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A DEEP-SUBMERGENCE PARAMETRIC ARRAY

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1. INTRODUCTION.

There is a lack of correspondence between the acoustic properties of deep-sea sediment samples and acoustic back-scatter signal strengths. Sediment properties are measured in the laboratory at ambient temperatures and pressure rather different from the two to three degrees Celsius and tens of MPa found below the sea floor. Sample sizes of a few inches diameter are very small compared with the pixel size of a typical side-scan sonar like GLORIA. Mike Somers of IOSDL proposed and got support for this project with our deep-towed side-scan system TOBI in mind as a platform. Using non-linear acoustics a pencil beam can be produced having a foot-print smaller than a side-scan pixel but larger than a core sample. As the narrow beam can be maintained over a wide frequency range the same area of sediment can be examined at different frequencies. It should be possible to derive a signature characteristic of the sediment type. There are regions that create a thin film interference effect on side-scan sonars. We may be able to estimate the thickness of such layers by measuring back-scatter at several frequencies. The degree to which side-scan sonars penetrate the surface of the sediment may be discovered. On a recent survey of the Monteray Fan (off California) some "fingers" observed on GLORIA side-scan images (operating at 6.5 kHz) could not be found with the TOBI side-scan system (31 kHz). They must be buried features. If this technique could provide a reliable wayof identifying sediment it should prove to be more cost-effective than "ground-truthing" by coring or dredging. As far as we know there is no other instrument of this type in use or being developed.

2. THE PARAMETRIC ARRAY (SCATTEROMETER)

This is a hexagonal array of 721 elements driven at two frequencies centred on about 90 kHz. Seven Kw of power will be available distributed equally between the two frequencies. Allowing for inefficiencies and back radiation, four to five Kw. can be transmitted into the water. The power at a difference frequency of 10 kHz is about 1.5 watts.

The virtual end-fire array formed by the non-linear interaction of the two high frequencies generates a beam at the difference frequency of width about 2.5 degrees between 3 dB points. The high directivity index (39 dB) makes up for the low efficiency of the parametric source. It has been estimated that an array operating directly at 10 kHz would weigh at least 20 tonnes in water - the parametric array will weigh about 20 kg.

As the instrument is to be used on a deep-towed vehicle the array has been designed to withstand at least 50 MPa of water pressure. The individual element is pre-stressed by a bolt through the centre of the stack but as the water pressure builds up it takes over the pre-stressing.

Difference frequencies within the range - one to 20 kHz are generated. This wide range is achieved by making the mechanical 'Q' of each element as low as possible and by modulating the power amplifier supply voltage to provide extra voltage to drive the transducers off resonance.

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3. USAGE.

The intended role of this instrument is to insonify small regions of oceanic sediment and to make measurements of the back-scatter signal strengths. If the same area can be examined at different frequencies a signature characteristic of the sediment can be built up.

The array will be mounted on our Towed Ocean Bottom Instrument (TOBI) to provide it with a stable platform close to the sea floor. TOBI carries a side-scan sonar and a profiler and sends back attitude and altitude information. Although the vehicle is stable in yaw and roll it may be necessary to electronically steer the array to compensate for its pitching.

4. THE CONSTRUCTION.

4.1 Single Element Design.

4.1.1. The First Approach. Our experience with a number of under-water transducer designs led us to choose:-

A frustrum shaped head (Fig 1) of aluminium alloy.

A short narrow PZT4 stack.

A quarter wave-length long tail-mass of stainless steel.

A one wave-length diameter radiating face.

