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San Diego, California 92152

FIXED VERTICAL ARRAY

Fred H. Fisher, Principal Investigator

FINAL REPORT - Prepared for the Office of Naval Research Contract N00014-84-K-0097 for the Period October 1, 1983 through September 30, 1988.

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The Special Focus Program on Vertical Surveillance Arrays was initiated as a result of the Multipath and Caustics program funded through ONR and augmented by LRAPP funding, representing a combination of 6.2 and 6.3 funding.

The object was to design and build a high gain, single vertical line array capable of being deployed up from the bottom of the ocean, as well as downward from FLIP. It was conceived as a low drag array that would exploit the vertical directionality characteristics of the noise field and the vertical separation of multipaths, especially between surface and submerged sources, to improve array performance in the 100-400 Hz region. At the time (circa 1983), there was much to be exploited in this frequency region. A bibliography of publications and reports as a result of this contract are included.

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VERTICAL SURVEILLANCE ARRAY - FINAL REPORT

The object was to design and build a high gain, single vertical line array capable of being deployed up from the bottom of the ocean, as well as downward from FLIP ~~(Figure 1)~~. It was conceived as a low drag array that would exploit the vertical directionality characteristics of the noise field and the vertical separation of multipaths, especially between surface and submerged sources, to improve array performance in the 100-400 Hz region. At the time (circa 1983), there was much to be exploited in this frequency region. Publications and reports as a result of this contract are listed in the attached bibliography.

After a number of difficulties, the connectorless array became the vertical surveillance array and has been used in a number of deployments with funding augmentation from the Broad Band CUARP (CNO Urgent ASW Project) and is expected to be used in the new Special Research Program on Reverberation. There is some possibility that, with the AEAS program under the Oceanographer of the Navy taking over the Critical Sea Test experiment involving FLIP, the connectorless array will be used in sea trips related to this work. It should be mentioned that although technical and funding difficulties changed the vertical surveillance program from a rather large five-year program to a much reduced one, it eventually culminated in a useful array for gaining new and unique data on the vertical directionality of the ambient noise field. Keywords:

The array is described in Appendix A of this report. The Broad Band funding was through NAVAIR 933A and supported sea trips and data reduction [14,17]. The results on vertical directionality of noise as a function of longitude at 32°N were also presented at the NATO Advanced Study Institute, 18-29 July 1988 in Kingston, Ontario, Canada [22]. The results on source ship contamination removal in a Broadband Vertical Array Experiment were presented at the Oceans 88 Conference in Baltimore, MD [20].

The use of the array has led to a concept of a Mills Cross type of experiment to study the two dimensional characteristics of the noise field, especially with respect to the role of downslope conversion of shipping noise as a major source of long distance ambient noise. This would be done using the connectorless array in conjunction with the horizontal array developed at MPL. A further iteration is the concept of a high gain vertical DIFAR array which is funded for a feasibility study by ONT in FY 89. At one point, the connectorless array was proposed to be modified for use in the Office of Naval Technology Single Vertical Line Array (SVLA) experiment, but it was found that our horizontal array could be deployed in the vertical and had the desired lower frequency characteristics, as well as acoustic navigation built into its design.

ACKNOWLEDGEMENTS

The Special Focus Program on Vertical Surveillance Arrays was initiated as a result of the Multipath and Caustics program (N00014-79-C-0075) funded through Capt. Gilmore at ONR and augmented by LRAPP funding through Dr. Roy Gaul, representing a combination of 6.2 and 6.3 funding.

