A 32 KW DOPPLER SONAR

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Abstract

Doppler acoustic scattering is proving to be a valuable technique for measuring motion in the upper part of the sea. The Doppler shift of the backscattered echo provides an estimate of water velocity as a function of range and time. The Marine Physical Laboratory has constructed a narrow beam, high frequency sonar system to study internal waves. The transmitter is an array of 1,680 transducers assembled in a flat, hexagonal shape approximately 1.5 m nominal diameter. The array is driven in phase, at constant amplitude, between 65-90 kHz at 32 KW electrical power. The system currently is operated from the Research Platform FLIP.

Introduction

A Doppler sonar has been constructed at the Marine Physical Laboratory for use in the study of the oceanic internal wavefield. Mounted on FLIP, the sonar transmits acoustic pulses in a narrow beam. From the Doppler shift of the backscattered echo the component of scatterer velocity parallel to the sonar beam can be estimated as a function of range. The MPL sonar differs from other recent Doppler sensors (1,2,3) in that great range (1-2 km) and narrow beamwidth ($\sim 1^\circ$) are achieved. Compared to other Doppler systems, relatively high power levels (32 KW peak) and low carrier frequency (65-90 kHz) were necessary to achieve the long operating range. A 1.5 m diameter aperture was required to get the narrow directional beam. The aperture was densely filled by 1680 transducers (Figure 1). In order to actually achieve this narrow beamwidth in operation, it was necessary to insure the uniform phase response of the transducers, as well as the geometric flatness of the array. A numerical simulation of the beam pattern indicated that the phase of the signal must be kept uniform to less than $\sim 8^\circ$ rms across the face of the array, if significant degradation of the beam was to be avoided (Figure 2).

In addition to these basic design requirements, it was desired to construct the sonar as simply as possible. Many useful features, among them amplitude shading, were not built into the prototype. The emphasis was placed on reliability and versatility. For example, no active electronic components were put in the underwater portion of the array. Also, a modular approach was emphasized in the design. The individual transducers, the mounting plates and the power amplifiers were to be interchangeable within their separate systems.

The purpose of this paper is to describe the mechanical design of the sonar. The design and the assembly of the individual transducers will be discussed first. The trapezoidal plates on which they are mounted will then be described, followed by an outline of the assembly of the sonar framework. Finally, the electrical and galvanic problems associated with the array will be mentioned.

Transducers

To avoid a lengthy development program, the transducer design was adapted from the work of Mr. Ward Widener of the Applied Research Laboratory, University of Texas (4). He developed a half wavelength resonant transducer, in which a ceramic cylinder 1/4 acoustic wavelength long was glued to a 1/4 wavelength conical metal front mass. When the assembly was fastened to its external mount by means of a thin membrane in the plane of the ceramic-metal joint (the nodal points for half wavelength resonant motion) very little energy was lost to the mount. Widener found these transducers to be 80-95% efficient.

Additional development work at MPL was concentrated in several areas. First, the design of the conical front mass was explored. Cost and machineability requirements dictated the use of aluminum over other possible metals for this part. A very broad cone was desirable, in the sense that each transducer has a larger frontal area; fewer would be needed to fill the array. However, it was difficult to make a broad cone resonate in the piston mode. Experimental tests were conducted on aluminum cones (alloy 6061, T-651). Cones cut at a 45° angle failed to resonate as a piston. At 30°, successful operation was achieved.

A second area of effort was to minimize the variability between transducers. Widener electronically checked each of his transducers while the cone was being cut to final length in a lathe. This tuning process would be very time consuming if 1680 transducers were involved. Our effort centered on determining the proper length for the cone and then insuring uniformity of production, such that all finished transducers would have identical phase response to within 8° rms.