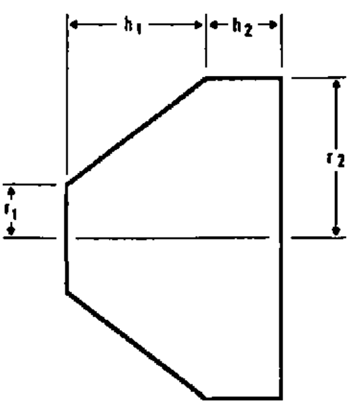

Fig 1 Frustrum Head

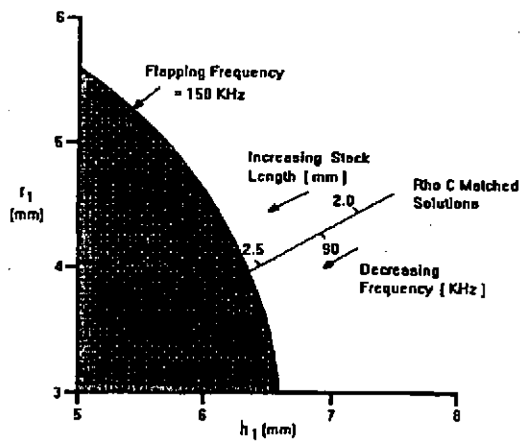

Fig 2 Frustrum Constraint Diagram (r2 = 1/2 wavelength h2 = 0.5 mm)

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This stack was assembled into an aluminium alloy honey-comb with a thin diaphragm making contact with the radiating face. The tail-mass was glued to the step where the honey-comb changed diameter - this being the nodal plane. By making the exposed areas of the head and tail-masses equal the stack is in equilibrium under pressure and merely suffers a compressive stress. The diaphragm on the face of the transducer can be thin to reduce acoustic coupling between elements. It need only support the pressure acting over the small anular gap between head and honey-comb. The tail-mass was sealed with a piston-seal 'O' ring. It was intended that electrical connection be brought through the tail-mass by an insulated terminal.

This approach was unsatisfactory for several reasons:-

The head plus stack was constrained to be a quarter wave-length long.

The flapping frequency of the frustrum shape, required to match the water impedance into the ceramic, was too close to the desired working frequency.

It was difficult to fit in sufficient volume of ceramic to handle the power.

A computer programme, using the transmission-line equation, was written to help map-out these constraints. (Fig 2) Outside the left-hand region it was just possible to achieve the design frequency but with scarcely an adequate volume of PZT4. A change to magnesium alloy as the material of the head looked more promising. However, the large diameter tail-mass - driven over a small area - was not stiff enough giving this stack a resonant frequency of only two thirds of that required. More seriously - the static load on the ceramic, magnified by the frustrum head, was close to the safe working limit. This approach was abandoned.

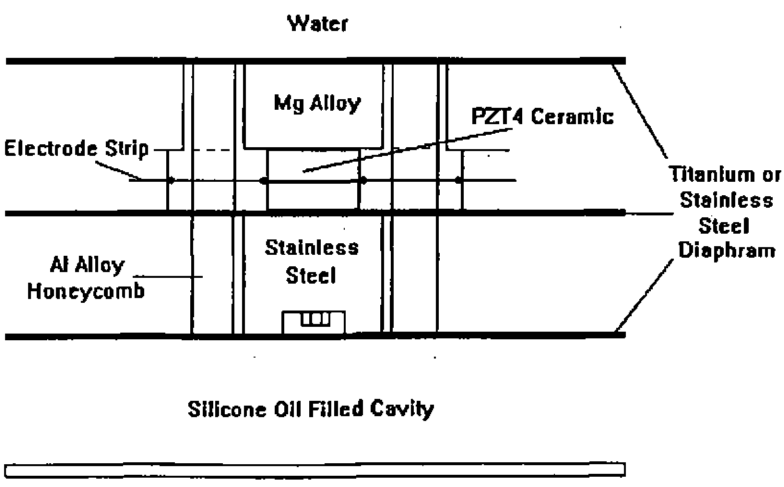

Fig 3 One Element of the Final Design

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4.1.2. Second Approach. Both the magnesium head and steel tail-masses were designed as equal diameter cylinders. The area of the stack could then be increased. No attempt was made to mount the stack at its node, instead a thin diaphragm was used to support and align the element. (Fig 3). A further diaphragm was used to seal the rear of the tail-masses. With a large area of contact between ceramic and head/tail-masses the design became much stiffer and its resonant frequency exceeded the 90 kHz target.