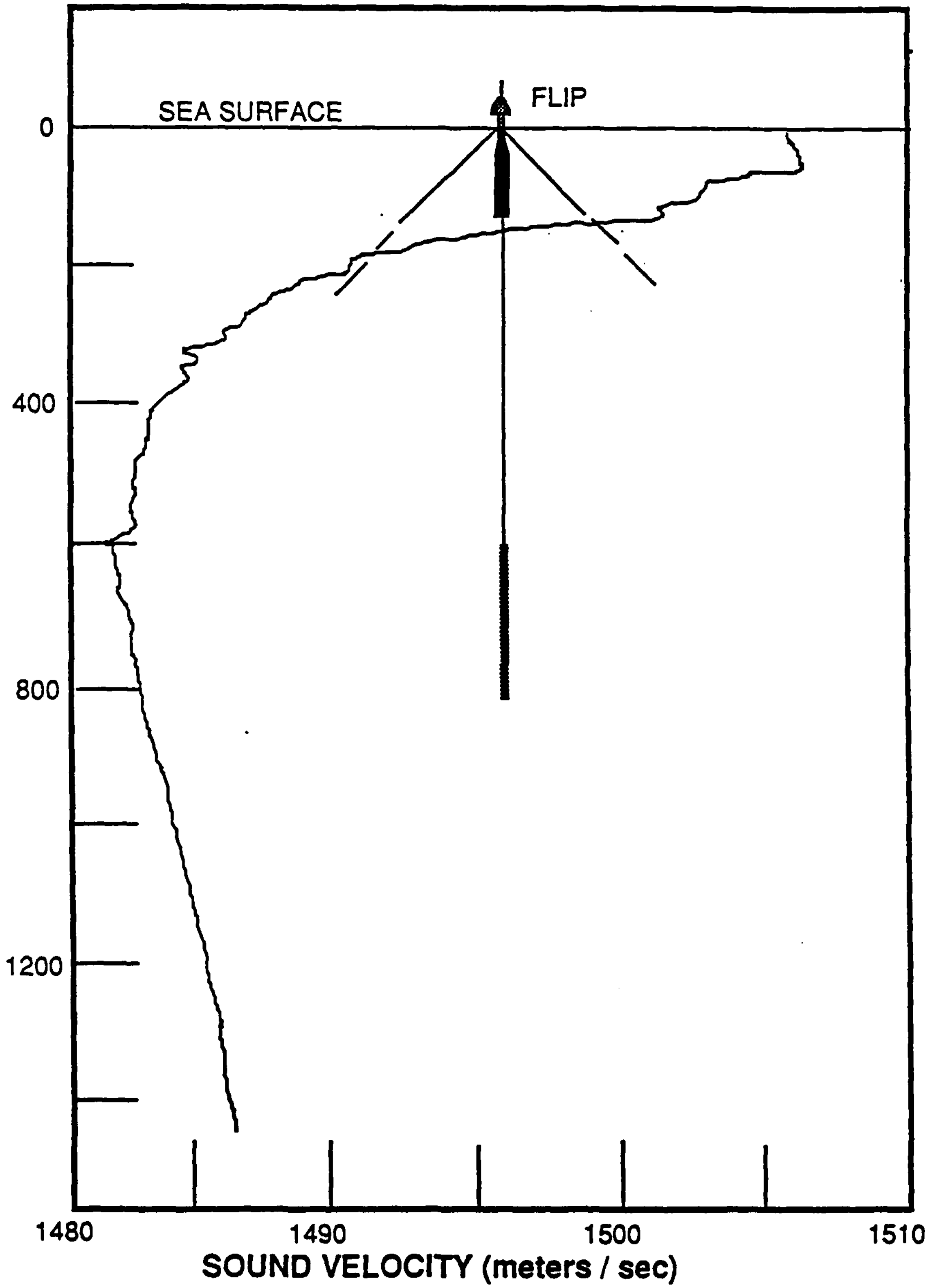
FLIP
SEA SURFACE
0
400
800
1200
1480
1490
1500
1510
SOUND VELOCITY (meters / sec)

Figure 1.

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APPENDIX A

" Sea Test Performance of a Unique Connector-Less Hydrophone Array"
by F. H. Fisher and R. A. Harriss

Reprinted from **Current Practices and New Technology in Ocean Engineering,** OED-Vol. 12, pp. 143-147 (1987).

