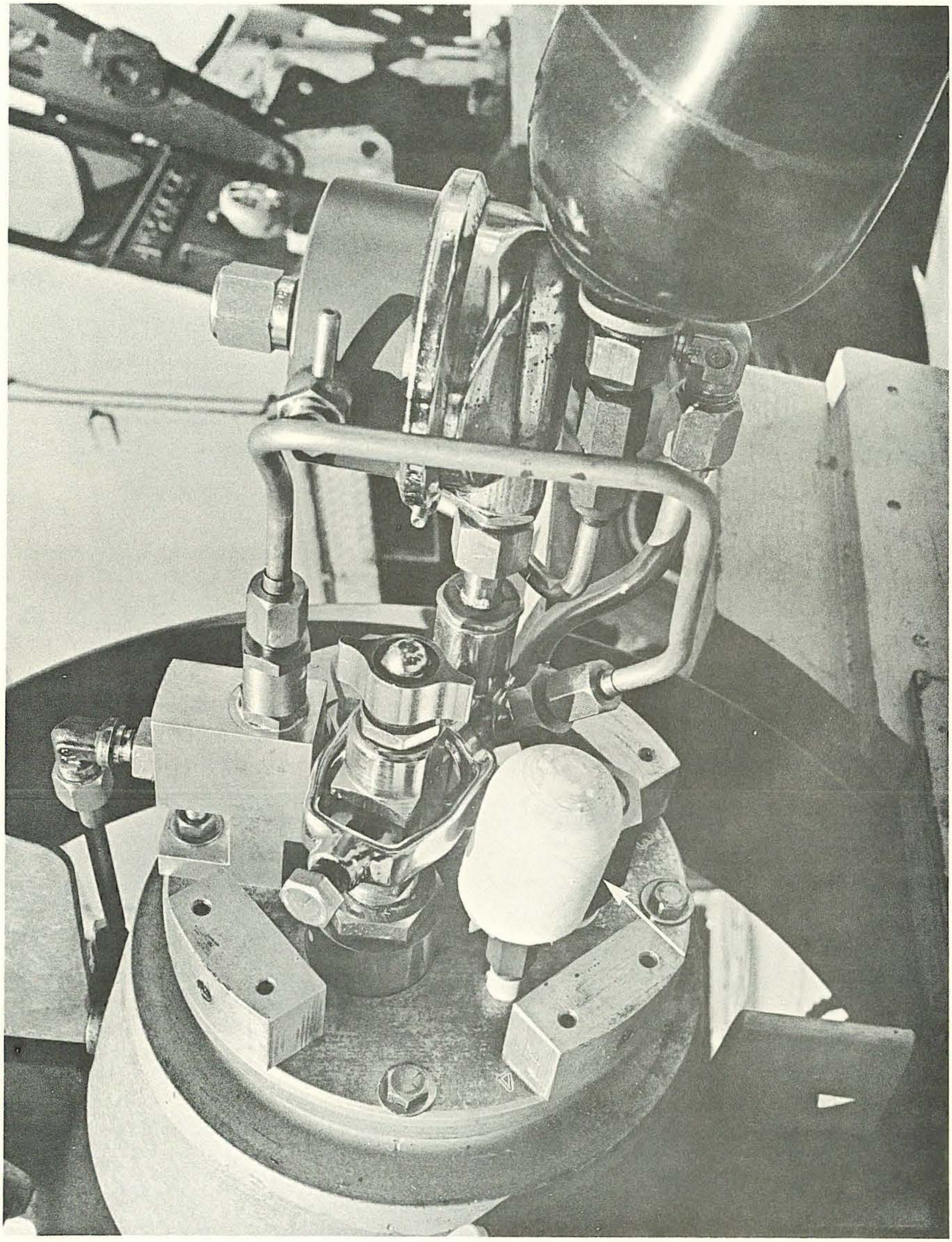


Figure 17. Oil Filled Pressure Transfer Bladder

2.7.3. Instrumentation Power Supply

Both the depth sensing transducer and the temperature sensor require a regulated DC power source. A DC power board was constructed and installed in the nose cone of the fish, as shown in Figure 18. In order to utilize the 230 volt 60 cycle single phase voltage available in the fish, a transformer was used to reduce the voltage to the 110 volt level required by the two model MM24A-110 power supplies. The two assemblies were procured from Power/Mate Corp., Hackensack, NJ. Figure 19 illustrates the wiring schematic for the power distribution panel.

2.7.4. Leak Detector

A conductivity-type leak detector is located in the bilge of the fish. The conductivity probe consists of two pins mounted in an insulator, which is secured at the lowest point inside the hull. Any water that seeps in, or leaks from a pump or tube fitting, will short the pins sounding an alarm topside.

Figure 20 is a block schematic of the system; it consists of a Darlington switch, the detector pins, and a Sonalert audio alarm manufactured by the Mallory Company. A press-to-test button provides a means of checking the circuit.

The sensitivity of the system is such that condensation or high humidity can cause a low audio level of background bleeps. However, if water actually shorts the pins, a high level bleeping overrides the background.

It is interesting to note that as experience is obtained in its operational characteristics, the operator can distinguish between a high humidity signal and actual water in the bilge. The total volume of water can not be ascertained, but quantities in the range of 100 ml will slosh

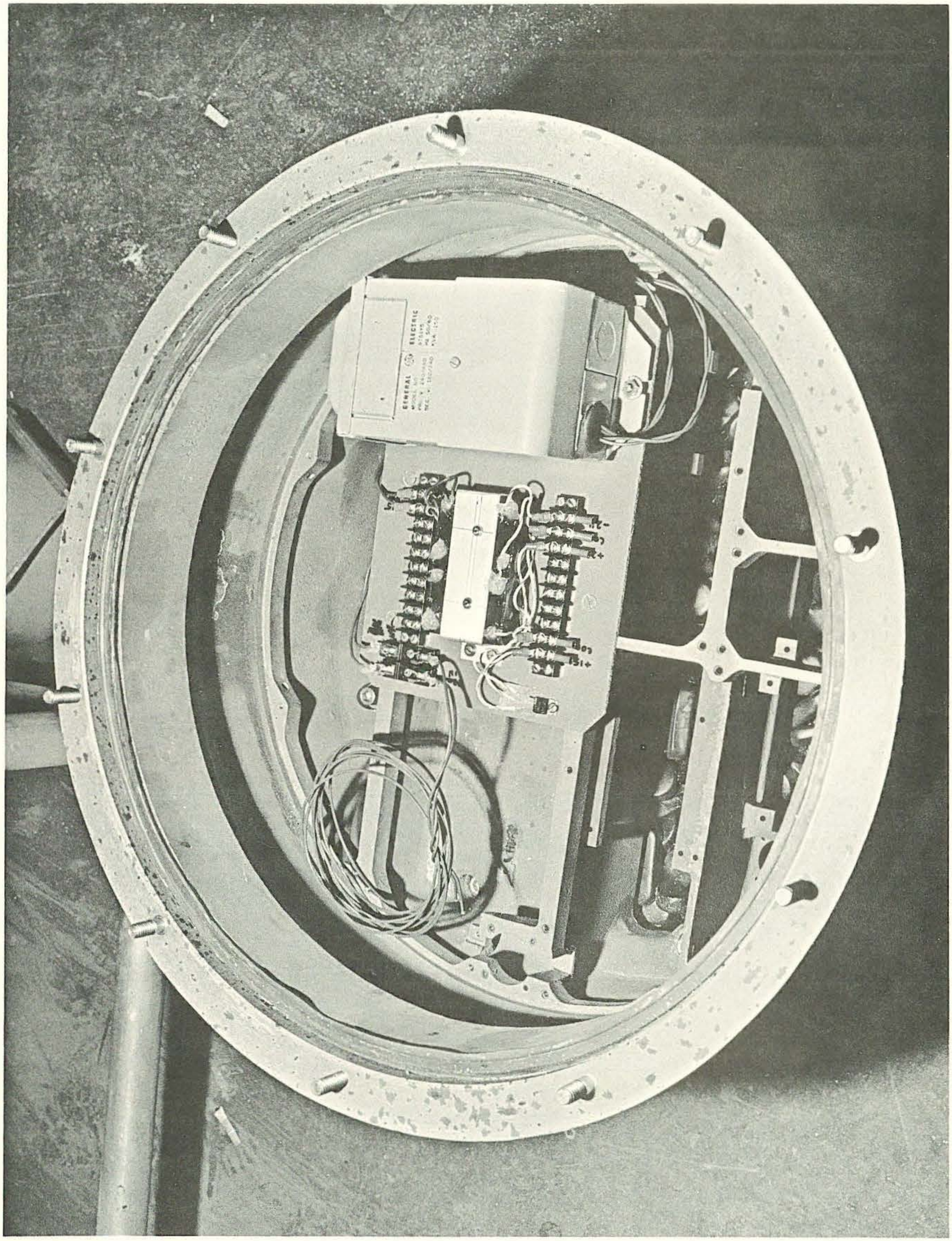


Figure 18. DC Instrumentation Power Board

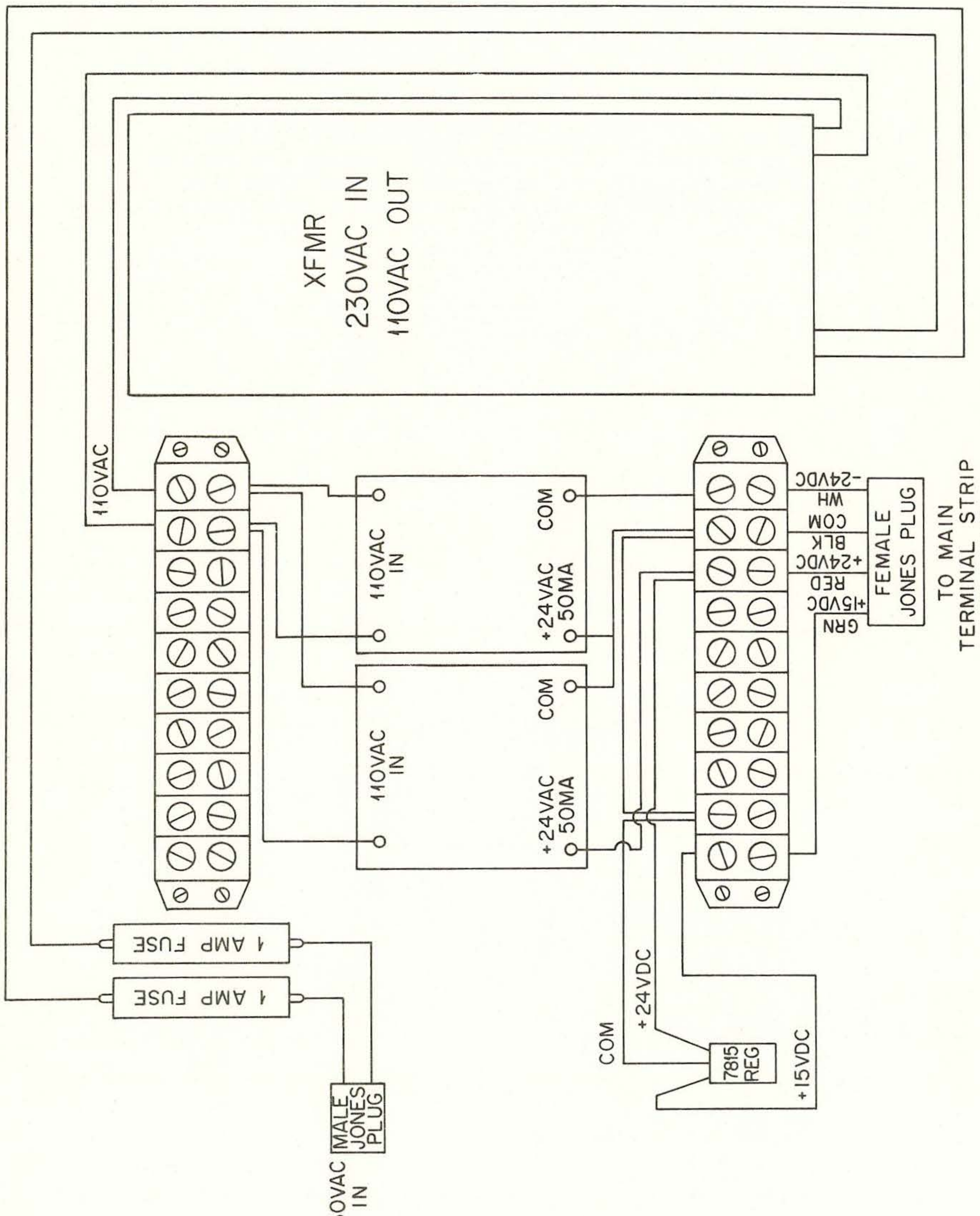


Figure 19. Wiring Schematic of Instrumentation Power Board

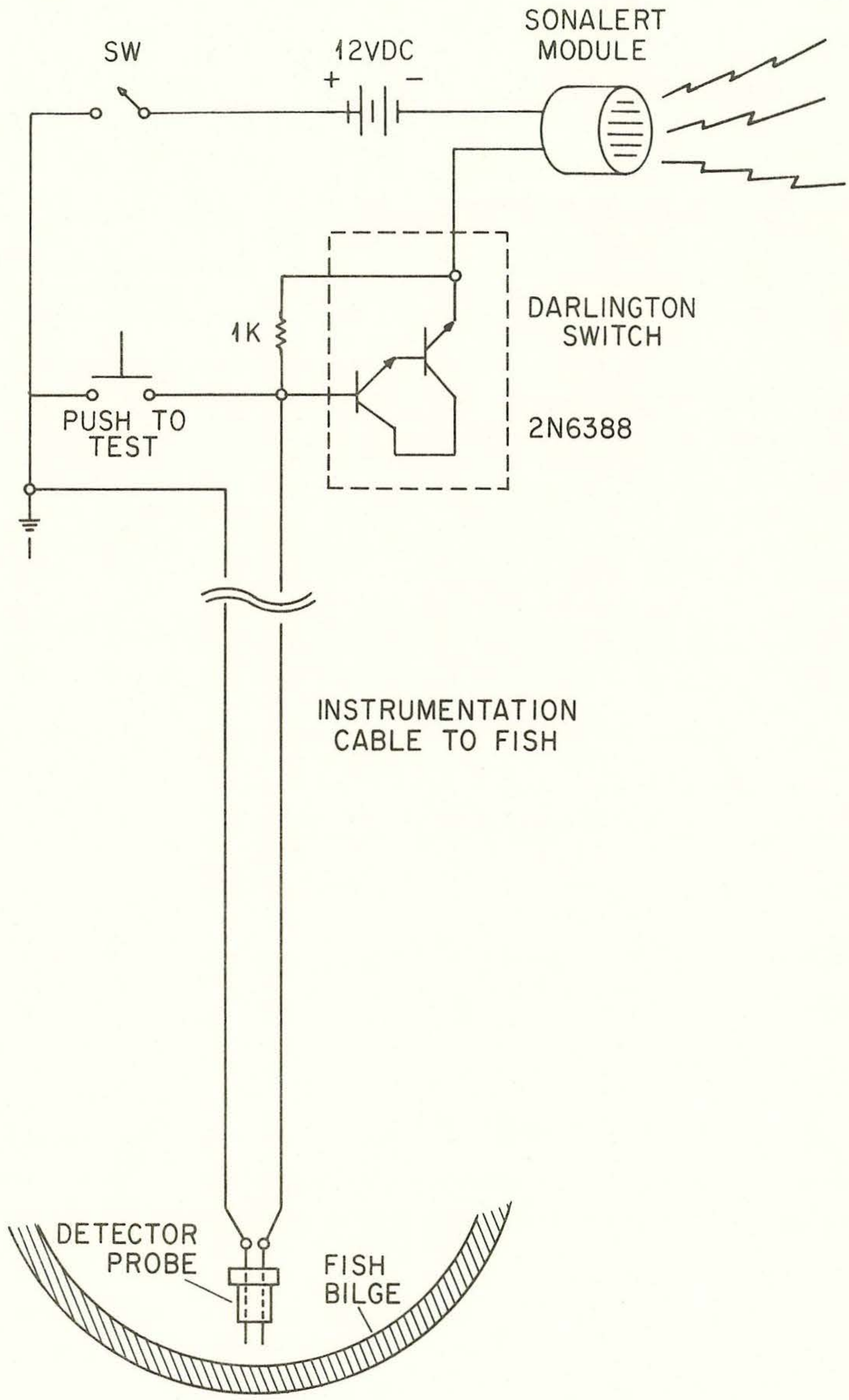


Figure 20. Conductivity Leak Detector Schematic

around in the bilge as the support vessel turns providing an intermittent warning as the probe is covered and uncovered by the fluid. Greater quantities provide longer time periods of bleeps with shorter periods of background sound.

2.7.5. Fish Power System

Initial power for the six pumps is obtained from ships' generators. The string of six pumps will operate on 230 volt, 60 cycle single phase directly; however, to add flexibility to the system and to accomodate a wider range of voltages, the transformer system illustrated in schematic 21 was used. Figure 22 is the actual control panel package. Judicious use of standard shipboard watertight plugs, and generous cable lengths, allow mating with power junction points on most vessels.

The transformer panel plugs directly into the fish control box mounted on the winch frame, as illustrated in Figure 23. The fish control panel also houses the ground fault detector lights. Under normal operating conditions both lights will glow with equal brilliancy, if there are no grounds in a hot wire. If a short occurs due to a loose connection, shorted motor winding or capacitor, chafed insulation, or water infiltration in a cable connector or the fish, one lamp will become dim to the point of going out, indicating a shorted power lead somewhere in the system. Power is immediately shut down to prevent a possible hazard to operating personnel.