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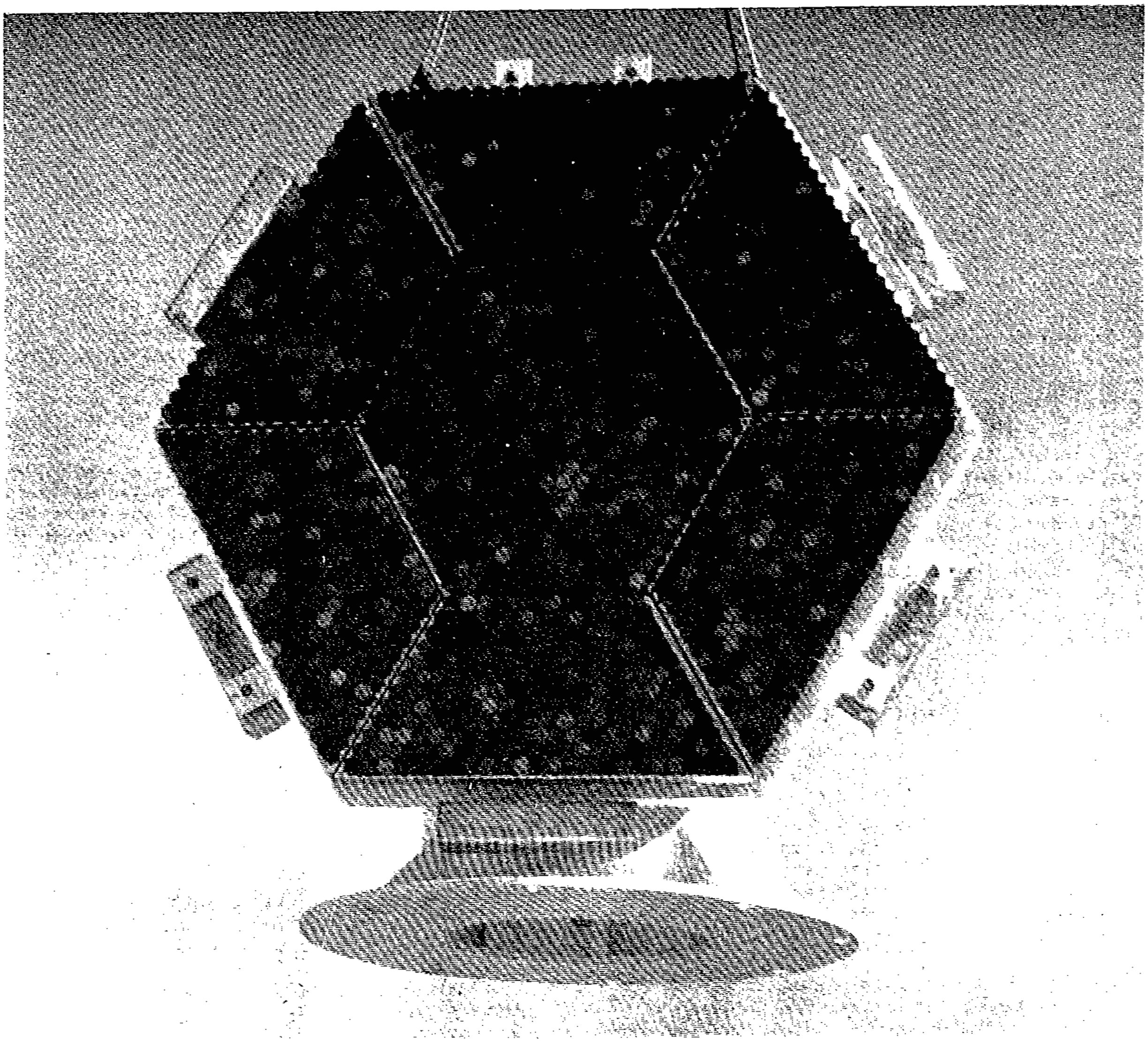


Figure 1. Photograph of MPL Doppler sonar

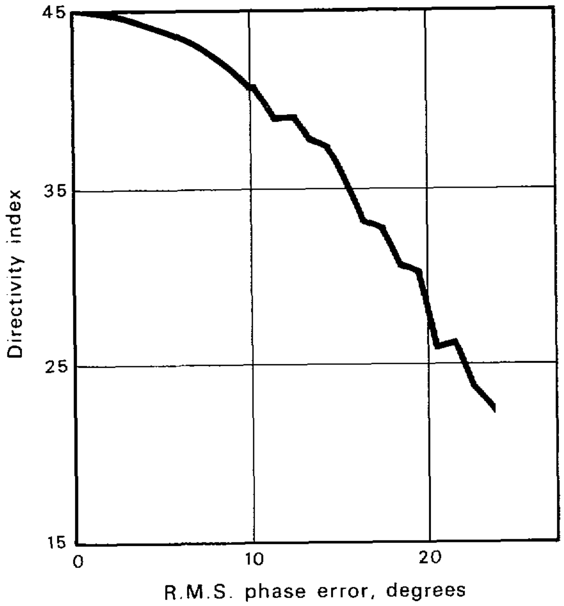


Figure 2. Numerical simulation of the degradation of array directivity index as a result of random phase variability in transducer response.