SEA-TEST PERFORMANCE OF A UNIQUE CONNECTOR-LESS HYDROPHONE ARRAY

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ABSTRACT

To produce a low drag, easily deployed, large aperture, 64-element hydrophone array an electromechanical termination and seal was potted coaxially with the hydrophone assembly. The braided armor cable (.312" OD) of 26 gauge wire (1700 lbs UTS) was terminated in a distance of 0.625" with a steel conical clamp that in turn was joined to the Torlon end-cap stem by roll pins, with the clamp located coaxially inside the hollow stem. Each end-cap is about 3" long and 2.5" in diameter; together with a 4" long electronics case, the entire unit is 2.5" by 11". The array has been deployed successfully at sea nearly fifty times over the last two years from the R/P FLIP [1,2,3] without any mechanical failures.

INTRODUCTION

We have built a 64-element vertical hydrophone array that has been designed for low drag and ease of deployment. Currently it is a uniformly spaced array cut for 200 Hz with a 3.75 m distance between elements. It takes only about twenty minutes to get the array into the water once it is connected to the pendant and weight. It has been deployed nearly fifty times at sea since May 1984 in operations between Hawaii and San Diego. The array has a unique connector-less design in which the strain termination is potted coaxially within the hydrophone. During our operations no mechanical failures or leaks have occurred. Problems with the braid on the braided armor cable are beginning to show up, corrosion and strand failure. These problems and those associated with deployment of larger aperture arrays with greater hydrophone spacing will be discussed.

ARRAY DESIGN AND CONSTRUCTION

The guiding consideration for the mechanical design of the array was to keep the drag down so the array could be kept as nearly vertical as possible, within 0.5 degree. While this is not crucial to array performance when FLIP is in a tight three-point [4] moor in deep water (4000 m or greater), low drag becomes very important for operations in which FLIP drifts or when we want to make a bottom-moored array installation.

An overall drawing of an array element is shown in Figure 1 in which we see the unique feature of incorporating the armored coax as an integral part of the hydrophone element. A cross-sectional view of the hydrophone is shown in Figure 2 in which we see how the strain termination is made using two conical clamps to grip the braided armor and how roll pins transfer the load from the outer conical clamp to the Torlon endcap stem. Figure 3 is an exploded view of the whole hydrophone assembly showing details of the mechanical termination as well as the hydrophone mounting. We will examine details of the construction separately in the following discussion.

Hydrophone

The cylindrical ceramic element is air backed by mounting inside it a brass tube whose outside diameter is slightly smaller than the inside diameter of the ceramic cylinder. Proper spacing is maintained by ring-shaped endcaps which are mounted to the cylinder and tube with epoxy. Electrical connections are made with a glass to metal seal header and buss wire and the entire unit is then coated with a urethane sealer. The coated assembly is then cycled to 6000 psi three times and then held at that pressure for an hour. When removed from the pressure tester each unit is checked for signs of leakage. Leaky units are discarded. This unit is then seated on an O-ring spacer on the base of the endcap with the stem of the endcap inside the hydrophone assembly. The headers for the hydrophone penetrate the Torlon endcap directly under the ceramic; these details are shown in Figure 2.

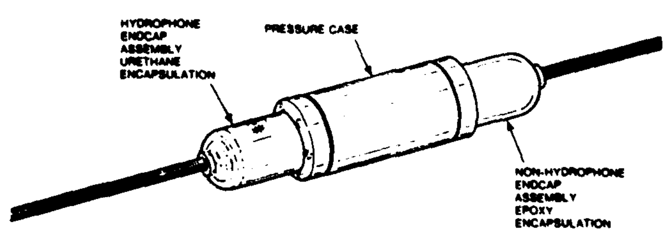

Figure 1. Hydrophone and cable assembly. Length of hydrophone is 11 inches.