An added feature of this circuit is the push-to-test button. This is not a short-the-system test. Under some short conditions, high humidity or even a moisture film across a hot wire could pass sufficient current through a person's body to be lethal, and still not cause an indicator lamp to go out. Assume one lamp dims slightly, but both lamps "appear" the same.

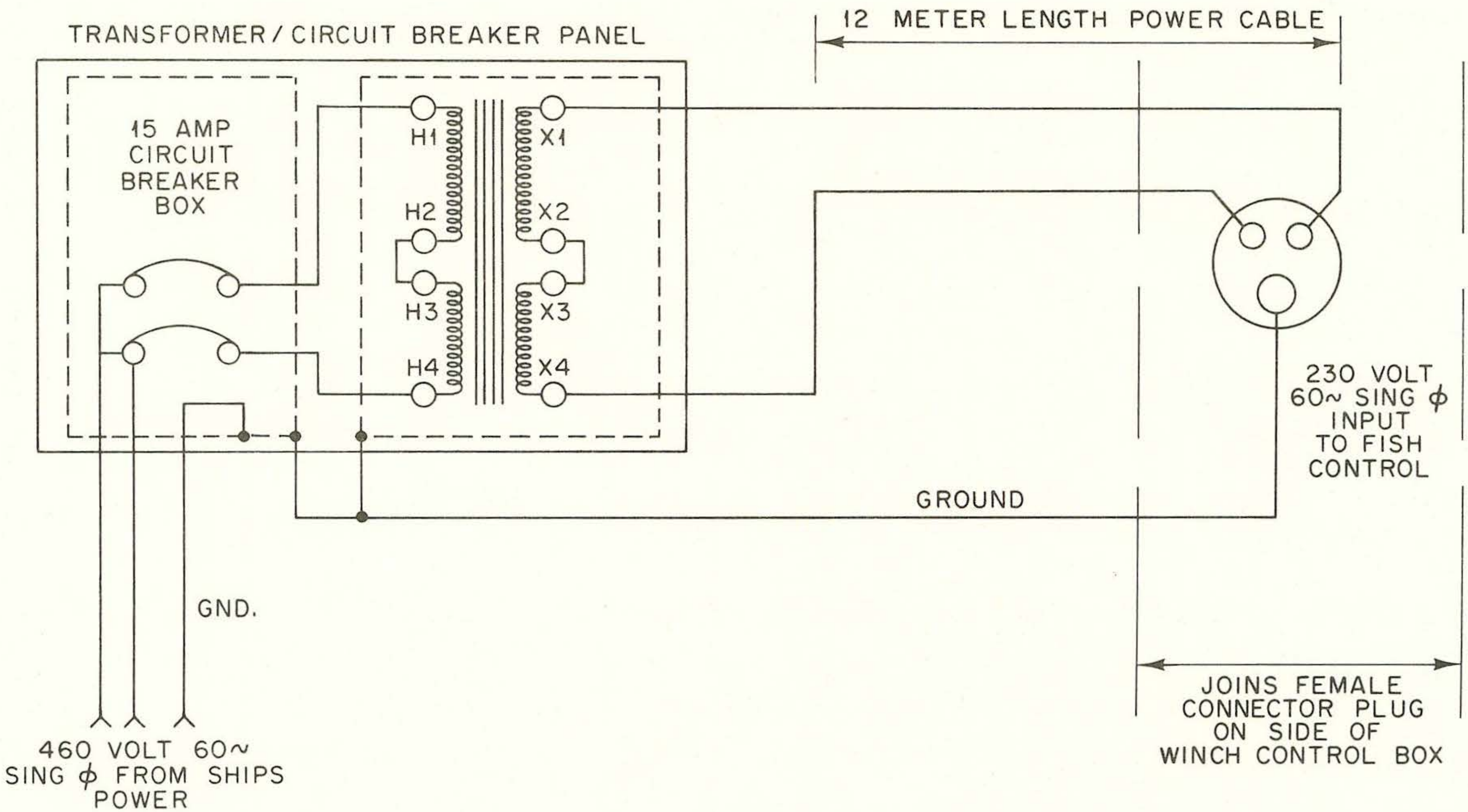


Figure 21. 460 Volt to 230 Volt Step Down Transformer Schematic

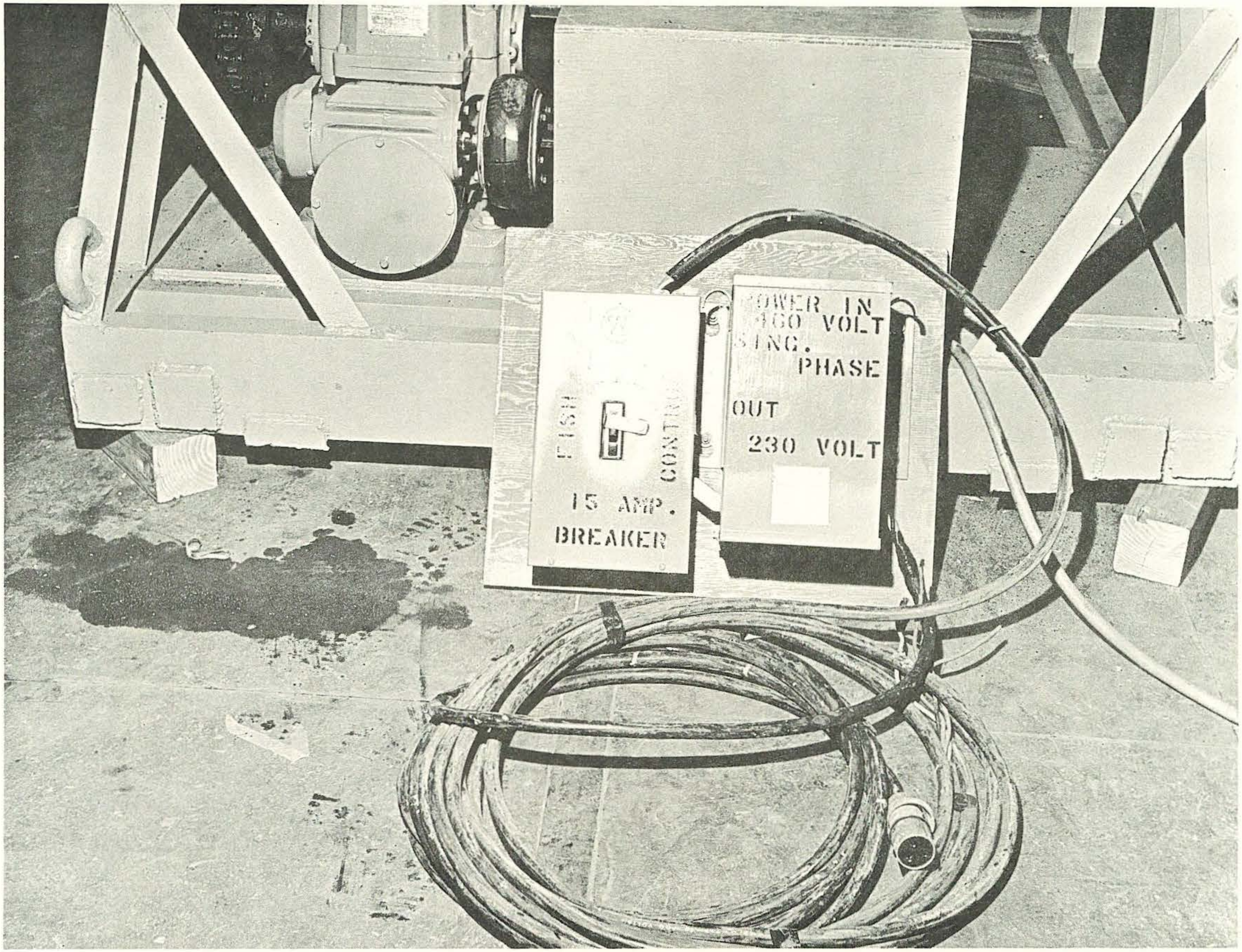


Figure 22. Step Down Transformer and Circuit Breaker Panel

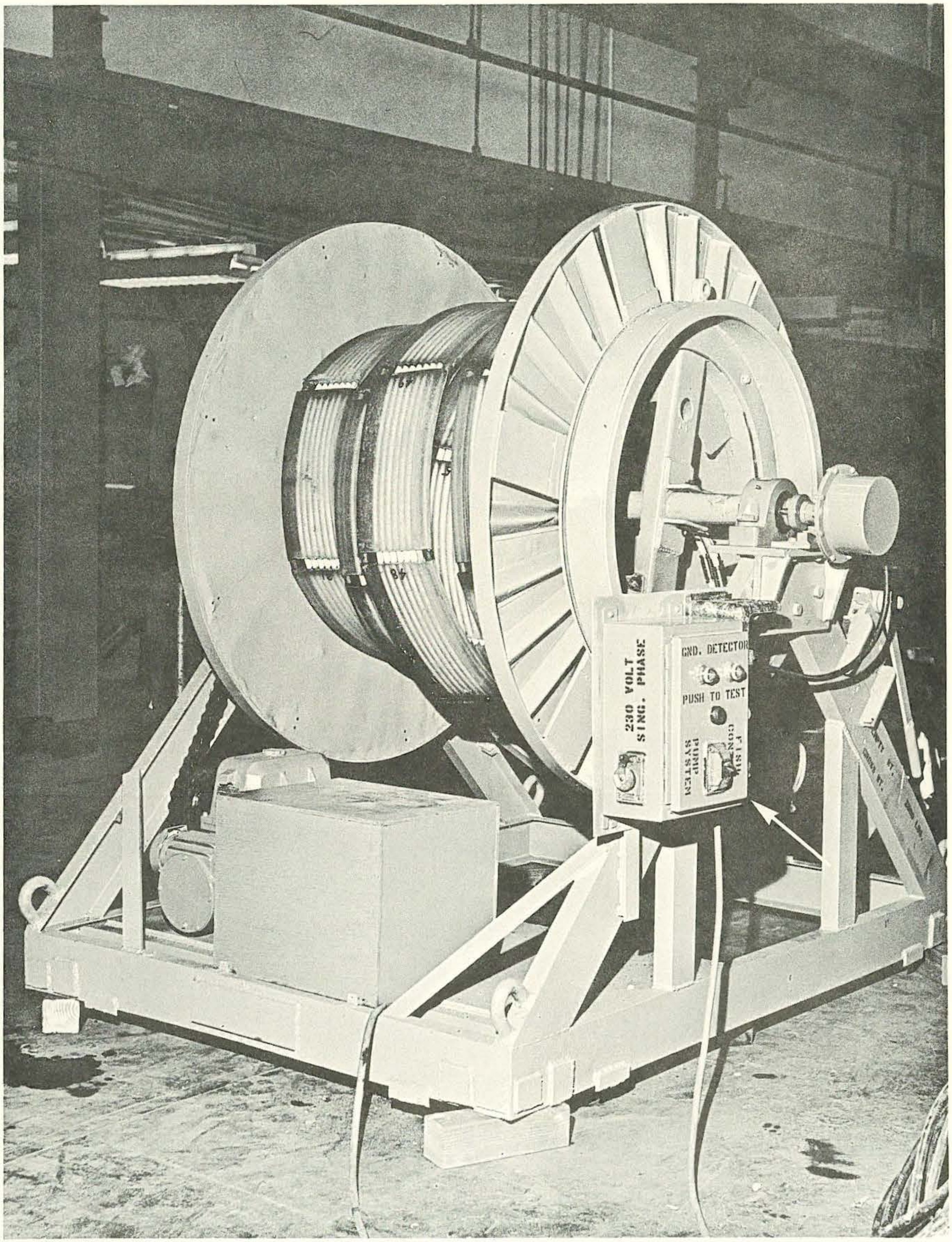


Figure 23. Fish Control and Ground Fault Detector Panel

The push-to-test button will make both lamps of equal brilliancy. When released, even a slight change in the lamp on the shorted line become obvious. Figure 24 is the detailed schematic for the ground fault detector circuit.

The three wire number 12 power cable enters the fish through a four pin, four conductor male and female plug assembly procured from Electro-Oceanics Inc., Compton, California. The three leads are directed to the power distribution panel in the fish, shown in Figure 25, then rerouted to the various electrical devices. Figure 26 is the schematic for these circuits.

The main power consumption devices are the pump motors. These are individually fused to assure multiple failures can not shut down the entire system. Figure 27 illustrates the fuse layout and wiring harness around the periphery of the three forward pumps. The schematic in Figure 28 provides the details of the motor wiring circuits.

2.7.6. Winch Power System

The winch drive is a 10 horsepower, 1750 RPM, 480 volt, 60 cycle, 3 phase motor. It is controlled with conventional magnetic contact relays, and fused in accordance with shipboard wiring standards. A three position lever-type switch (in-off-out) controls the drum operation. The switch location can be seen in Figure 29. The cylindrical component on the shaft end is a 3 conductor slip ring, which directs the 230 volt power to the fish. Figure 30 is the wiring schematic for the winch motor drive.

2.8. Winch Assembly

Figure 31 illustrates the winch mounted on the fantail of the NOAA research vessel MT. MITCHELL. At the time of the photograph the winch and