A batch of PZT-8 ceramic cylinders were obtained from the manufacturer. These were .330" long by .75" diameter, poled axially. Theoretically, they should have been a quarter wavelength long at 80 kHz. This was checked by glueing two of the ceramics together, positive to negative, to form a half-wavelength resonator, and exciting the system electrically (Figure 3a). The measured resonant frequency differed from the theoretical by only a few percent.

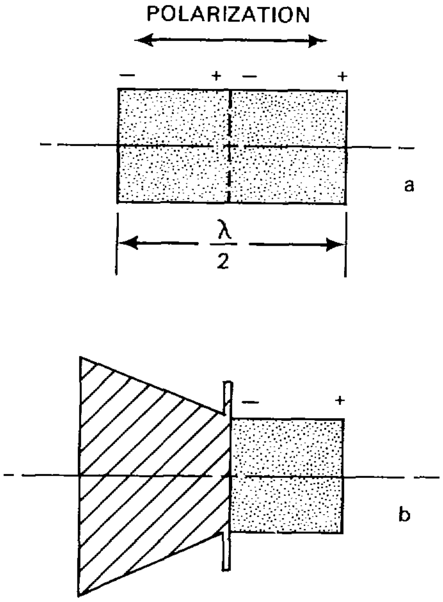
Next an "oversized" aluminum cone was glued on the front of a ceramic and packaged so that the assembly could be operated underwater (Figure 3b). The frequency response of the transducer was checked, and the resonant frequency compared with that of the double-ceramic. The cone was then trimmed by a few thousanths of an inch, and the process was repeated until the proper resonant frequency was obtained. *

The testing procedure was hampered by the difficulty of making accurate acoustic measurements in a small laboratory tank. The dimensions of the tank were 2 m x 2 m horizontally, 1 m deep. To get repeatable measurements, it was necessary to "degas" the water in the tank. This was accomplished by suspending an electric pump ~2 m above the tank and circulating the tank water through it for several hours. The suction at the input of the pump encouraged the dissolved gas to form into large bubbles. The bubbles then floated on the surface after the water was returned to the tank. The input suction could be adjusted to the point of cavitating the water by restricting the diameter of the pump suction line.

Even after an adequate degassing scheme was developed, it was still not possible to make repeatable measurements. The difficulty was finally traced to the instantaneous corrosion of the aluminum cones being tested. Microscopic bubbles were forming on the transducer surface, affecting the acoustic performance. This problem was resolved by hanging a large sacrificial annode in the tank. At this point reproducible measurements became possible.

A related problem appeared when the aluminum cones were annodized. A hard annodize finish was selected because of its abrasion resistance. However, the performance of an annodized transducer varied considerably from day to day. The structure of the annodized surface was the source of this problem. The annodize finish is itself a porous layer of microscopic cavities, very similar to a honeycomb. The interior of these cells contains various metallic salts (5) as well as trapped air. Various remedies were tried; the simplest solution turned out to be a standard annodize process called a "hot water seal", which is a brisk boil in water for a few minutes. The sealed finish retained most of its durability and excellent acoustic repeatability was achieved.

Figure 3. (a) Schematic diagram of ceramic resonance test configuration, and (b) Widener transducer design.



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* Initially, misleading results were obtained because the transducers were not resonating in the piston mode. These could have been quickly noticed, had the beam pattern of the transducer been routinely checked.