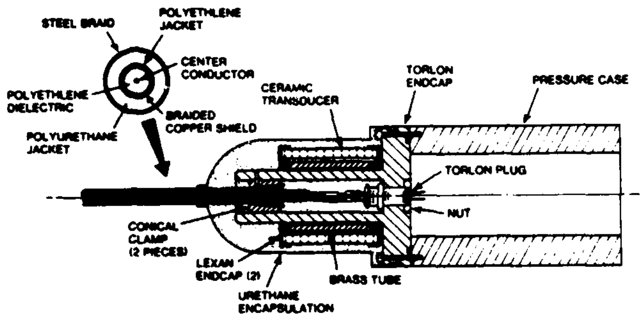

Figure 2. Cross-section of hydrophone end-cap assembly showing electromechanical termination. Roll pins transfer load from outer conical sleeve to torlon stem.

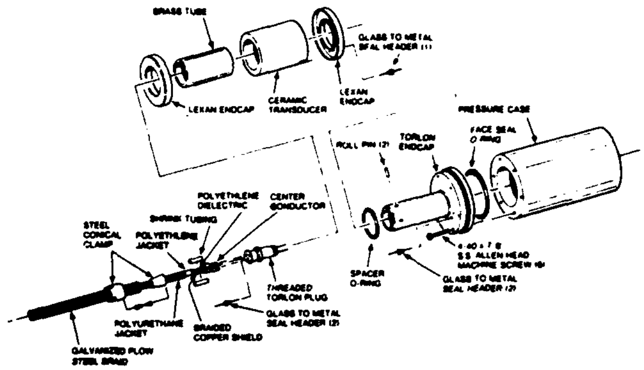

Figure 3. Exploded view of hydrophone and termination assembly.

Electro-Mechanical Termination in Hydrophone

The termination is a variation of the UNICLAMP design [5] used at this laboratory for many years, the principal difference being that the load from the braided armor has to be transferred to the Torlon stem in a very short distance. This is accomplished by using a press to force the two conical clamps together as they grip the armor until the epoxy sets. In this way the strength of the termination is fully developed before the load is applied. This termination has been tested to 2300 pounds. The wire is a braided armor cable made by South Bay Cable of galvanized "extra improved plow steel", 26 gauge, with an OD of .312". A pull-to-failure test ended at 2100 pounds.

Electrical connections are made through a threaded Lexan plug which is inserted through the endcap, sealed with epoxy and secured with a nut. Then the mechanical connection from the cable to the endcap is made using roll pins as shown in Figure. 2 and 3.

Assembly and Potting

The torlon stem with the electromechanical connection in place is shown in Figure 4. Once the hydrophone and the termination are in place the whole unit is ready for potting. The greatest problem encountered in potting was lack of provision for pressure equalization for the urethane inside the stem area. This caused leaks when the potted unit was subjected to 6000 psi pressure tests. The problem was solved by inserting thin rods seen in Figure 4 adjacent to the inner surface of the stem during molding, rods which were removed after potting. The hydrophone before removal of pins is shown in Figure 5. Grooves in the inner surface of the stem were milled to permit the semicircular cross-section rods access to the full length of the stem. This eliminated stress induced failures in the urethane at high pressures.

Pressure Cases and Endcaps

We decided to use a plastic pressure case to minimize the weight of the array. We bought some glass filled polycarbonate rod, bored it out to the desired dimension, pressure tested it and it worked adequately to 10,000 psi. We then had an injection mold made and, after considerable delay on the part of the molder, found that the injection molded material was not as strong as the extruded rod and the cases were inadequate. By that time we had been looking at Torlon, an AMOCO product,

Figure 4. Torlon end-cap and stem with electromechanical termination in place. Pins are for pressure equalization holes. Transducer assembly not in place.

and we tried some cases made of that material by a compression molding technique. They withstood the pressure tests perfectly. There was no effect detected by our measurement system at 10000 psi. We purchased 70 pressure cases. We found that the production run of Torlon cases tended to be brittle and the manufacturer replaced several which shattered. We also lost several cases because we had some problems with the fine threads stripping out early in the project but since introducing the use of torque limiting drivers to the assembly process this problem has disappeared.

A year after our first purchase of Torlon pressure cases we needed more pressure cases but the price of Torlon had gone up so high that we decided to use the mold we had bought for the polycarbonate cases to make some ULTEM cases. ULTEM is a General Electric polyetherimide with very high compressive strength. These parts also withstood pressure tests perfectly without the brittleness of the compression molded Torlon.