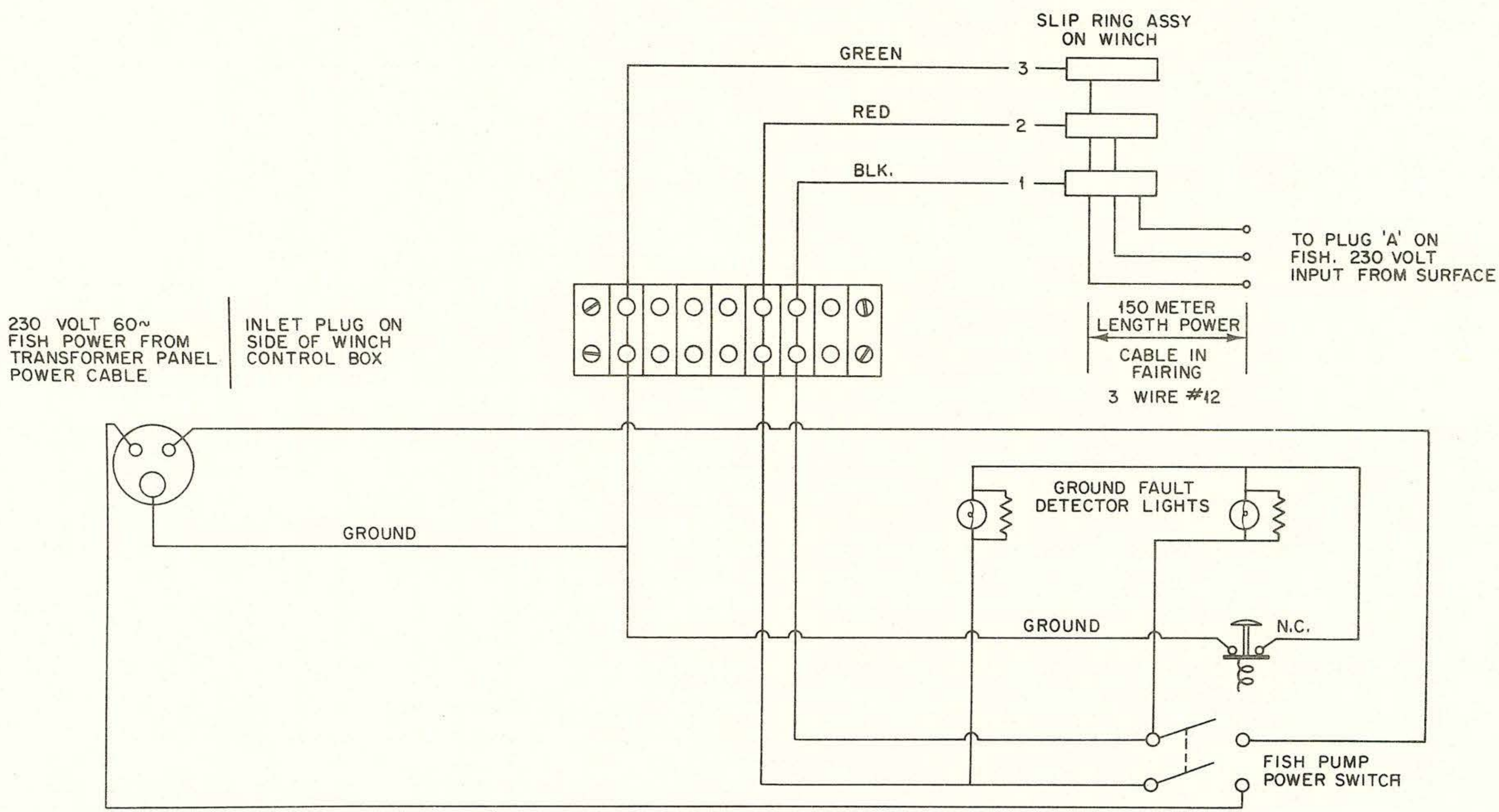


Figure 24. Fish Control and Ground Fault Detector Schematic

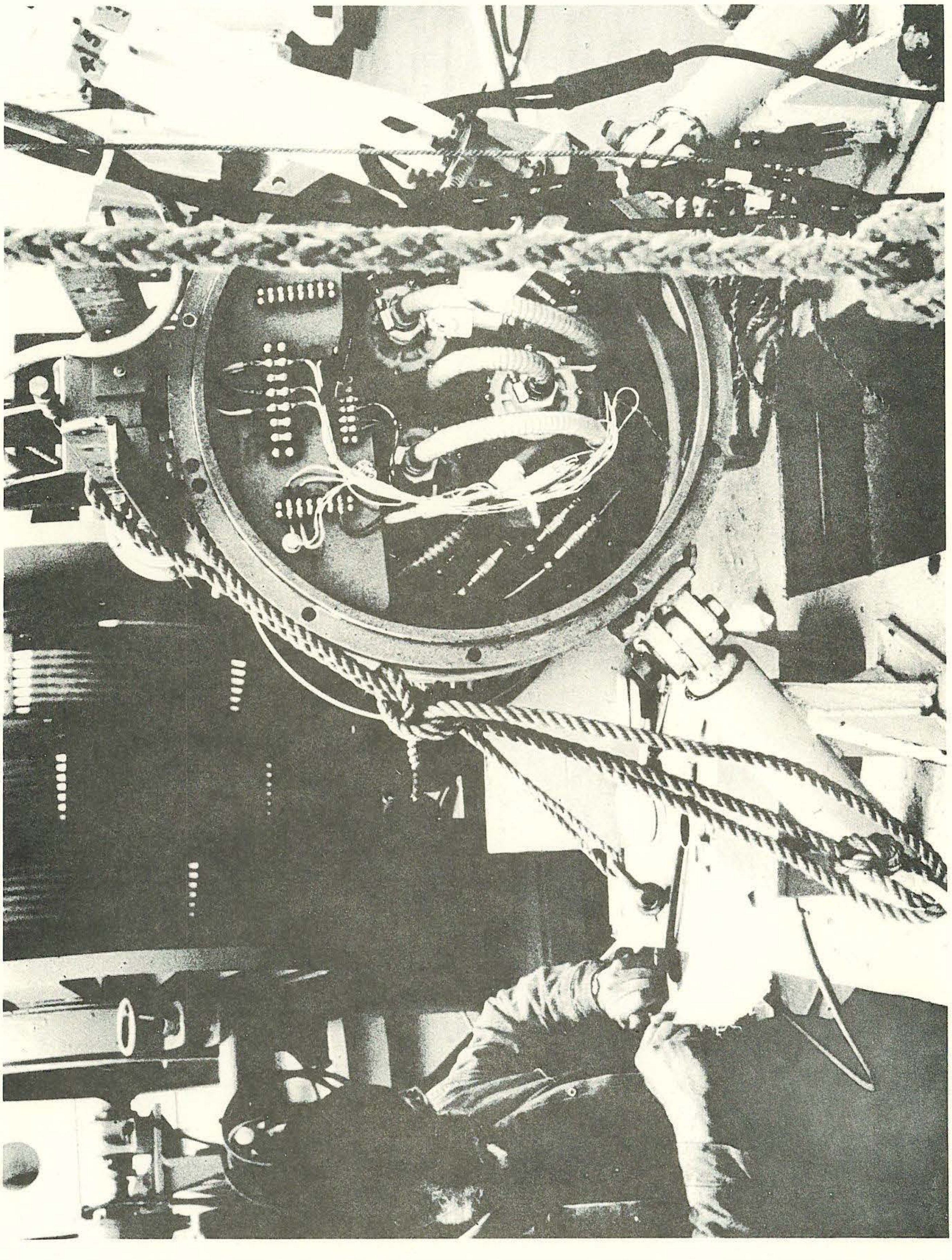


Figure 25. Power Distribution Panel in Fish

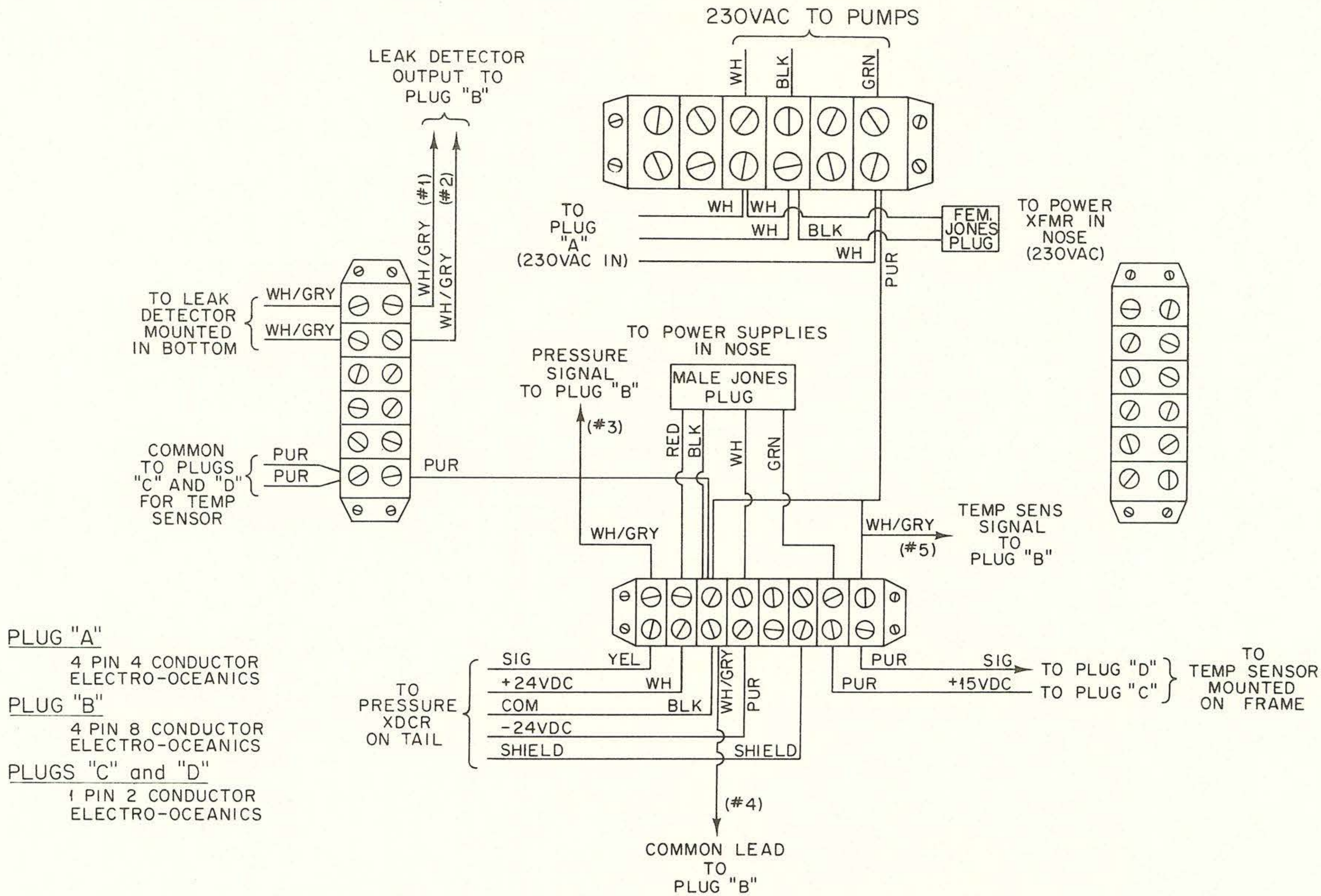


Figure 26. Electrical Power Distribution Schematic in Fish

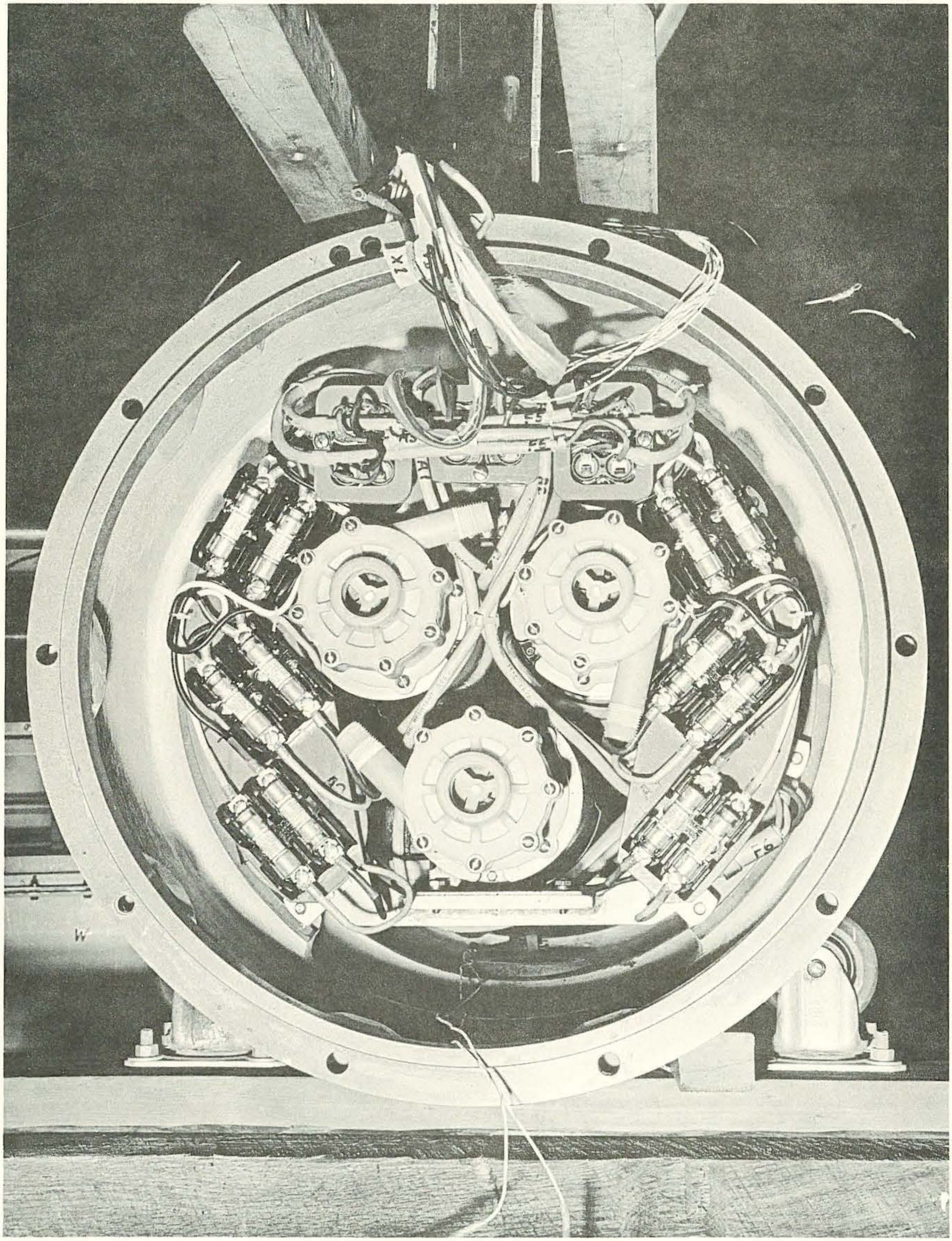


Figure 27. Pump Motor Fuse Assembly in Fish

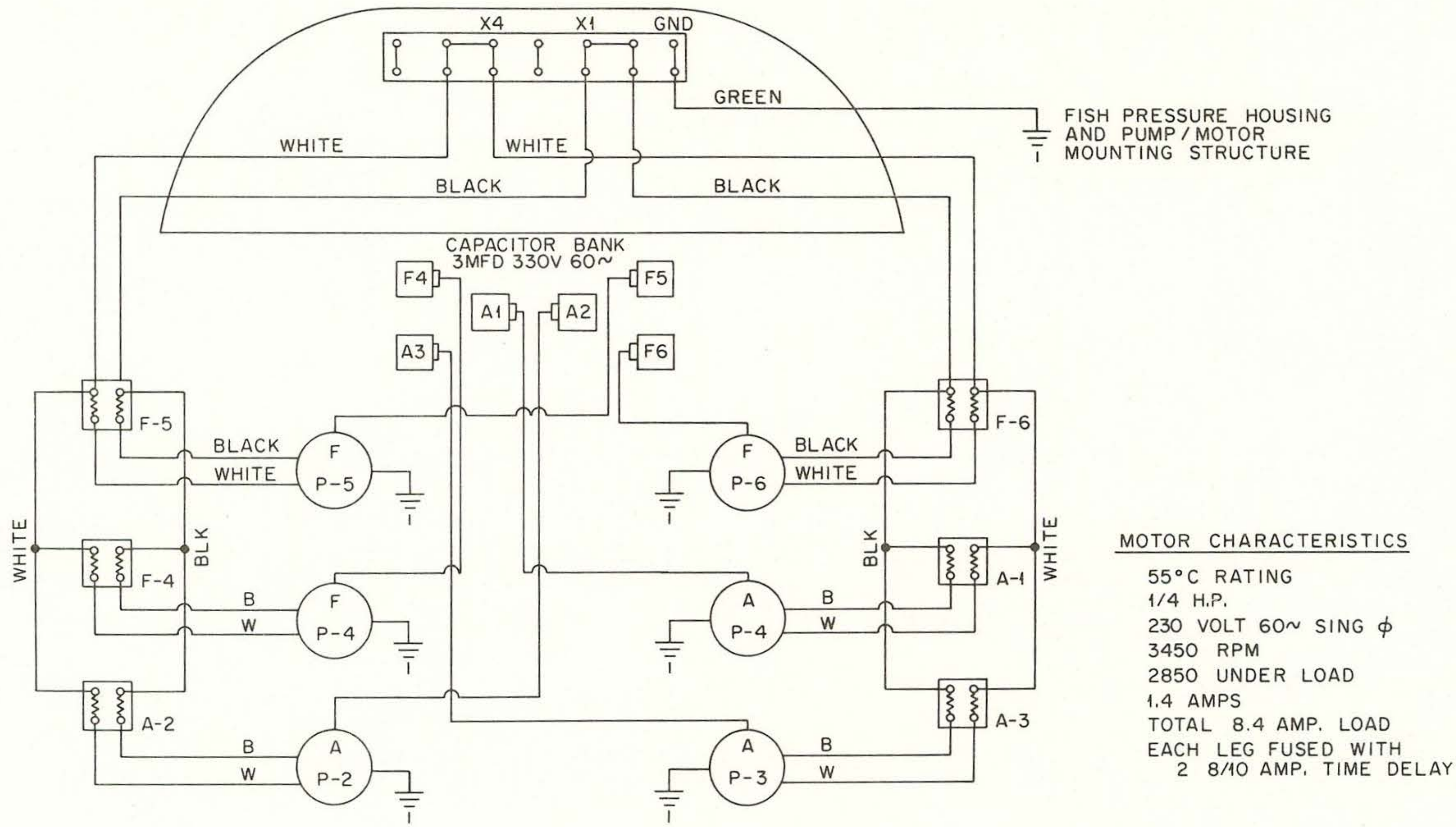


Figure 28. Pump Motor Fuse Wiring Schematic

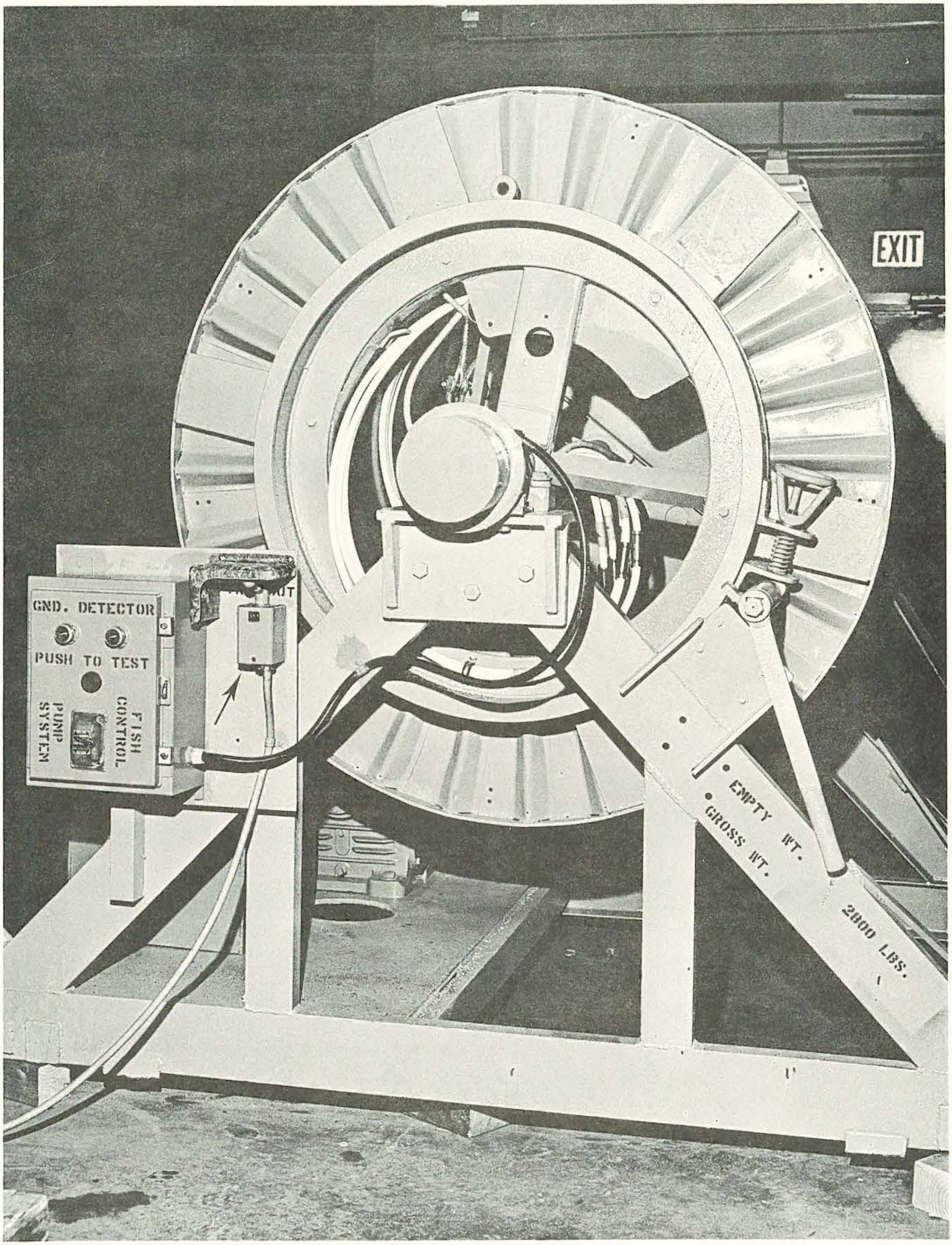


Figure 29. Winch Control Switch and Slip Ring Assembly

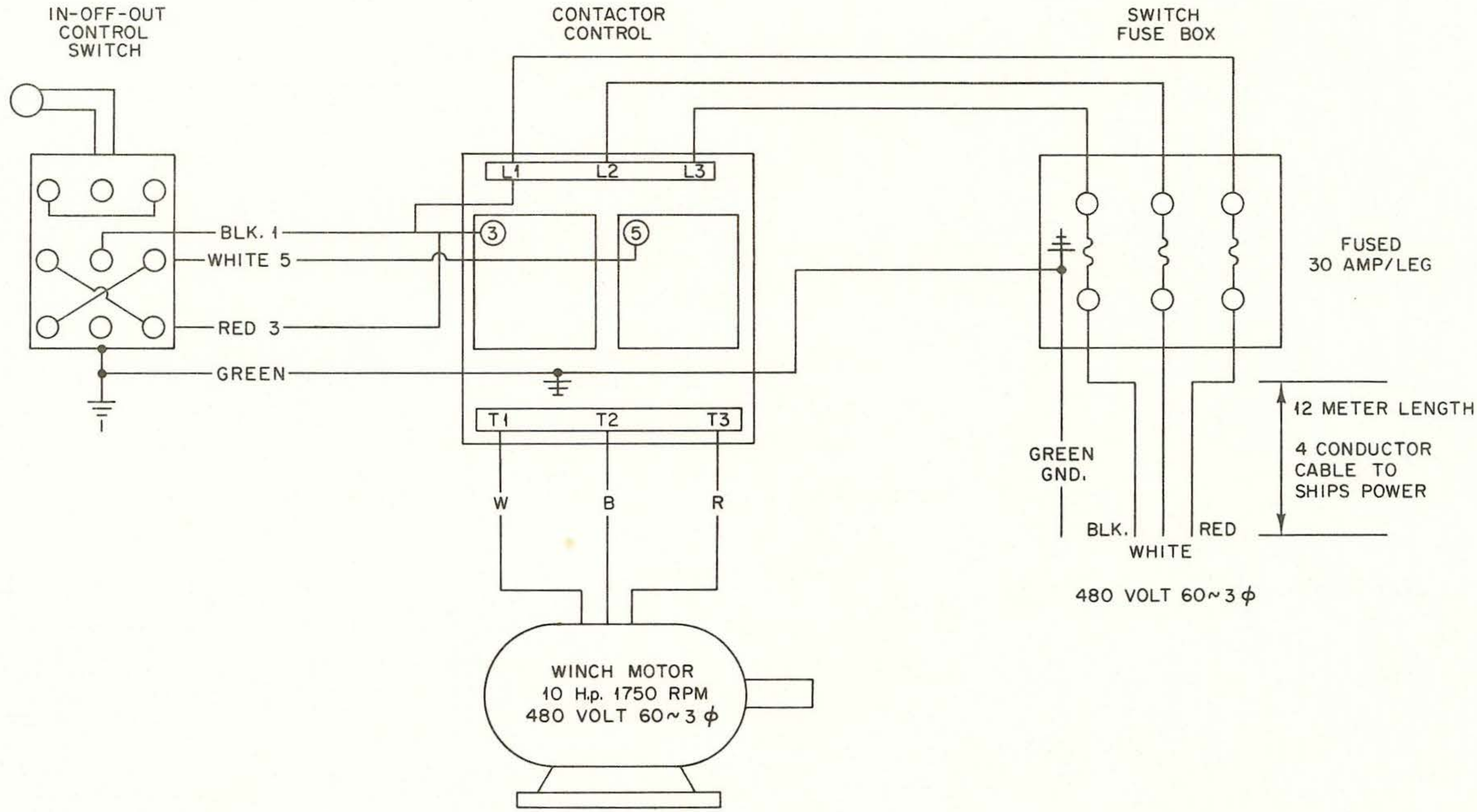


Figure 30. Wiring Schematic for Winch Motor Drive

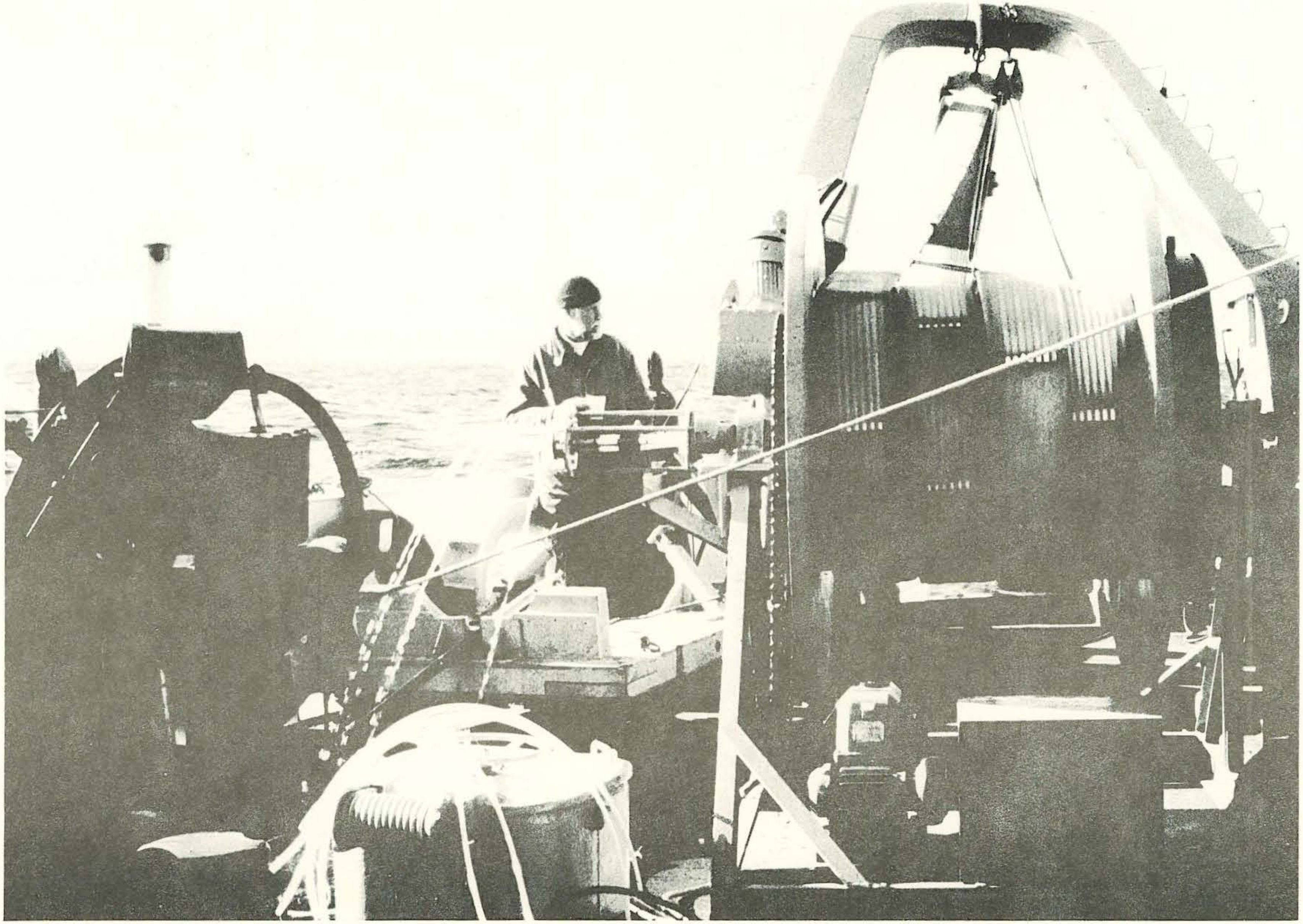


Figure 31. Winch Assembly in NOAA Vessel R/V MT. MITCHELL

fish were operating in an ocean dump site. Water samples from the six pump ports can be seen flowing from the quick disconnect assembly to the left center of the winch drum. Figure 32 illustrates a close-up of the assembly. It is identical to the two disconnects mounted on the fish. With three identical assemblies, spare parts requirements are substantially reduced.

The winch frame is constructed of 15 cm wide channel and 7 cm angle iron, sand blasted and primed with Dimetcote, a top coat of gray enamel seals the steel structure from element exposure. The winch is 1.5 meters wide, 2 meters deep, with an overall height from the base to the top of the drum being 2 meters. The empty drum weight is 1270 Kg. The gross weight of the assembly with 150 meters of fairing is 1800 Kg.

A 10 horsepower, 3 phase, 480 volt, 60 cycle motor powers a DWB-600 double worm reducer with a 125:1 reduction ratio. A Dodge PX70 paraflex coupling isolates shock loads and aids in motor-to-gearbox alignment. Both items can be seen in the lower right of Figure 32. The square housing protects the motor from spray and inclement weather conditions.

The drum is driven through a bolted-on steel sprocket P/N 100A-70 type A steel. A P/N 100B-22TL drive sprocket is mounted on the output shaft of the gear reducer. The roller drive chain is P/N FR-RC-100, 31.7 mm pitch by 19 mm width.