With these problems solved, a final source of variability between transducers was found to be in the glue joint. Conductive epoxy is frequently used in this application. However, we were not successful in obtaining bonds of uniform strength with it. After a small testing program was conducted, the strongest repeatable bond was found to result using Hysol two part epoxy, type EA-6. The joint was spaced with a piece of 4 mil copper screen, mechanically compressed to 1.5 mil thickness. All of the parts were solvent degreased with methelyne chloride. The glued joint was then clamped at a fixed pressure and baked at 200°F for one hour. In subsequent high power tests, it was found that the ceramic shattered before the bond failed. With the development of a reproducible glue bond, the variability between transducers was greatly reduced. Tests of production cones indicated an rms phase variability of $\sim 6^{\circ}$, of which 2° was associated with the testing procedure. At this point it was felt that the individual tuning of each cone was no longer necessary; mass production techniques would be suitable.

Once the basic dimensions of the cone were chosen, a modular transducer design was developed. The cone, mounting membrane (now .050" thick), and mount were machined out of a single piece of 1-1/4" hexagonal aluminum stock (Figure 4). The exterior of the mount had a seating shoulder which rests on the mounting plate. An "O" ring groove was machined below the seat, to prevent seawater from leaking into the mounting plate. A step was machined into the interior of the mount to provide a seating surface for the plastic penetrator. The length of the cone, thickness of the membrane, and installed height were held to within ±.001". An automatic lathe was used in the production run. The ceramic was glued to the base of the cone within the hollowed out mount.

A spring contact was soldered to the ceramic and an injection of molded plastic penetrator was inserted in the back of the mount. It was both glued and mechanically crimped in place. A threaded brass stud molded in the center of the penetrator made contact with the spring clip on the ceramic. The outside of the penetrator was also threaded and was used to attach the entire transducer assembly to the mounting plate. The completed assembly was powered by applying a voltage to the brass screw contact and grounding the base of the mount, (which was not annodized beyond the "O" ring groove).

Mounting Plates

The transducers were installed in eight trapezoidal (half hexagonal) mounting plates. Two hundred-ten transducers were mounted in each panel. It was necessary that the plates be manufactured with a very flat surface, and that the flatness be maintained through wave pounding and temperature changes. It was also desirable that the transducers be mounted as near to the edge of the plates as possible. This was necessary to minimize the gap between the transducers from one panel to the next.

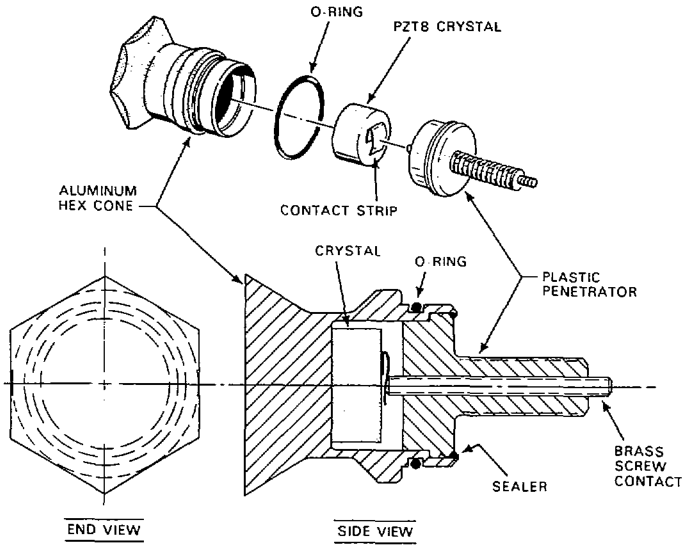

Figure 4. Drawing of the production version of the transducer. The thin walled section of the support cylinder was designed to acoustically de-couple the transducer from the mount.

The plates were fabricated from 1/2" thick alloy 316 CRES. Each plate was counter-bored in 210 places using a numerically controlled machine. Thin stainless steel sheets were then welded to the edges of the plate forming a shallow box. This enclosed the backplane in which all electrical connections were made. Threaded studs were attached to the side rails of the box. These studs protruded through the box lid and served to secure the lid, as well as to mount the panel to the array frame. The assembly was stress relieved twice during manufacture. The final machine process was a Blanchard grind, followed by an electropolish. While the machining produced a "locally flat" surface, a slight bowing of some of the plates were observed. The force of the machine tool on the plate caused the deformation during the machining process. Curiously, when the plates were straightened and the transducers installed, the assembly became significantly stiffer. The assembled panels were flat to within ±.005".