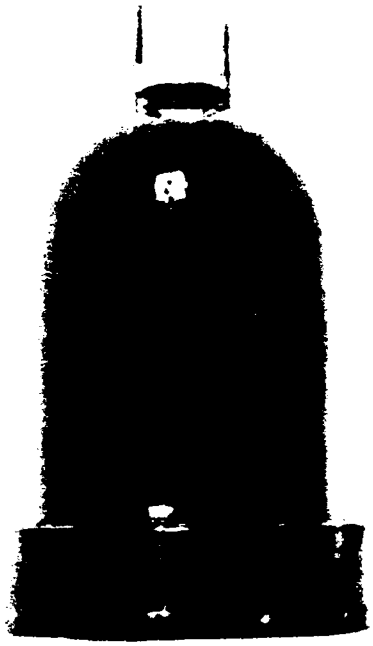

Figure 5. End-cap after potting, without termination.

The endcaps are made of Torlon because of its very high tensile strength. Figure 2 shows that a small amount of material holds the entire tension of the array and the bottom weight. No other plastic available to us had that much strength. We tested the endcaps rigorously for brittleness and other properties and found them to be quite satisfactory. AMOCO claims that the difference is that the endcaps were injection molded and use longer glass fibers than the compression molded products. The endcaps are held to the pressure cases by six 4-40 stainless screws threaded into tapped holes in the plastic cases. This seems to cause people to become concerned about the tensile strength of the array but, thus far it has held well. We have done tensile tests up to 2500 pounds on this system and have not yet caused any damage which we could recognize. (As a matter of fact by accident we once put the array down with only two screws in one of the endcaps and didn't realize it until 24 hours later when we brought the array up. Again there was no observable ill effect.) The calculated strength of six 4-40 316 s.s. screws is at least 3000 pounds.

ARRAY TESTING

After the endcap assemblies were potted the individual elements were given pull tests to 1000 pounds before they were joined together in groups of six for pressure testing to 6000 psi in the MPL 8" gun barrel test facility. Some of the units were pulled to failure to test the termination and surpassed the advertised breaking strength of the braided armor, 1700 pounds, by going to at least 2100 and as high as 2300 pounds. Each cable/endcap assembly was then tested for continuity and high voltage resistance between leads.

ARRAY DEPLOYMENT

The entire array is assembled and laid in figure 8 fashion in a plywood box, 4'x8'x1.5', which is loaded on FLIP. A winch with 2000 m of faired double lay armored coaxial cable shown in Figure 6 is also loaded on FLIP to handle the array. This wire has an OD of 0.250" and a breaking strength of 5000 pounds. To