The cable storage drum rides on a 76 mm OD 4130 cold drawn steel tube, having a 52 mm ID. The power cable and six Teflon sampling tubes are fed through the hollow core, and are connected to the power slip ring mounted at one end of the shaft, and the sample distribution quick disconnect at the opposite end.

To assure a positive drum lock during long tows, a mechanical over-center lever actuated toggle brake has been installed. Figure 28 shows the

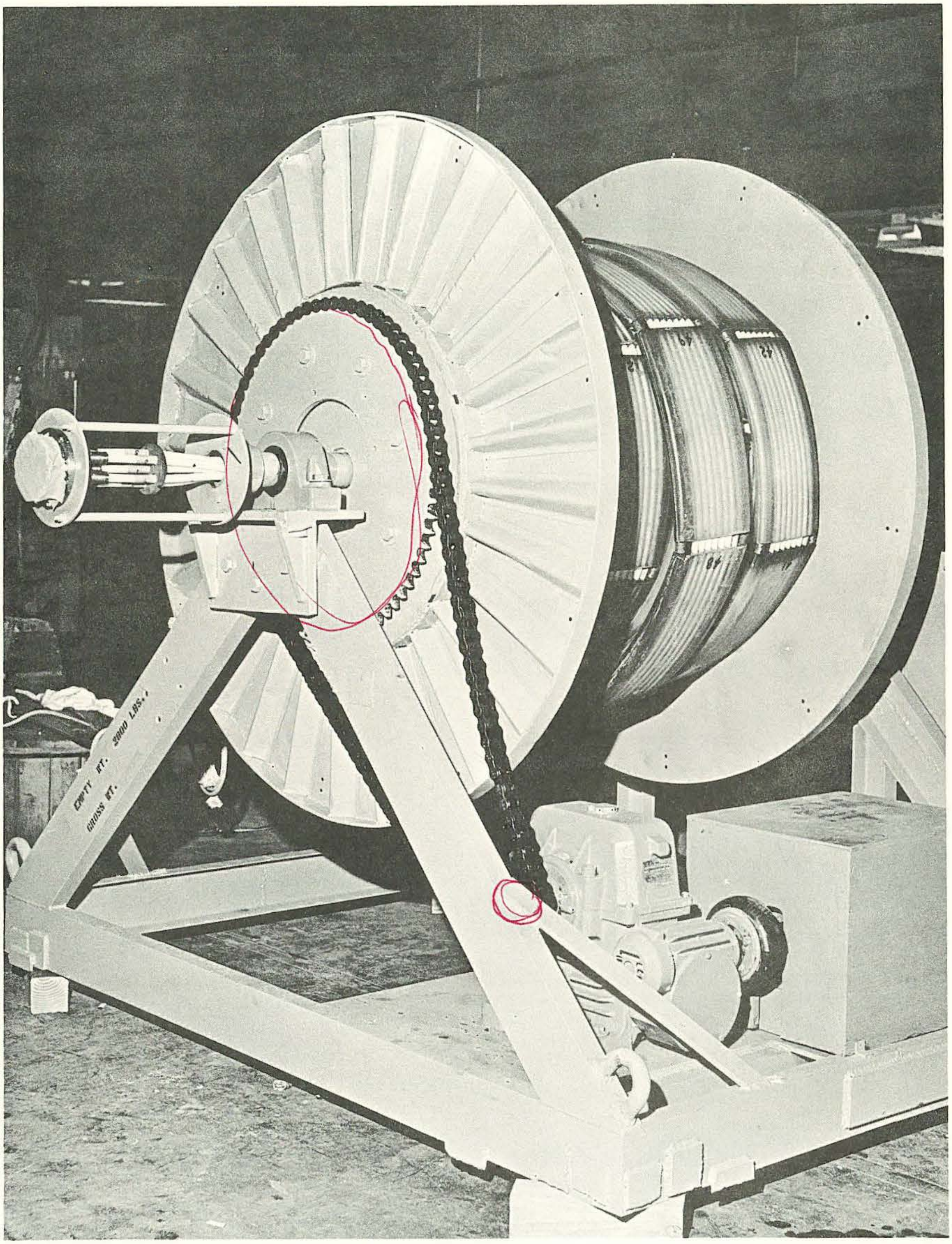


Figure 32. Winch Discharge Port Disconnect Assembly

brake band mechanism and the actuating lever to the right of the winch.

The winch is capable of raising or lowering the fish and associated fairing while underway at ship speeds of 2 m/sec.

2.9. Fiberglass Composite Sheave

The sheave illustrated in Figure 33 was fabricated by Astronautics Industries, Marlboro, Massachusetts. It is 91 cm in diameter, 31 cm wide, with a 24 cm groove width to pass the pliant fairings. The groove depth is 5.7 cm. The inside face of the groove wall has a 15° outward taper to assist in guiding the fairings and to reduce the ride-out during deployment and retrieval.

A circular aluminum compression disc has been molded inside the sheave. It equalizes the load by supporting the center point of the inner face of the sheave groove, transmitting the compressive forces to the axel hub. The hub has a fixed bronze bearing riding on a stainless steel shaft. Grease fittings at both ends of the shaft maintain adequate lubrication to the sleeve bearing.

The cheek plates are 12 mm 6061-T6 aluminum, while the top attachment plate is 25 mm thick stainless steel. The plate has a semicircular section machined in its bottom edge, sufficiently large to pass an assembled sample tube disconnect, facilitating at-sea setup.

The two side plates and the cylindrical portion of the sheave are of wet lay-up vacuum bag construction. The final wall thickness of the cylinder is 15 mm, the side walls at the OD is 38 mm, increasing to 62 mm at the shaft hub. The three sections of the sheave were assembled by wet lay-up resin and fiberglass mat. Six through bolts and internal spacer rods assist in maintaining a compression force on the side plates preventing bowing when under load. The air weight of the total assembly is 115 Kg.