Sonar Frame

The mounting plates could be assembled in several different configurations, to form arrays with beam patterns appropriate to specific tasks. A hexagonal array was selected for the initial internal wave studies (see Figure 1). Since the entire array was to be bolted to the hull of FLIP and submerged through the surface wave zone, a strong mount was required. The array and frame were designed to withstand 1000 psf wave loading without permanent deformation. The frame was constructed of carbon steel. Bolt pads of alloy 304 CRES were welded at appropriate spots to pick up the studs on the back of the mounting plates. The entire frame was then put in a large lathe and the bolt pads were machined flat to ±.015" across the face of the array.

The transducer panels were mounted on the frame while it was horizontal. Each of the mounting studs on a panel were double nutted. The panel was then placed on the frame and jacked up or down on the nuts until alignment was achieved with neighboring panels. Alignment was checked using an array of dial micrometers and surfacing tables. When in position, the panel was bolted to the frame and the double nut jacking system was secured. The perimeters of the panels could be aligned to within ±.001". Post cruise measurements showed no noticeable change from the original alignment.

Array Backplane

The transducers did not need to be individually wired in separate circuits since they were being driven in phase and with uniform amplitude. They were connected electrically by sections of printed circuit board material, which were drilled with a hole pattern matching the pattern of the brass stud electrical connectors on the transducers. The boards were placed over the studs and nutted down, thereby connecting a large number of transducers electrically. The various pieces of circuit board necessary to connect all of the transducers in a panel were joined together with silver braid.

The disadvantage of this approach is that a short circuit in a single transducer shorts out the entire panel. Following initial sea trials, in which this proved to be a problem, the printed circuit boards were removed. A hole saw was used to break the conductive surface in a ring around each hole in the board. The rings were bridged by 1 amp fuses, which provided the sole electrical path to each of the transducers. In the course of the second sea test of the sonar, several transducers also flooded. However, the fusing system worked and the loss of the transducers was not noticed until the sonar was checked out ashore.

The back lid of the backplane was sealed with a Gore Tex gasket. The entire backplane was then filled with turbine oil. An external oil reservoir was mounted on FLIP's hull below the sonar. This reservoir consisted of sections of 6" diameter rubber hose filled with oil. If oil leaked from the array, the hose would start to collapse, refilling the array. In practice the array did not appear to leak significantly. The vulnerability of the reservoir and its associated plumbing was of greater concern.

Galvanic Protection

Given the variety of materials used in the sonar and the amount of electrical power involved, galvanic protection of the array was a prime concern. The carbon steel frame was sand blasted and then immediately primed with an inorganic zinc primer. It was then coated with epoxy paint. The mounting plates were electropolished and the cones were hard annodized, as mentioned previously. The useful lifetime of the aluminum cones was particularly uncertain. The annodize coating was thinnest at sharp corners, such as the outside edge of the cone; galvanic corrosion tends to be most intense at edges. To further protect the aluminum, five active annodes were installed around the perimeter of the array. These were purchased from Kaiser Magnesium (type KA-90) and consisted of aluminum, zinc, and tin. They were rated at +1.11 V potential. The annodes worked extremely well; after three weeks of saltwater exposure there was no sign of corrosion on the cones.

Conclusions

The sonar was tested successfully on cruises in October 1978 and January 1979. When driven at 75 kHz at a peak power of 32 KW, useful Doppler measurements could be made out to a range of 1.6 km. Approximately twenty transducers flooded during the first operation; five flooded during the second. The sonar could be successfully operated between 65 and 90 kHz. Accurate measurements of the beam pattern of the array have yet to be made. A rough estimate of the beam pattern can be obtained by measuring the intensity of first arrival echos from the seafloor. This will be done in the coming year following development of a new receiver system. A second sonar is currently being constructed, allowing Doppler measurements to be made in two directions simultaneously. With few exceptions, it is an exact duplicate of the first. The ultimate test will come in early 1980, when several sonars are operated continuously for a month, to obtain a detailed statistical picture of the oceanic internal wavefield.

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