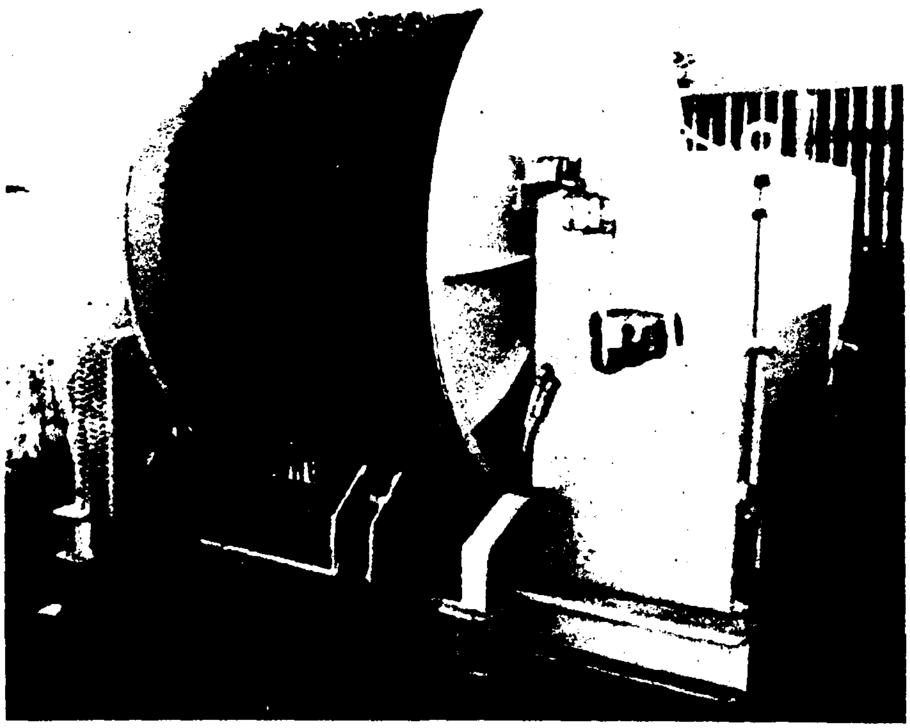

Figure 6. Array winch with faired umbilical wire to array.

guide the array through the ring frame at the bottom of FLIP without damaging the hydrophones, we inserted a two layer set of urethane covered rollers, with the upper layer of four rollers rotated 45 degrees with respect to the lower set. The rollers are four inches in diameter and will clear a nine inch diameter cylinder. A weight of 350 pounds is attached to the top of the pendant which goes through the ring frame at a depth of 300'. The total weight including the pendant is 500 pounds, which is sufficient to keep the array vertical within 0.5 degrees as long as FLIP is in a three point moor.

The array is assembled with the hydrophone ceramic at the top end of the electronics pressure case and the molded endcap without hydrophone at the bottom end. For the bottom element of the array, the molded urethane endcap without hydrophone is replaced by a metal endcap with a fitting for attaching the array to the weight and pendant. Once the weight and pendant are assembled the array is deployed using two molded cups; one of these is shown in Figure 7. Each cup is attached to a small winch which can lower a hydrophone the distance of two decks on FLIP. A loop of bungee shown in Figure 8 connects the cups to the winch wires to take up the shock of the starting and stopping of the constant speed winches. A safety wire protects against failure of the bungee. By alternating the cups, the entire array can be placed in the water in about 20 minutes. Recovery of the array is equally simple. If we were to use larger element spacing we would need a different handling procedure.

Once the entire array is deployed it is attached to the winch wire with a special assembly unit that matches the non-hydrophone endcap. This unit is then attached to a mechanical termination that is another variation of UNICLAMP also shown in Figure 7.

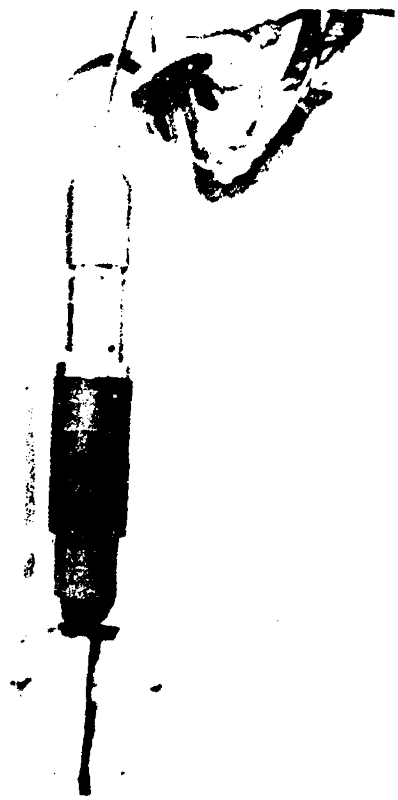

Figure 7. Molded cup in aluminum support for handling hydrophones. Also shown is mechanical termination to winch wire.

PROBLEMS ENCOUNTERED

While the array has performed flawlessly to date after about 50 deployments, we are now beginning to experience corrosion problems and occasional wire strand breaks.