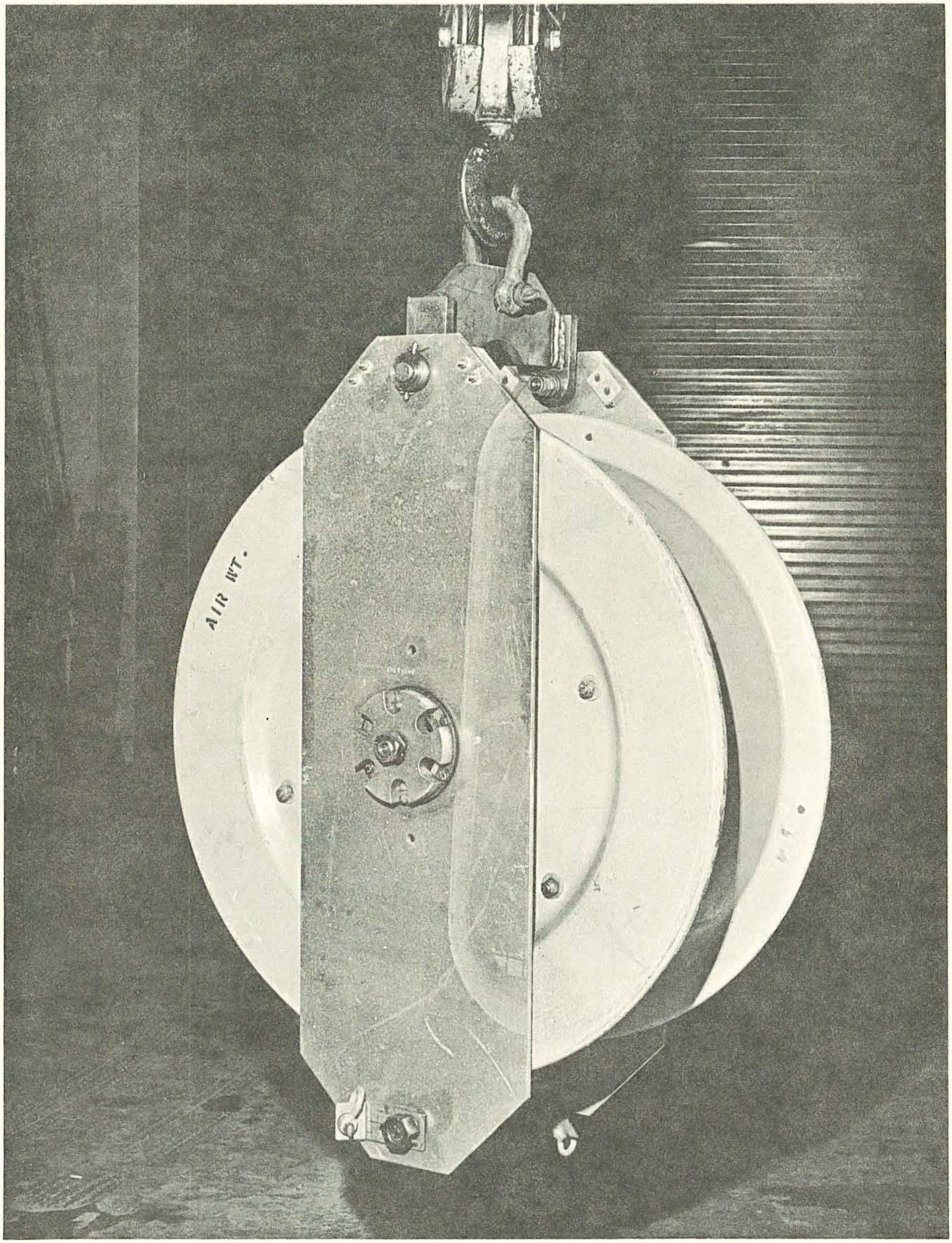


Figure 33. Composite Fiberglass Sheave Assembly

3.0. Fish Deployment and Operation

The design of the original equipment was geared for deployment from a side mounted 'A' frame. The fish is cradled outboard, along the after bulwark, with the sampling probe secured in the position illustrated by Figure 34. To initiate deployment, the boom is lowered and locked in place as shown in Figure 35. The fish is then lowered to the selected sampling depth while the vessel gets underway.

Figure 36 is an overall view of the assembled device, while Figure 37 shows the fish and probe in its predeployed position. These photographs were taken during dockside tow tests at the Woods Hole Oceanographic Institution.

The tests were performed by lowering the apparatus in the water, booming out the crane, then traversing the length of the dock, approximately 120 meters. Steady state forward velocities were performed between 0.4 m/sec. to as great as 2.0 m/sec. The fish and the sampling probe exhibited excellent vertical position and tracking stability throughout the test program.

Figure 38 illustrates the swivel lock joint at the base of the fish and the upper end of the sampling probe. Aerofast lock pins are used to secure the probe when it is in the vertical or deployment ready position. The sampling probe is constructed from a modified aluminum sailboat mast having an air foil cross section. Six Teflon sampling tubes run through the hollow center of the mast. They exit through individual holes at the top, and are attached to a quick disconnect assembly that mates with the suction inlet at the bottom of the fish.

The individual suction lines are a continuous length of Teflon tube. The actual inlet is held rigid through the use of a stainless steel tube

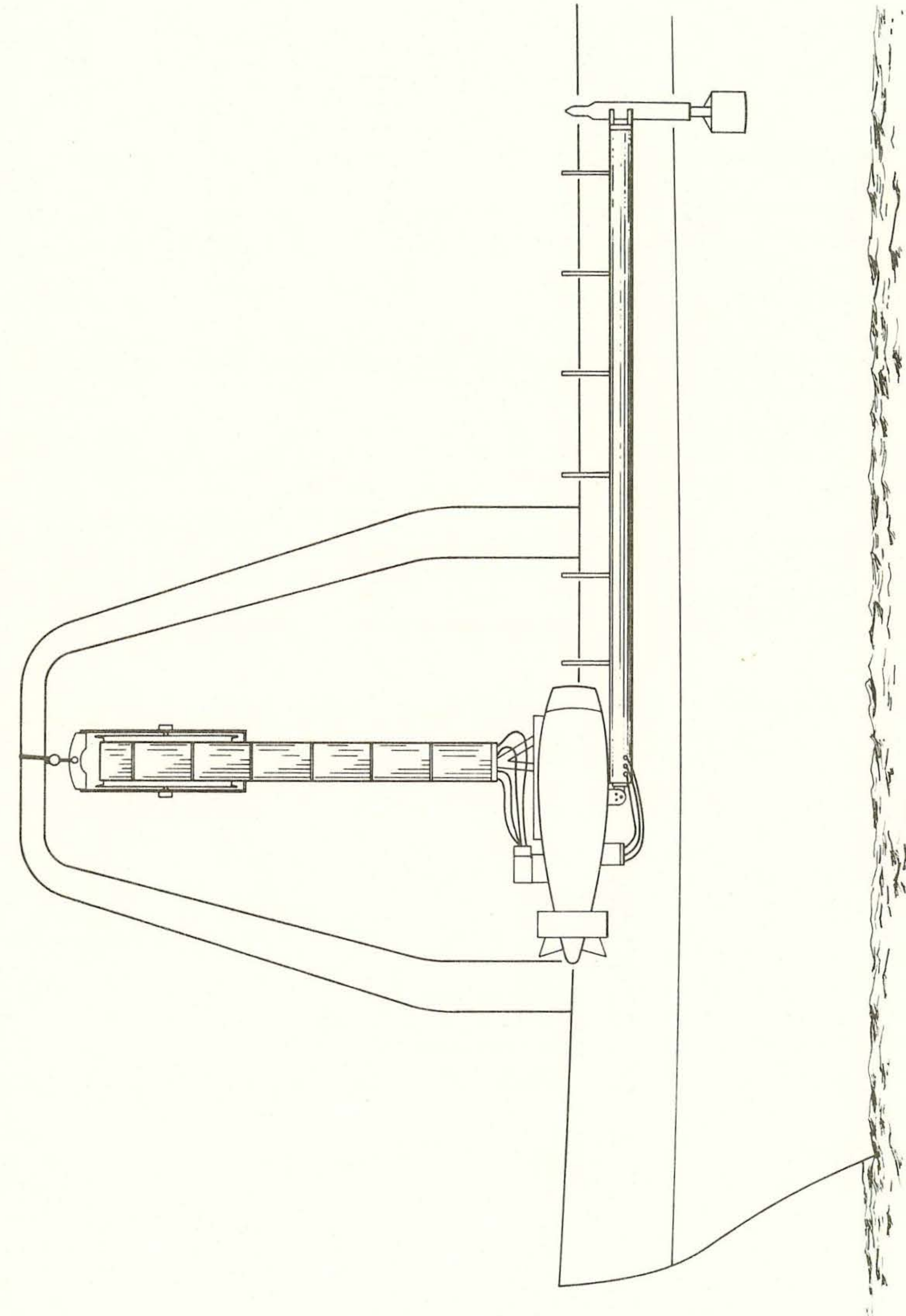


Figure 34. Side Mounted Fish in Standby Position

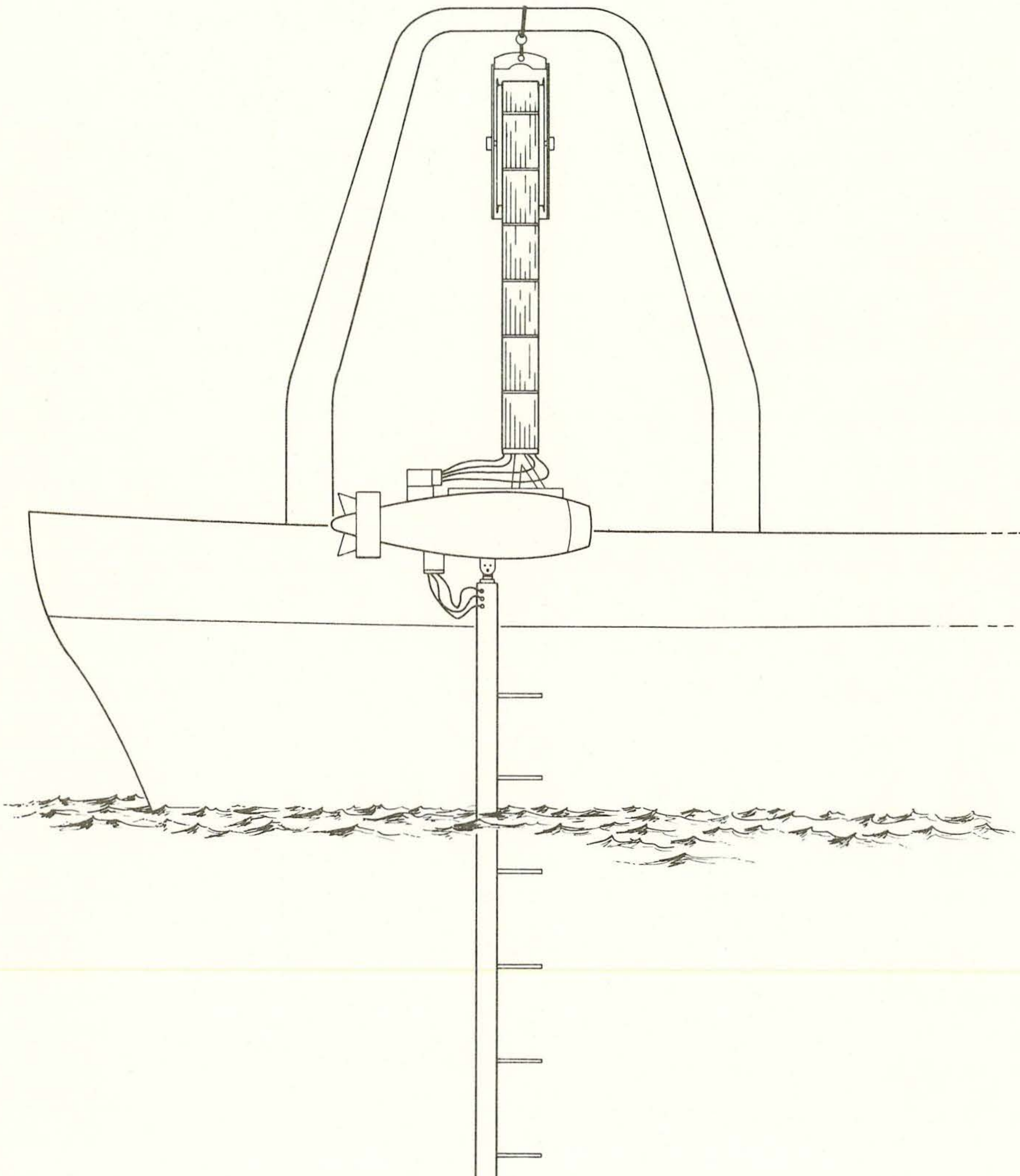


Figure 35. Side Mounted Fish in Deployment Position

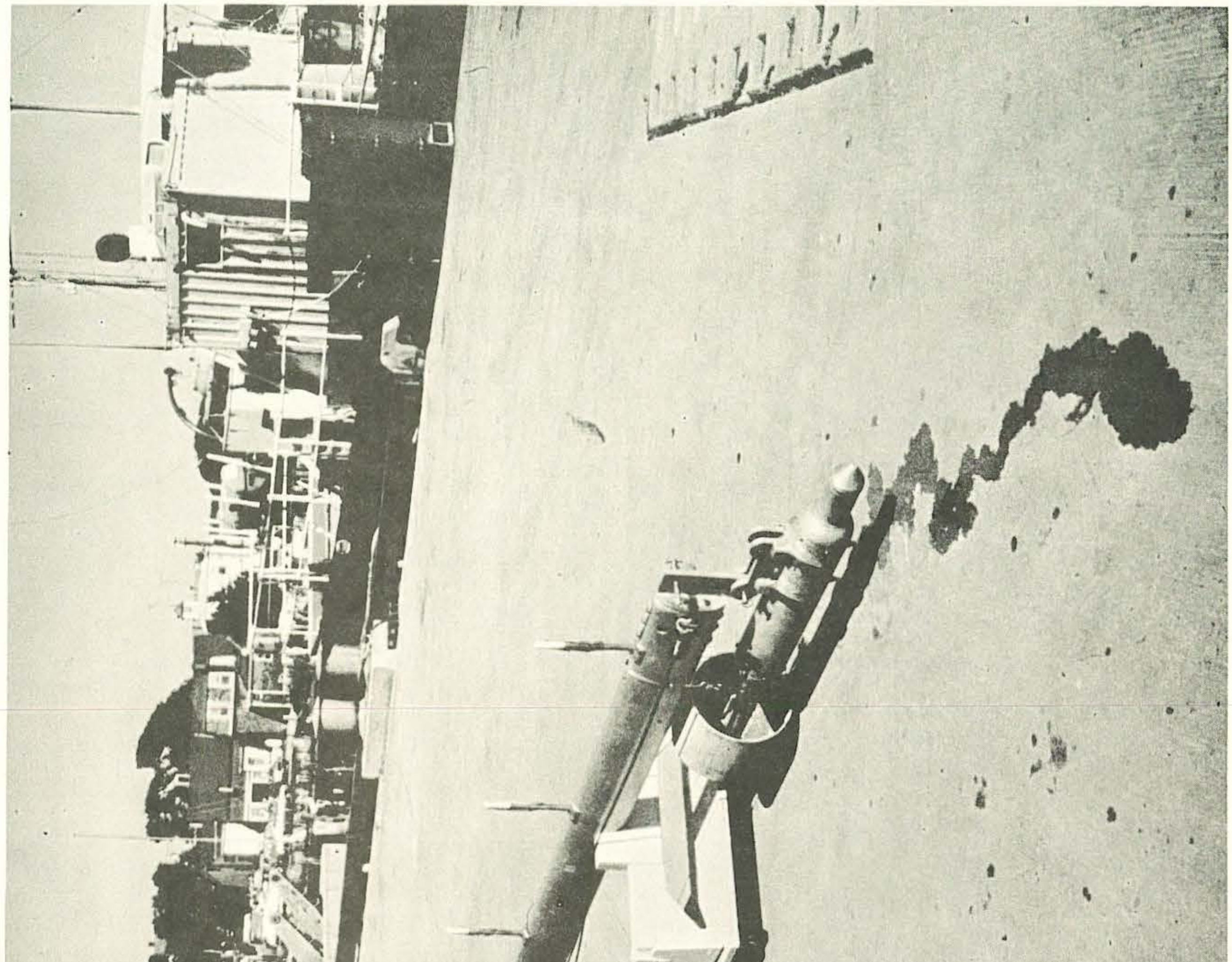


Figure 36. Rigid Boom Sampling Fish

Figure 37. Rigid Boom Fish Preparing for Tow Test

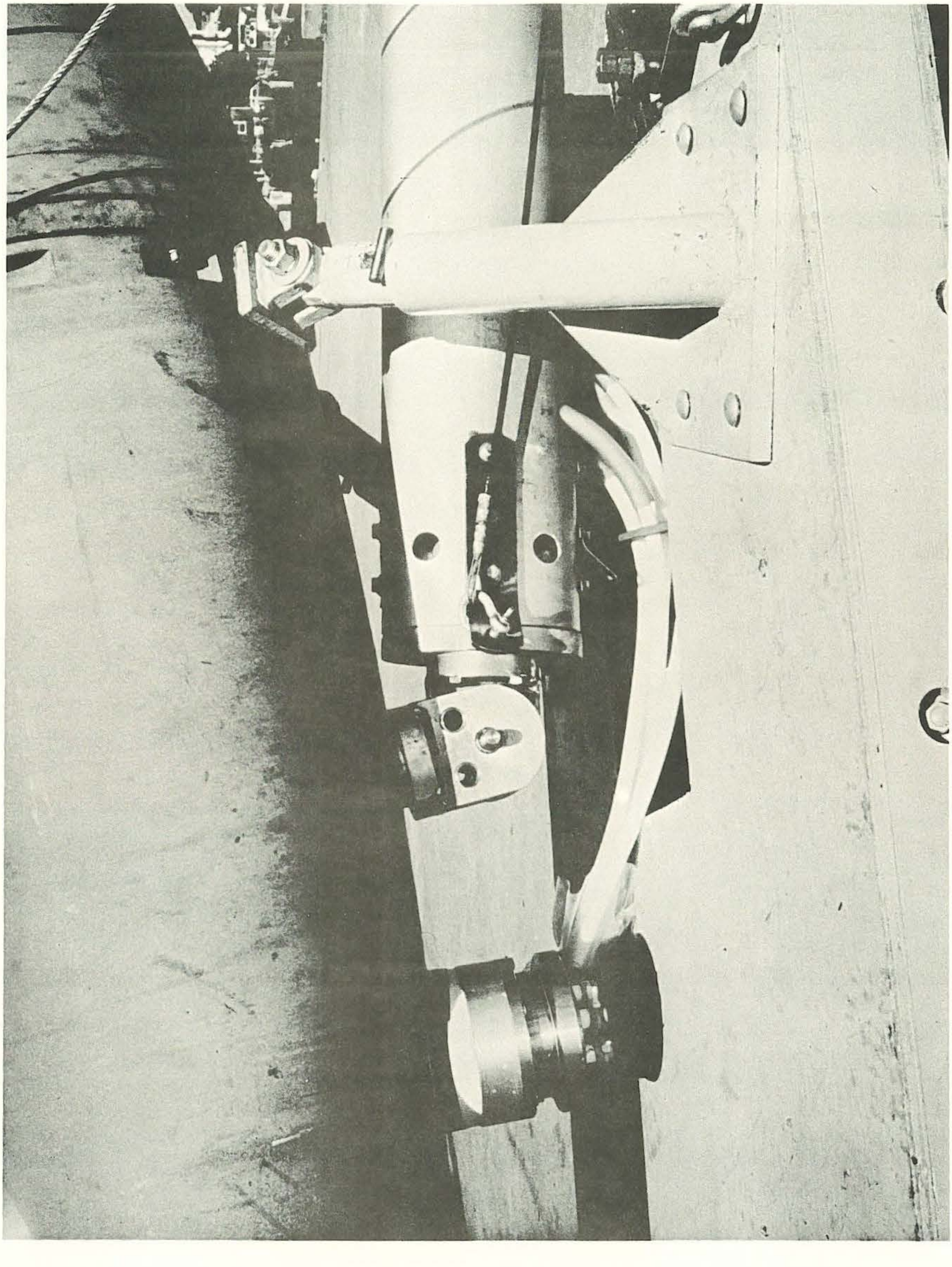


Figure 38. Rigid Boom Swivel Lock Assembly

secured to the leading edge of the mast. The inlet openings are maintained at a 10 cm distance from the nearest metallic surface, and are always upstream of any possible contamination when sampling is being undertaken. Figure 39 illustrates the inlet probe assembly details. The Teflon ball closing the inlet blocks the port during initial deployment. It prevents oil slick or other foreign surface material from contaminating or plugging the system.

The Teflon closure ball is automatic in operation. As illustrated in the photograph, two rubber bands restrain the ball against the inlet port. In actual operation, the left hand rubber band is looped around a crystal mint Life Saver, which is then hooked to the large open loop on the lower half of the rigid tube. After deployment and immersion, it requires between three to five minutes to dissolve sufficiently for the rubber band to fracture the crystal, allowing the ball to snap off the inlet. Tests indicate water temperature does not appear to have any detrimental effect on the time required to fracture the crystal.

Figure 40 is a close-up of the weighted fish attached to the base of the inlet probe mast. Its weight is 125 Kg and was calculated to maintain the fish in a slight nose-high attitude when in a static or dead-in-the-water condition. During the tow mode, the drag imposed by the bottom mounted mast tends to level off the fish, and consequently maintain the inlet probe in a near vertical position.

3.1. Deployment of Rigid Inlet Probe Assembly

The initial sea deployment occurred on the NOAA research vessel ALBATROSS. Time did not permit the fabrication and installation of the bulwark side mounted cradle to aid in the launching process. Consequently,

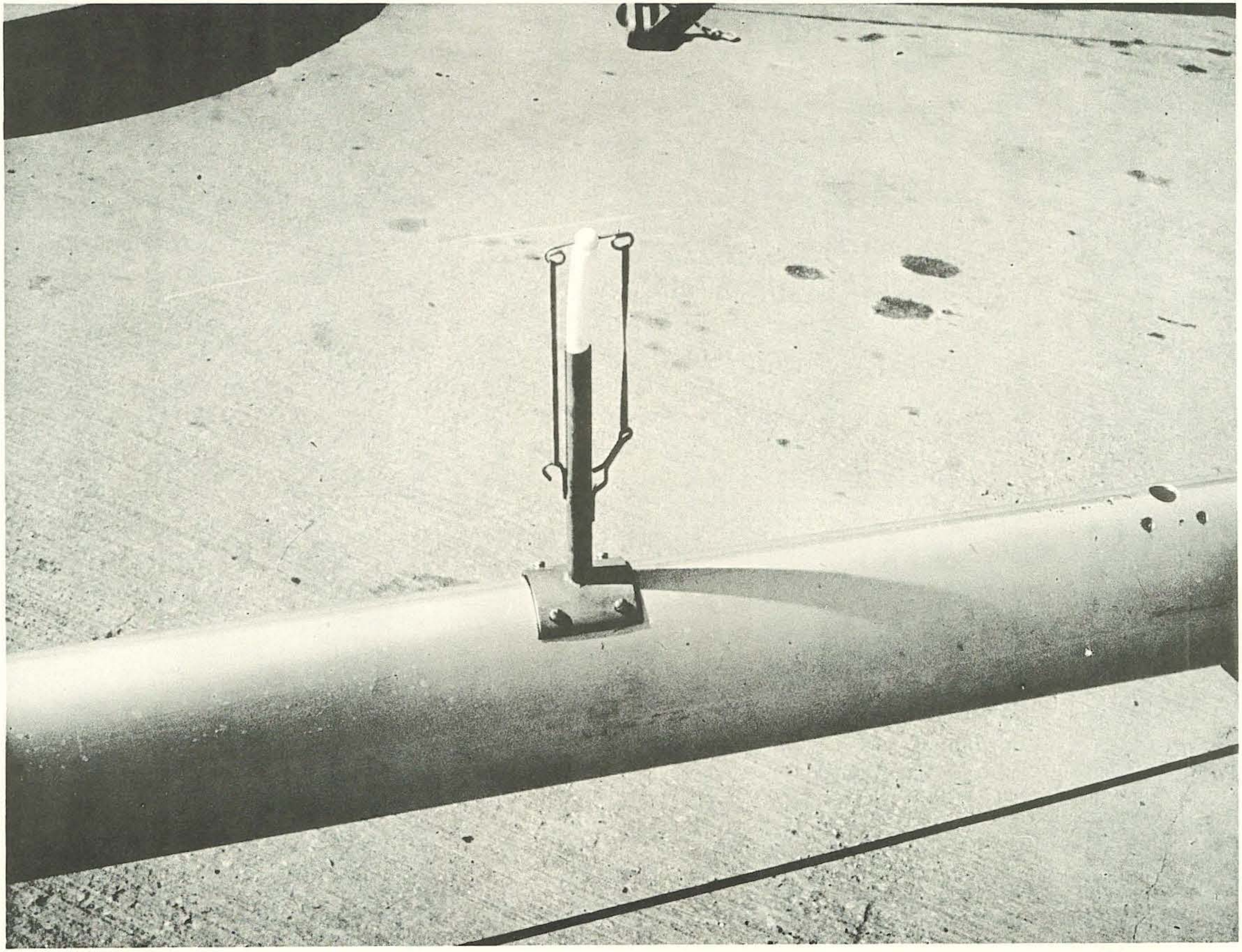


Figure 39. Inlet Probe and Port Closure Ball

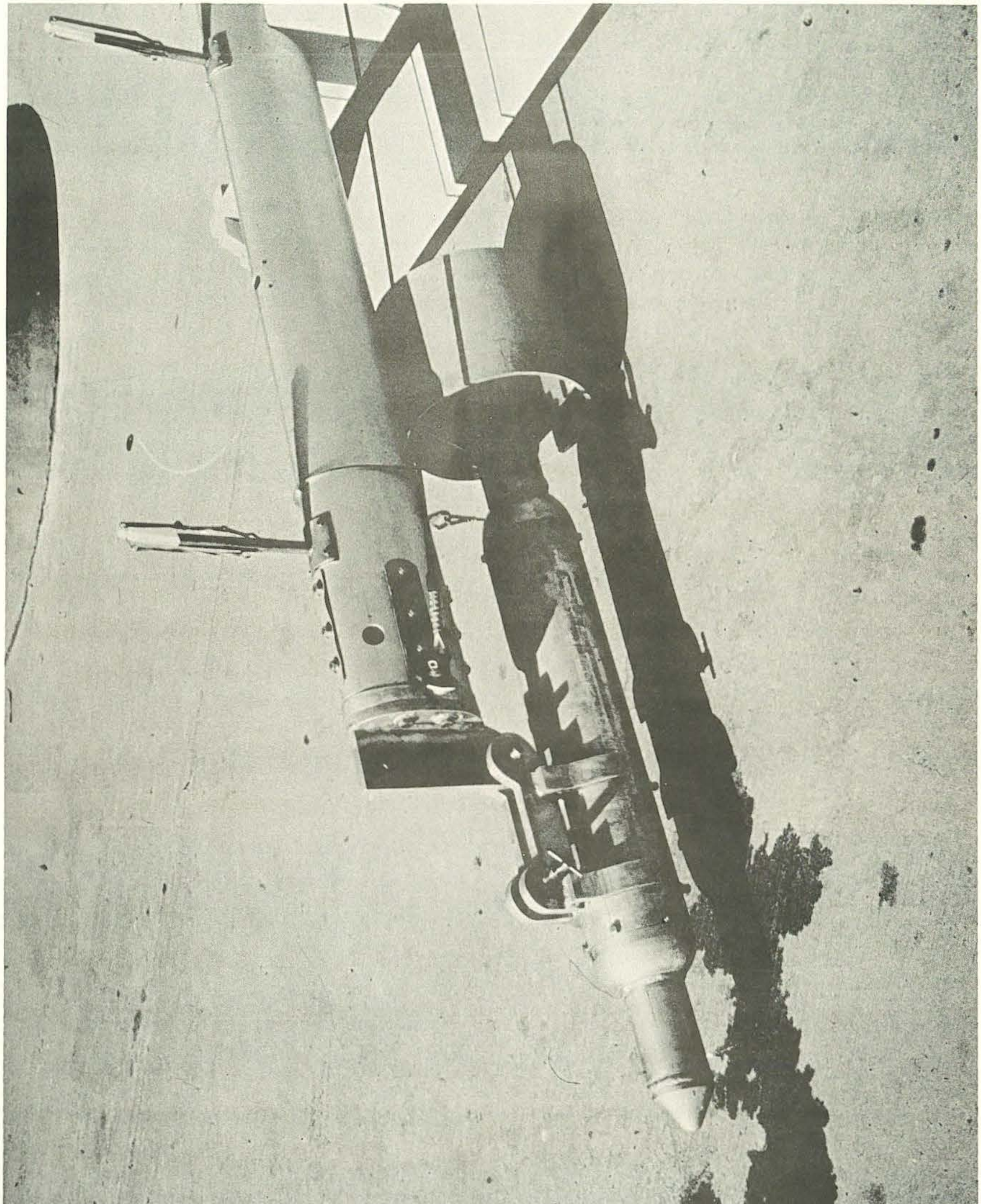


Figure 40. Rigid Boom Bottom Mounted Weighted Fish

the fish and probe were deployed from athwart ship using the side mounted 'A' frame aided by block and tackle.

The launch was completed with considerable difficulty, and imposed excessive strain on several components, one of which was the mast-to-fish swivel assembly. Shortly after deployment, and while final preparations were being made to start descent, the weld at the swivel joint parted and the inlet probe was lost. Figure 41 illustrates the point of weld failure (indicated by the arrow). Inspection of the weld on the remaining mating part showed good penetration, no porosity, although it was extremely granular in structure.

A jury-rig inlet suction assembly and bottom weight was constructed aboard the vessel. Deployment was difficult, but satisfactory, and the mission was successfully completed.

3.2. Bottom Weighted Flexible Inlet Probe Assembly

Routine maintenance and fabrication of a new inlet probe assembly was initiated for a dump site sampling cruise on the NOAA research vessel MT. MITCHELL. This vessel was equipped with a stern mounted 'A' frame, and did not adapt itself to the deployment of the rigid inlet probe concept. Consequently, a flexible probe assembly was constructed using pliant fairing to house the six sampling tubes. A bottom weight was constructed to sink the fish and to assure the polyurethane fairings were stressed sufficiently to hold them in a semi-rigid vertical mode during the tow. Similar to the original inlet ports, the Teflon tubes were restrained in a rigid parallel plane through the use of the stainless steel tubular structures illustrated in Figure 42. Deployment was satisfactory, but not recommended for rough weather conditions. Lowering the weighted fish and fairing assembly, then

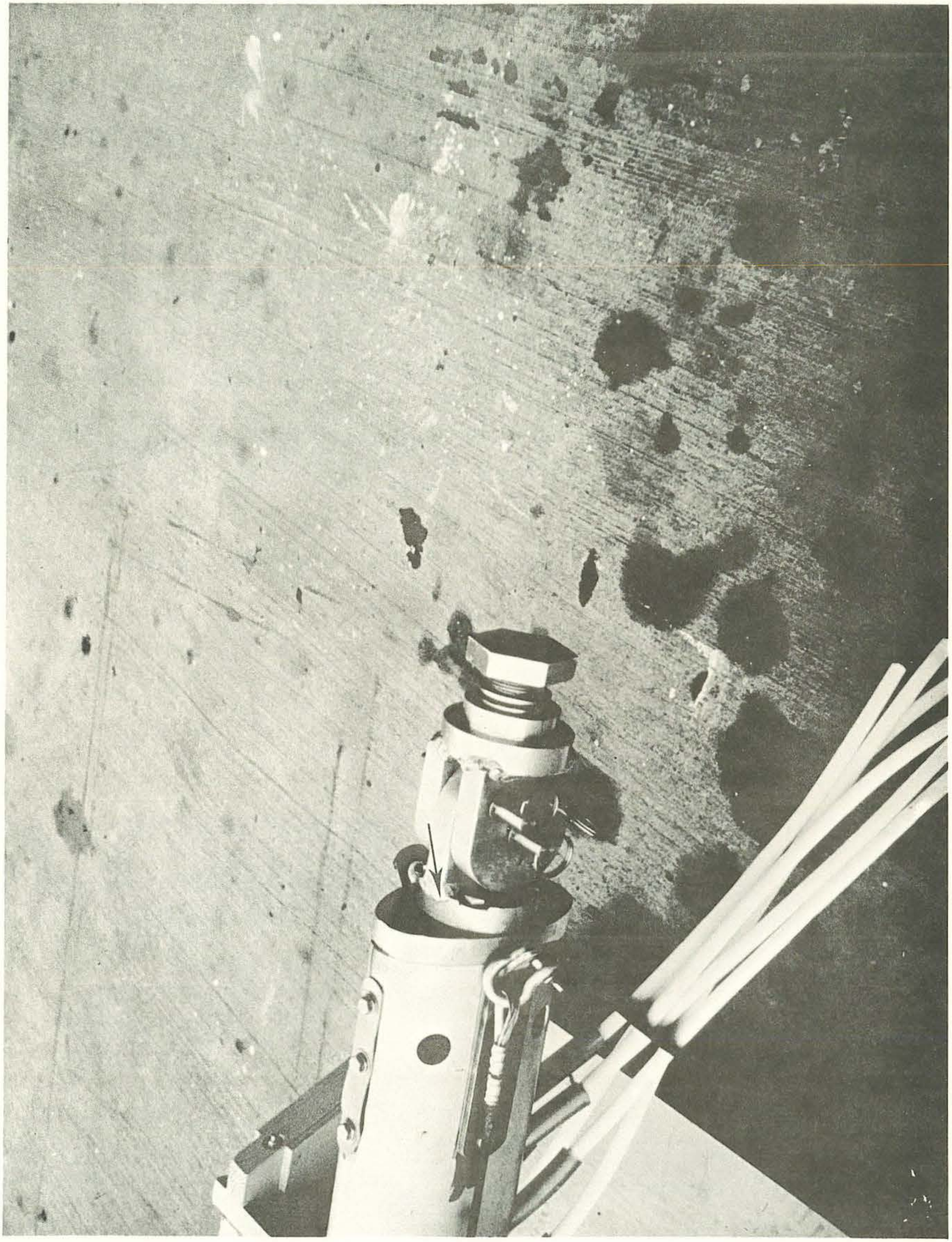


Figure 41. Rigid Boom Swivel Joint Failure Point

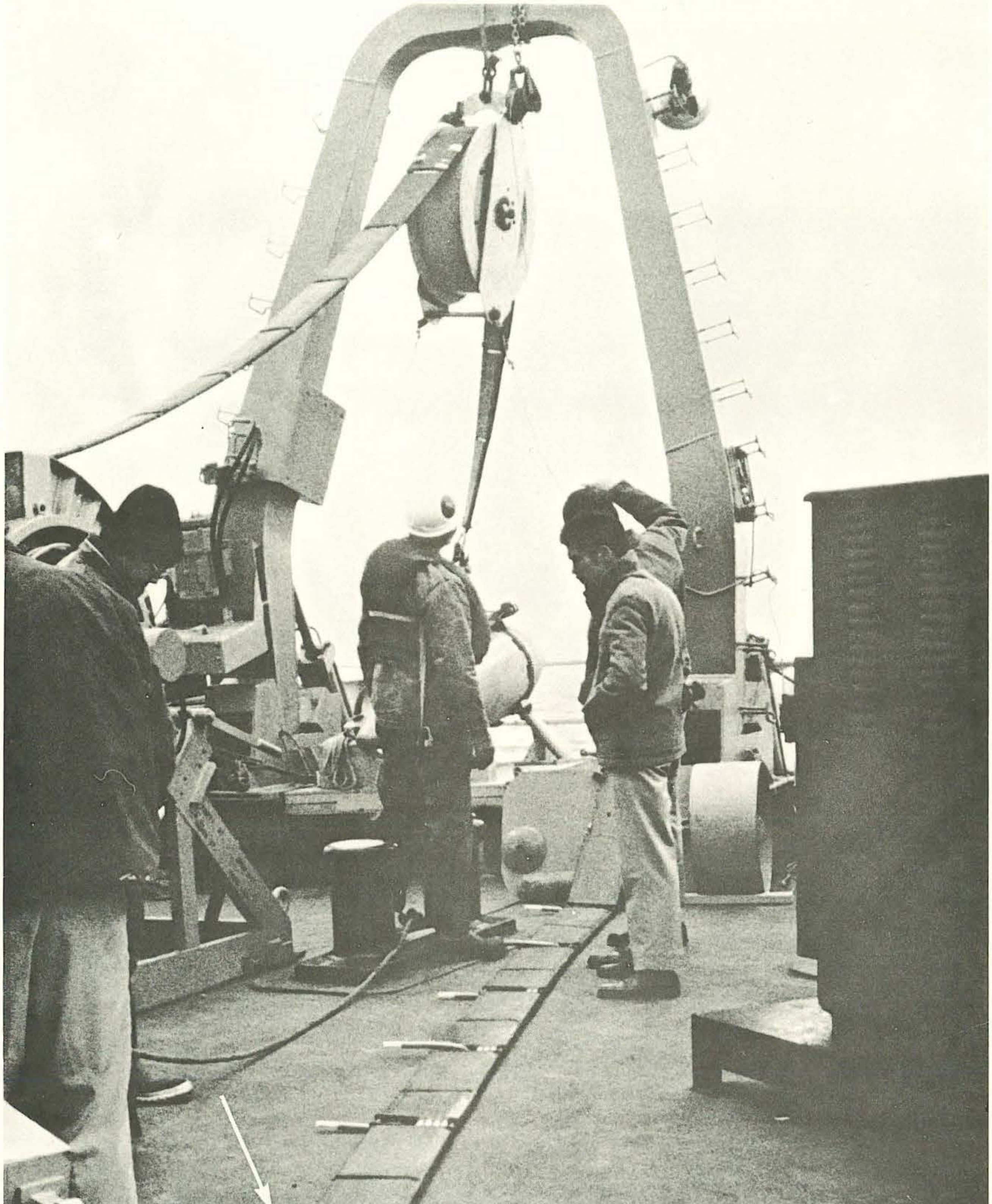


Figure 42. Pliant Fairing and Inlet Port Assembly

securing the device to the underside of the fish is a difficult operation.