Corrosion

Because of the small gage of the armor wire only a very light galvanize coating was possible. As a result rusting of the armor was apparent after only a few lowerings of the array. An attempt was made to repair this flaw by dissolving the rust and recoating the cables with a zinc loaded paint. The attempt failed. The paint all fell off in handling and the rust solvent had removed what little galvanize remained. We have also explored various protective coatings and have run long term tests in the flume at the Scripps pier for the seawater supply to the Scripps Aquarium. These measures provided only short term delays of the corrosion and in our April-May, 1986, experiments we were forced to attach the array to a strain cable because laboratory pull tests showed that the array cable breaking strength had deteriorated from 1700 lbs to as low as 350 lbs. To overcome this problem we are switching to ARMCO Nytronic 50 for the armor; it is a high strength stainless steel with a yield point in the 200 ksi range.

Wire Strand Breaks

As a result of the rusting problem we have tried to be alert to wire strand breaks and have found one. We believe, however, that this is due to an accident which occurred during the testing

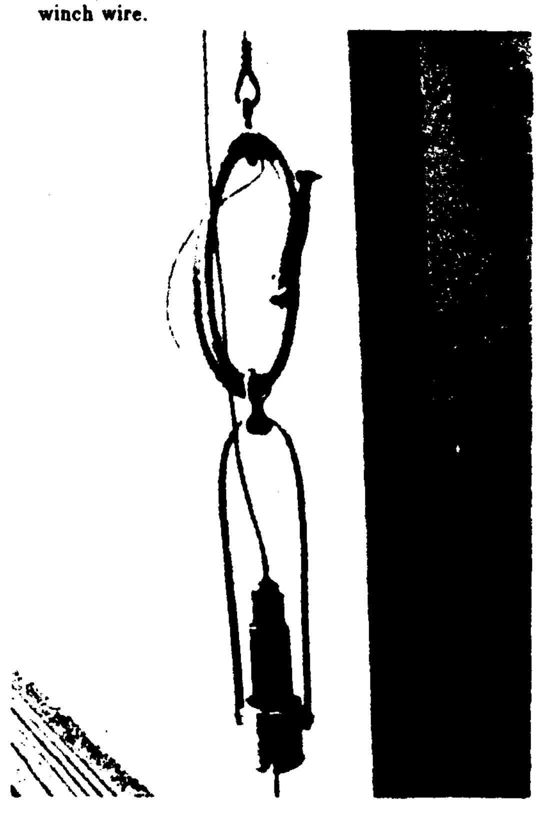

Figure 8. Hydrophone in cup with bungee and safety wire to hoist.

phase which caused the cable to be bent around too small a radius. The one cable in question *lost only one strand of armor* but still has been retired for safety's sake.

ACOUSTIC PERFORMANCE

In the frequency region of 25-300 Hz for which the array was designed, there were no artifacts in the acoustic spectrum as a result of the unique integration of the mechanical termination within the hydrophone. The response spectrum is rolled off very severely below 100 Hz to prevent saturation of the electronics from cable strumming within the array which can occur because there is no fairing on the cable between array elements. In a three-point moor, fairing on the winch wire prevents strumming from occurring in the upper waters where there are faster currents than at the depth of the array, 750 m. However, in the drifting mode of operation we have experienced strumming when FLIP drift rates get as high as 0.5 kt.

SUMMARY

The array described in this paper represents a great improvement with respect to ease of handling and rapidity of deployment of the earlier 20-element array used at MPL. We will be exploring the use of a linear traction winch recently developed by Ilinois Traction for larger element spacings. We are exploring methods to minimize corrosion and in the future [illegible] not strip the galvanizing in attempting to recoat the braid.

We feel that this design meets our needs for an easily deployable, low-drag, large aperture hydrophone array. We hope that this unique design may be useful to others.

Acknowledgements

This work was supported by the Office of Naval Research under contract N00014-84-K-0097. The original concept for the array is due to Dr. R.B. Williams. Richard Harriss, Howard Humphrey and Norman Waters contributed significantly to its implementation. Dr. V.C. Anderson has been most helpful in advising us how to overcome some of the problems we have encountered.

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