The bottom weight was constructed from a flat plate of steel, with a cylindrical tail welded at the extreme aft end. Lead weights bolted through the main plate provided the assembly with sufficient mass, 224 Kg, to maintain the pliant fairing in a vertical position.

During tow, its operation was considered as fair. During straight tows the weight remained in a vertical position; however, during shallow or abrupt turns of the ship, the large surface area of the plate forced the weight to kite or sail, allowing the pliant fairings to slide out from under the fish. It is estimated that in some turns, the fairings were 20° to 30° from a vertical position.

A second weighted fish was constructed to prevent this occurrence. Its configuration is shown in Figure 43. Similar to the flat fish, its mass is 224 Kg. The modified weight has not been tested under operating conditions.

4.0. Operational Findings and Improvements of the Multi-port Sampling System

During the initial deployment on the NOAA research vessel ALBATROSS the pliant fairing entry into the water was satisfactory. The use of the side mounted 'A' frame provided the fairing a clean leading edge entry at the air/water interface. The string remained parallel to the vessel's heading regardless of the operational depth or maneuvering.

Stern mounted 'A' frame operation on the NOAA research vessel MT. MITCHELL, however, allowed the pliant fairing to enter the water with a flat surface facing the direction of travel. As expected, an entry of this type forced the fairing string to sail out behind the stern for a considerable distance. At some point beneath the surface, the fish does force the

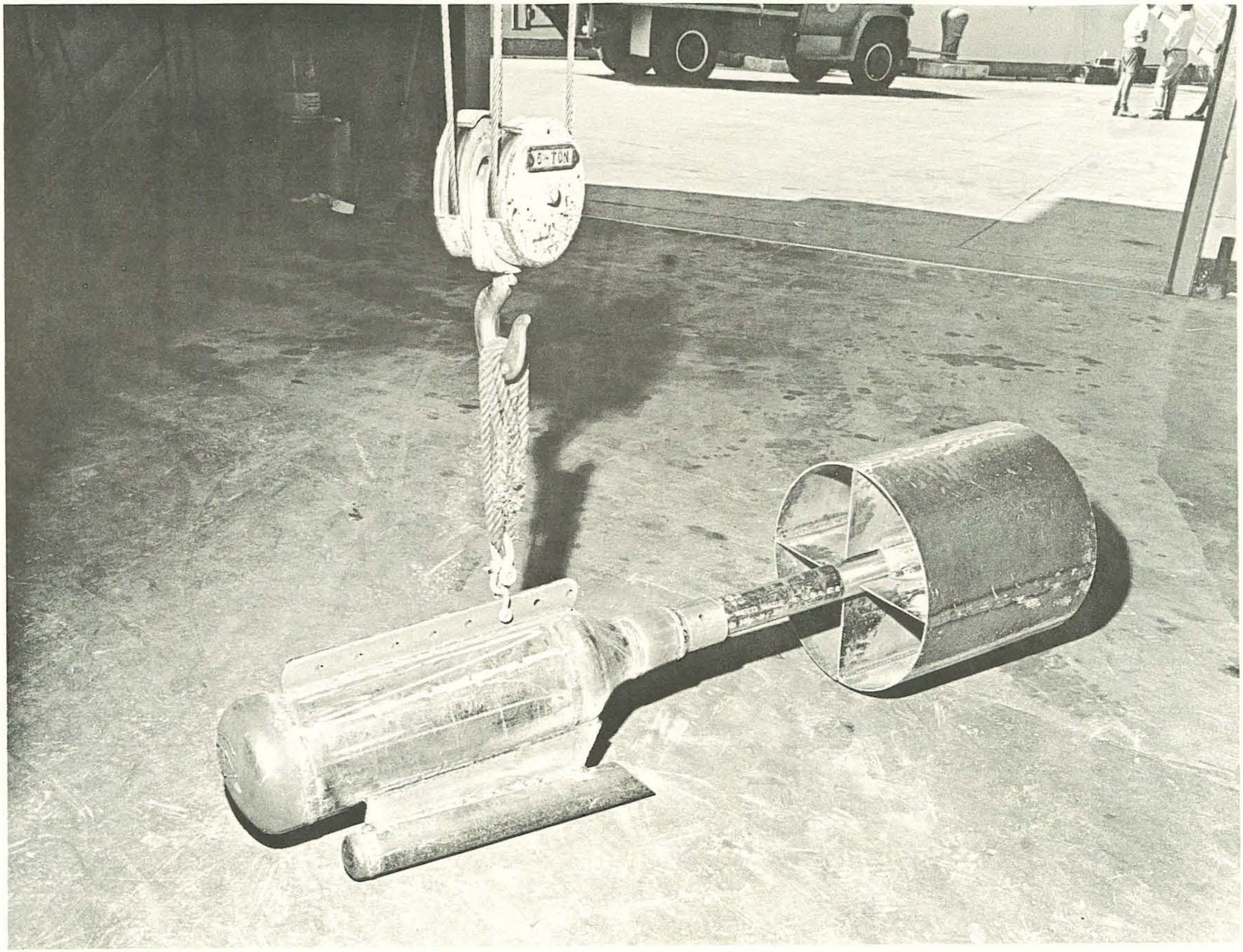


Figure 43. Cylindrical Weighted Fish for Pliant Fairing Inlet

fairings to conform to the faired position and face the line of travel. Unfortunately, off-stern operation does limit the maximum sampling depth that can be obtained with the present configuration. As a point of interest, when the vessel attained a forward velocity of 2 m/sec., it was difficult to get below a 10 to 20 meter operational depth.

It was also determined that when operating off the stern, it was mandatory to lower the fish below the turbulent area created by the propeller wash before the vessel began to make headway. If this procedure was not followed, the fish would stream out for approximately 40 to 50 meters and remain just below the surface. It appeared to "ride the wave" along the top of the subsurface turbulence.

4.1. Proposed Modification for Stern Operation

A tentative design has been formulated to use two rubber covered rollers to twist the fairings as they come off the deployment sheave. The 90° twist will allow the fairing string to enter the water in a more streamline aspect. The final design of the device will provide sufficient adaptability to be used with a vessel of opportunity. The system will be a rigid structure that will hold the string directly off the stern, and should help reduce kiting.

In the present configuration, where only the sheave is used to guide the fairing, any maneuvering of the vessel allows the sheave to partially swivel on its shackles. It tends to fair-lead toward the direction of highest strain, allowing the fish to slide off to the side of the ship. While the rigid roller structure will not completely eliminate this condition, it should provide a substantial improvement.

4.2. Stress Relief of Teflon Sampling Tubes

During the first set of deployments, it was noted that over a period of time a slight stretching of the two strength cables occurred. This coupled with the lubricity of the wetted Teflon tubes and polyurethane fairings, allowed the tubes to slide within the fairing. At several points along the faired string a small excess of tubing would loop up in the area of fairing separation. While it did not effect the system operation, it left the tubes unprotected as they came over the sheave during recovery.

To alleviate this condition, a tube lock bar assembly was constructed. As shown in Figure 44, it consists of two stainless steel bars drilled to accomodate the six Teflon tubes and the two outboard strength cables. Split tapered collars were placed around the Teflon tubes, the cables inserted into their respective slots, and the two bars bolted together.

Figure 45 illustrates a partially assembled lock bar assembly. The two split clamp plates are then assembled and secured. They are sized to clamp against the shoulder of the split collars, forcing them into the holes drilled through the split bars. As the collars compress, they clamp the tubes securely. Several clamps have been installed along the fairing run. A typical installation is shown in Figure 46. The device has a sufficiently low profile to pass over the sheave without difficulty.

4.3. Modification of Pressure Compensation System

The original pressure compensation system, covered in Figure 5, was sized to provide sufficient self contained air for a 12-hour run, including an occasional 10 meter vertical excursion while tracking the waste plume. During the initial deployment of the system, it immediately became obvious that yo-yoing, or numerous depth changes to 100 meters then back to 30

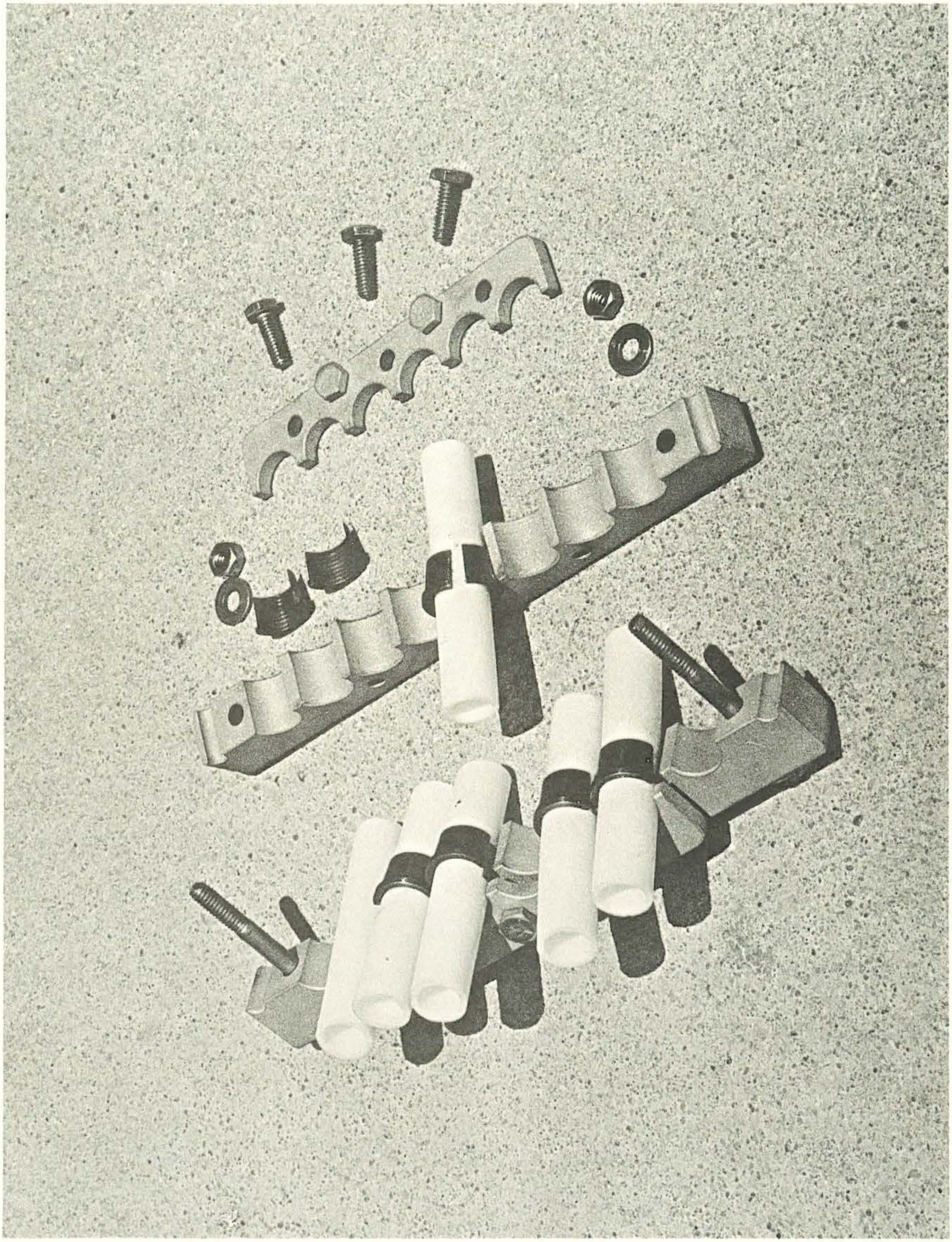


Figure 44. Exploded View of Teflon Tube Lock Bar Assembly

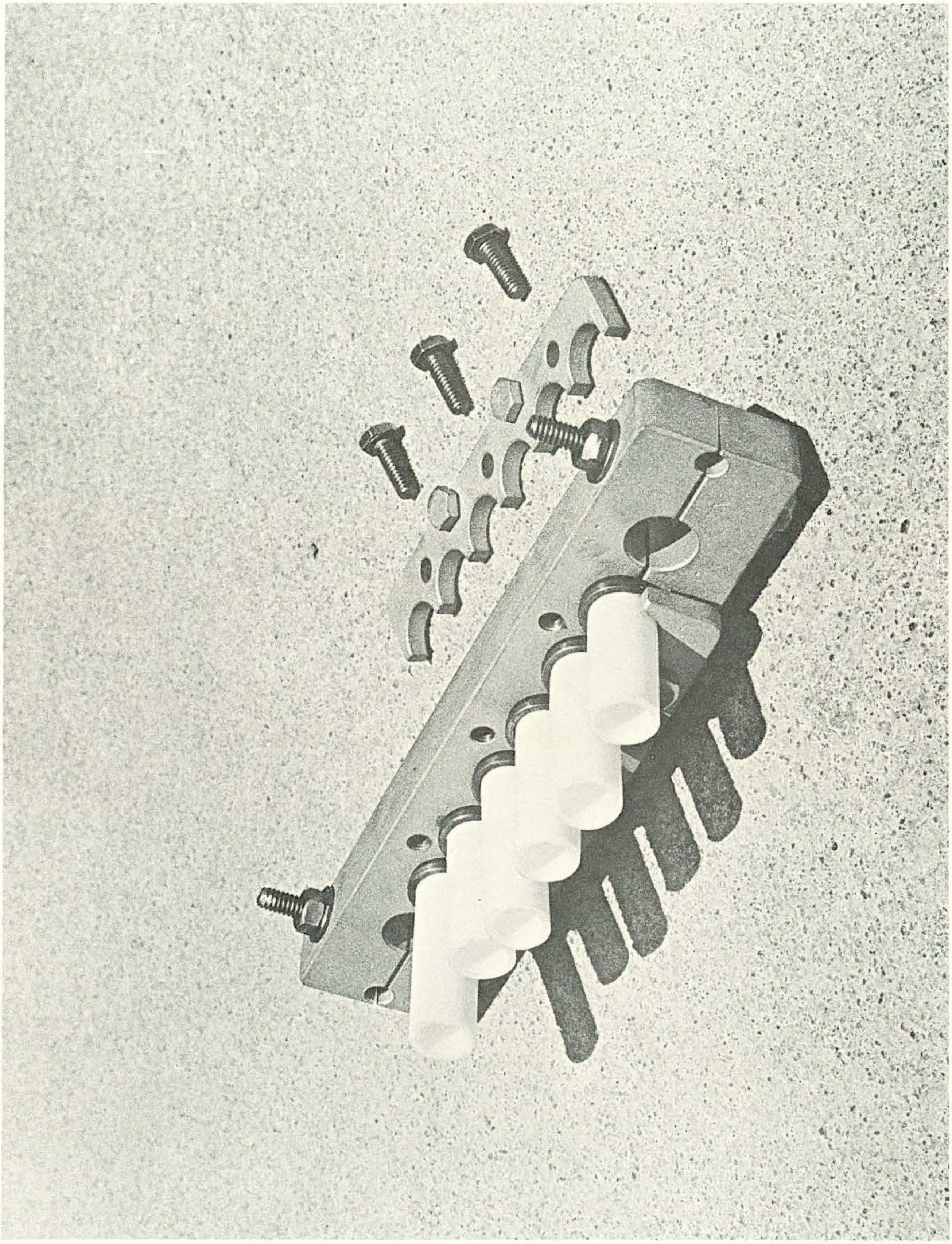


Figure 45. Partially Assembled View of Teflon Tube Lock Bar

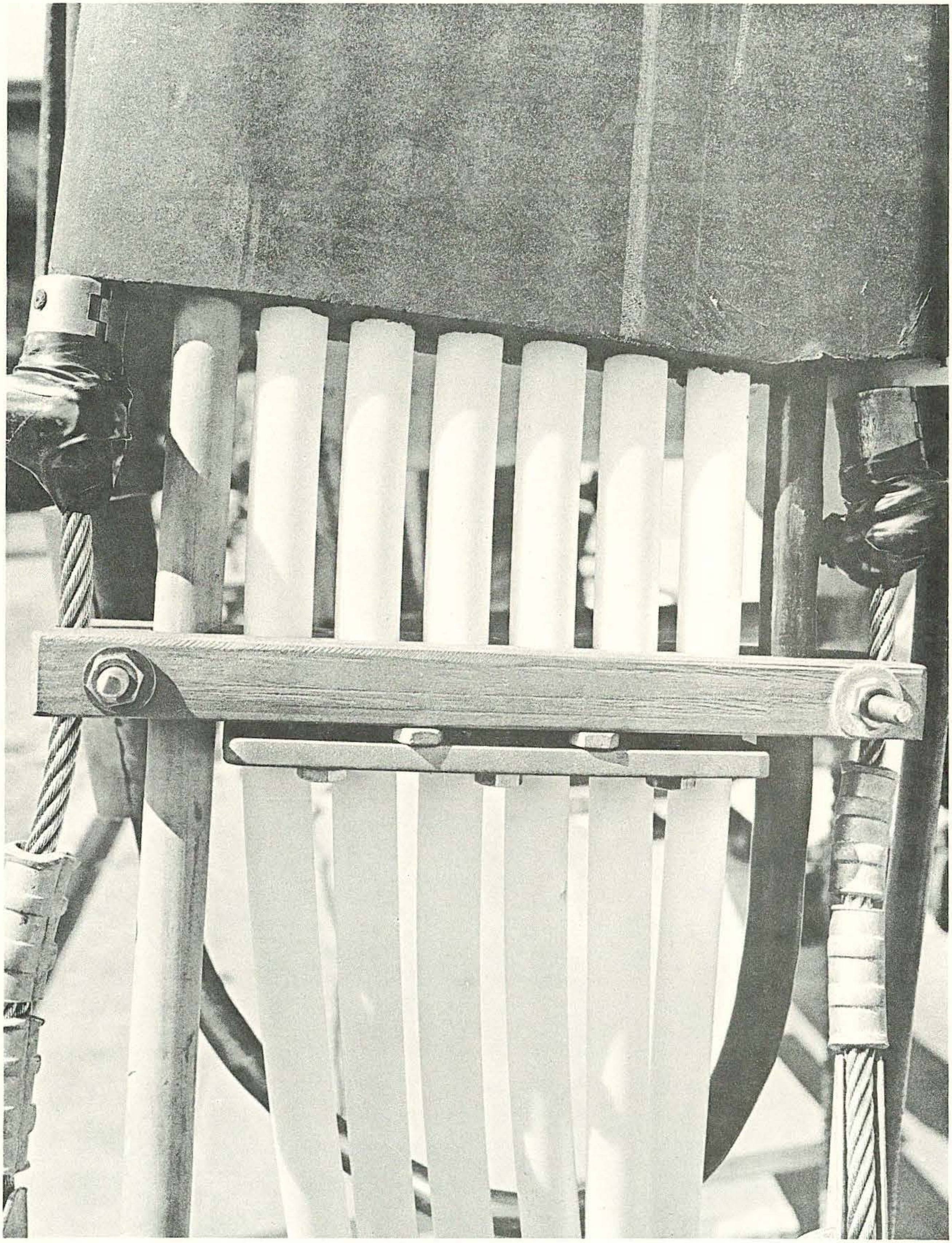


Figure 46. Lock Bar Installed on Teflon Tube Fairing Run

meters, then returning to some intermediate level would severly curtail mission longevity by depleting the internal air supply.

To alleviate this condition, and provide the capability of unlimited sampling time, the system illustrated in Figure 47 has been installed. The topside equipment consists of a Numotive P/N S-YCTGH102-1 air compressor powered by a 1/4 horsepower, 110 volt, 60 cycle single-phase electric motor, supplemented by a high pressure nitrogen storage flask as an emergency backup supply.

To assure the compensation supply has sufficient pressure to balance the system at the maximim operation depth of 100 meters, the compressor and the emergency supply regulator are set to a range operating between 150 to 160 psiG. The compressor is automatic in operation, pumping the storage reservoir to 175 psiG, at which time it cuts off. If there are no system leaks, or the fish is running at a constant depth, the compressor will remain off for a considerable period of time. When the pressure drops to 150 psiG, the compressor automatically recycles until it again reaches the 175 psiG cutoff point. The majority of water vapor in the compressed air remains in the storage reservoir as a result of condensation. To assure dry air is supplied to the fish, an additional moisture separator is located on the discharge line of the compressor system.

The feed line from the compressor to the fish is a 1/4" ID Synflex air hose, type GP-36. It is tie-wrapped to the after edge of the pliant fairing. At the fish, it ties into the inlet check valve shown on the sketch of the modified system. The check valve prevents compensation air loss from the fish in the event the feed line ruptures or parts at a fitting.

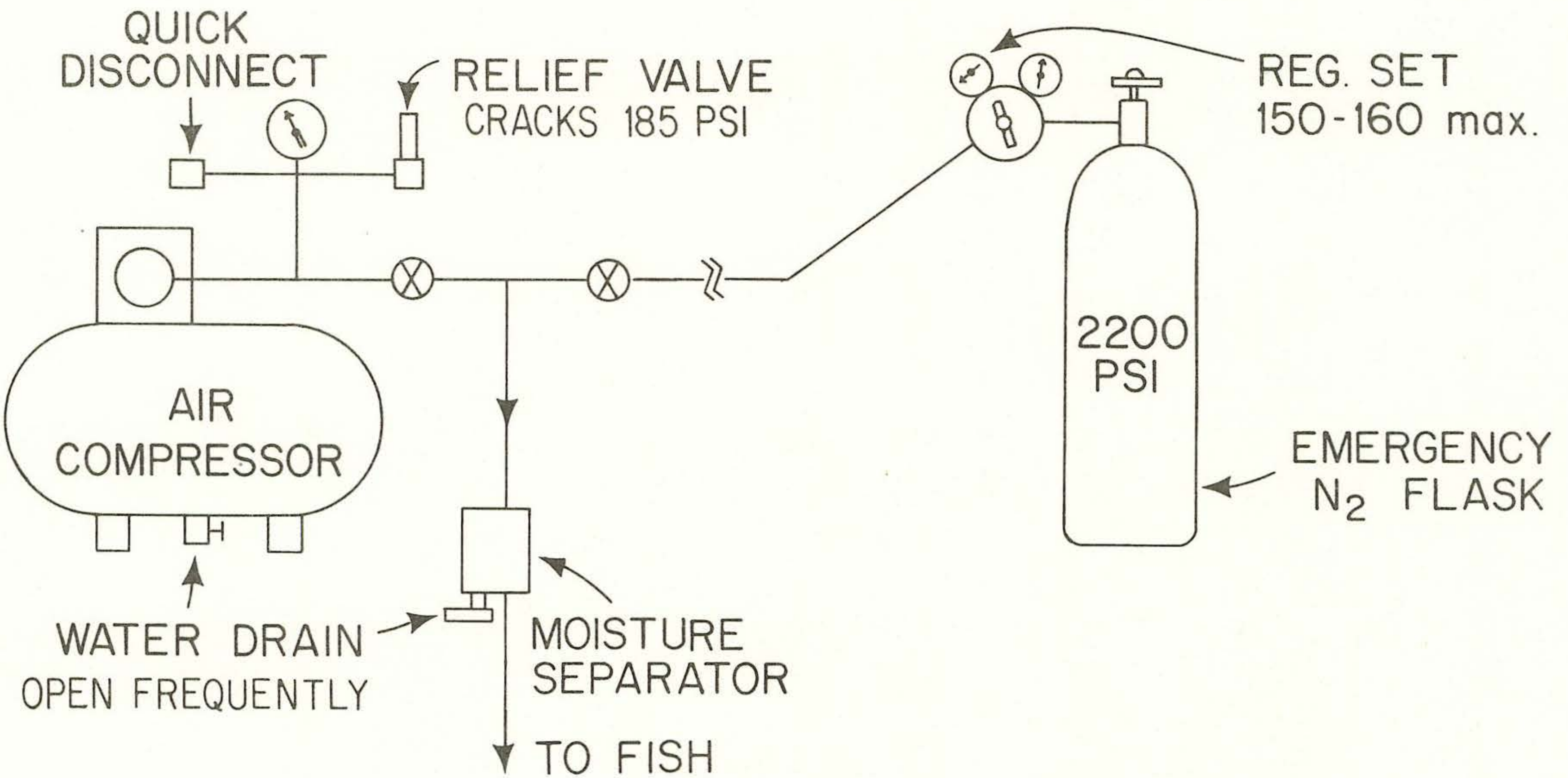


Figure 47. Top Side Compressor Mounted Compensation System

4.4. System Idiosyncrasies

If the pumps are actuated into "dry" loops of Teflon tube wound on the winch spool, the six pumps will pick up water once the fish has been lowered sufficiently to flood and dispell all the air from the system. The pumps are a centrifugal type and have difficulty in priming if any air remains trapped in a pump housing or the convoluted interconnecting tubes.

If the system has been shut down and partially drains, pockets of water remain in the lower portion of the loops on the winch drum, while an air pocket forms at the upper section of the loop. When this occurs, the system will start pumping into the Teflon sampling tubes, compressing the entrapped air, which tries to move the next slug of water against the next bubble, etc. Under this condition, the pumps have insufficient pressure capacity to overcome the resistance of the combination of air bubbles and water slugs. The entrapped water and air act as an accumulator, and begin to oscillate back and forth within the tubes. The system will not normally clear itself.

A Jabsco rubber impeller pump may be used to prime any tube that fails to discharge water, and is suspected of being air bound. If the suction side of the impeller pump is connected to the inoperative sample tube, it will operate as a push-pull circuit. The fish pump will continue to provide potential flow while the impeller attempts to pull the water through. An impeller pump in operating condition will provide a dry suction lift equal to 3 meters, while a wetted pump will lift up to 7 meters. A rubber impeller pump is very tolerant to slugs of air, and will not lose its lift during the priming operation. When the winch tube has been completely cleared, it will continue to pump a steady uninterrupted stream and the impeller pump should be removed.

5.0. Findings and Recommendations

Based on operational observations, deployment and recovery characteristics, as well as test information, the following suggestions and general comments are submitted for evaluation.

5.1. Fish Pumping System

The six commercial pump and motor assemblies are considered to be satisfactory units. Field operation has proven them to be reliable with no inherent problem areas. Difficulties experienced when pumping against a partially filled water sampling tube is considered as minor, and easily overcome with a suction pump. No changes are recommended in this system.

5.2. Water Infiltration Alarm

This device has proven to be reliable in operation. It provides a continuous audible readout of any major leaks into the fish housing. Its reliability and sensitivity has been demonstrated under actual operating conditions. During one deployment it provided an alarm, and the system was retrieved. An internal inspection of the fish revealed approximately 100 ml of water in the bilge. Further inspection divulged a discharge port disconnect had loosened providing the entry point for water. No changes are recommended to this system.

5.3. Composite Fiberglass Sheave

No difficulties have been encountered with this assembly. Its design and structural integrity are satisfactory. No design changes are recommended.

5.4. Construction Materials

The materials used in the pumping system and sampling tubes were dictated by the users' design requirements. No immediate major design changes are recommended for these components. At the time of construction, vendors capable of supplying Teflon tube were limited, and the material presently in use is extremely rigid, has a large minimum bend radius, and kinks easily.

In view of this, it is suggested that any future construction consider the use of Teflon lined tubing that has the physical characteristics of a Tygon tubing. Its flexibility would substantially reduce the present problems of using a large diameter drum and forming a generous radius at all bends.

The use of a tube of this type would not eliminate the fairings that now provide mechanical strength protection. The compression stress experienced by an unprotected tube bundle being wound on the drum would result in restricting or shutting off the sample flow as the tube was deformed.

The remaining components of the system, such as the fish housing, stainless steel fittings, lift cables, weldments and other mechanical assemblies have demonstrated excellent physical, mechanical, and corrosion-resistant charactistics. No material changes are recommended.

5.5. System Power

System power was dictated by the pump requirements. Liberal use of transformers provide the user with considerable flexibility when using a ship of opportunity. Safety features are built into the system to protect personnel and equipment. The ground fault detectors operate satisfactorily, and have demonstrated their ability to indicate a ground condition.

The 150 meter length of three wire #12 power cable is both electrically and mechanically satisfactory. It has proven its ability to operate over a long period of time in water and exposure to the elements. The power slip ring assembly mounted on the drum shaft has operated continuously without break down, and with minimum maintenance. No changes are recommended for any components or the design of the power system.

5.6. Fish Pressure Compensation System

The components used in the design of this system are, for the most part, modified commercial off-the-shelf items. Spare parts for all components are readily available. The inclusion of a portable top side air compressor to provide compensation air has improved the system reliability and provides the user with unlimited sampling time. No changes are recommended for this system.

5.7. Sample Tube Fairing String

The existing fairing string has proven to be mechanically adequate. The Teflon tube runs have shown no indication of detrimental effects from the various waste products that have been pumped. The stainless steel tube connectors are satisfactory. The polyurethane fairings have not shown any indication of deterioration from waste water immersion, exposure to sunlight, or inclement weather conditions. No mechanical failures have been experienced as a result of stress imposed while passing over the sheave or storage drum.

For stern mounted 'A' frames, it is recommended that a dual roller straightening system be constructed to twist the fairing string 90° after it comes off the deployment sheave. This will allow the fairing to enter the water with a leading edge facing the direction of travel. No other changes are recommended at this time.

5.8. Winch Assembly

The present winch has demonstrated its ability to deploy and retrieve the fish and sample tube fairings with adequate control. It is capable of paying out or retrieving the fish while the support vessel is underway. No major modifications are recommended for the structural or mechanical components of the winch. Control of the winch operation is satisfactory, and the mechanical brake and electrical mechanisms have performed without failure.

It is recommended that an electrical slip ring be installed for the instrumentation cable. There is sufficient room to add the ring in series with the power distribution assembly, although electrical cross-talk may be a problem with brush hash from the six motors and the 60 cycle power that is in close proximity. Adequate design investigation and state-of-the-art electrical shielding would in all probability reduce it to an acceptable level.

It is recommended that a water sample distribution ring be designed and installed in place of the present six port disconnect. A cursory investigation into this problem has been made, and it appears feasible. The slip ring assembly must not pick up and embed particulates from sludge or other waste products that would result in cross-contamination among the ports, or from samples in other waste areas. A more detailed examination into the problem is required.

5.9. Deployment and Recovery

The initial bottom mounted inlet port configuration is difficult to launch from the ship. It requires an 'A' frame to support the deployment sheave, and a separate sheave to lower the inlet fairing and bottom weight over the stern. The fish is raised in a two-block position, and the fairing string secured to the base of the torpedo shell. The disconnect is then attached to the inlet port at the bottom of the fish and secured with a large spanner wrench. The photograph in the frontispiece provides an overall view of the operation, and the potential difficulties involved.

The fish assembly has been modified to include a bottom mounted skid. It replaces the original ballast weight required to sink the device, as well as providing a built-in deck stand. The inlet sample tubes will be secured to the fairing string above the fish at one meter intervals as illustrated in the artist's sketch in Figure 1. Both the suction ports and discharge line will be secured to a common distribution manifold at the top of the fish. This modification will eliminate all extraneous gear at the base of the fish.

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12. Sponsoring Organization Name and Address U.S. Department of Commerce, National Oceanic and Atmospheric Administration	13. Type of Report & Period Covered Technical 14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

The experimental towed multi-port water sampler was designed to provide a shipboard science party with the capability of obtaining continuous water samples from the surface to a 100 meter depth. The device will simultaneously provide six samples spaced one meter apart in a vertical plane, while being towed by a surface support vessel at a forward speed of between two to three knots.

The device consists of a bottom fish containing six electric motors, each driving an individual pump. The six water samples are pumped to the surface using separate runs of TFE Teflon tubing. The tube is mounted in a pliant fairing that also houses the lifting cable, power leads, and instrumentation bundle. A drum winch is used to store a total of 150 meters of faired cable, and is capable of raising or lowering the fish while under way.

The sampler will provide a discharge flow rate of 5.6 liters per minute from each sample tube, while pumping through 150 meters of 12.7 mm bore tubing, against a 4.5 meter head.

17. Document Analysis a. Descriptors

1. Water Sampler
2. Towed Water Sampler
3. Multi-Port Water Sampler

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages 74
	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18) OPTIONAL FORM 272 (4-77) (Formerly NTIS-35)

Woods Hole Oceanographic Institution
WHOI-79-1

FINAL REPORT - THE DESIGN AND CONSTRUCTION OF A TOWED MULTI-PORT WATER SAMPLING PROBE FOR 100 METER DEPTHS by Clifford L. Winget and Marshall H. Orr. 74 pages. May 1980. Prepared for the U.S. Department of Commerce, National Oceanic and Atmospheric Administration under Contract NA79AA-D-0044.

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