The cavity behind the tail-mass was filled with silicone oil whose rhoC is less than that of water. It is hoped that this will increase the impedance mismatch between tail and water and produce a modest front to back ratio. As the difference frequency power is proportional to square of the primary frequency power the front to back ratio should be better at the difference frequency.

4.2 Seven Element Prototype.

This array was first constructed using a loaded epoxy material as the supporting honey-comb. This has a lower density than aluminium and is an insulator. But the surface finish was granular making it difficult to seal against. As this material was also expensive to produce, hard to machine and rather brittle, we returned to using aluminium alloy. This prototype survived a pressure test to greater than 50 MPa though it eventually leaked through the electrical connector. Before the leak occurred an admittance circle was plotted (Fig 4) The air 'Q' is low because of the loading of the tail-masses by silicone oil. In addition some of the mechanical joints of the stack were made using Vaseline to aid disassembly.

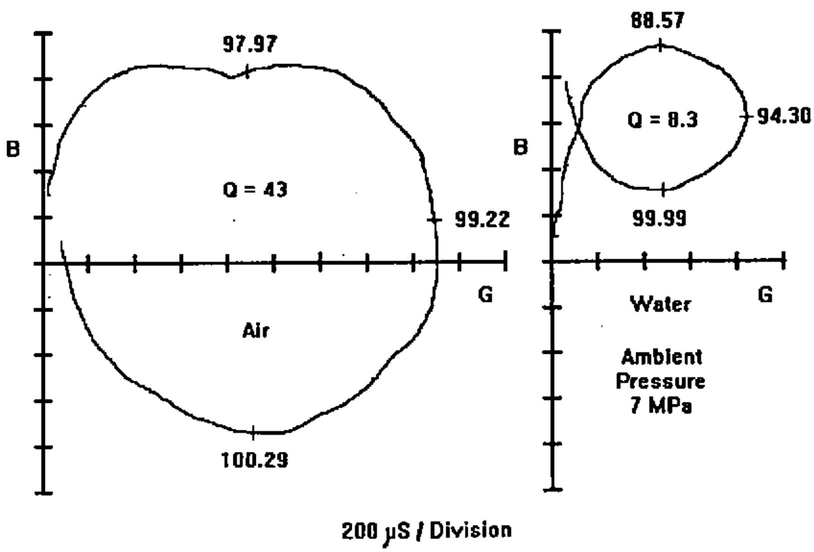

Fig 4 Circle Diagrams of a row of three elements of a prototype parametric array

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4.3 The Final Design of 721 Elements.

This array is being built at the time of writing. The elements have been designed to share a common electrode so that each row can be driven separately. This reduces the number of punctures through the critical pressure resisting bulkhead - a few good quality underwater connectors at the edges being sufficient. As each row is a single entity, it makes sense to drive each with its own amplifier of modest power. The failure of a few of these would leave the instrument still usable. By phase-shifting the drive signals and gating waveform to the various row it should be possible to electronically steer the array by up to + or - 20 degrees.

Testing the array will be a problem.

Reverberation within a pressure vessel will make acoustic tests at pressure difficult to interpret. It way be possible to create sufficient head of water to make measurements in an acoustic tank. Some pressure being necessary to press the diaphragms firmly onto head/tail-masses. It is possible that near-field;d measurements can be made so that the far-field response can be calculated. But how the array will perform as a parametric source will only be known after sea trials.

5. Brief Description of Non-Linear Effects in Water.

When a plane wave propagates through a fluid it alters the density of the fluid. Where the particle velocity is higher so is the phase velocity and vice-versa. The peaks in particle velocity thus try to catch up with the troughs ahead so that a sine-wave progressively distorts into a saw-tooth. This generates harmonics and if two plane wave at different frequencies follow the same path sum and difference frequencies will also be present. Due to attenuation the primary frequencies, their sum and harmonics will die away within a few hundred metres leaving only the difference frequency. Provided the medium is not dispersive the power at the difference frequencies accumulates coherently down the beam Attenuation of the primary frequencies limits this interaction zone. The beam pattern of the end-fire array so formed is narrow and has no side-lobes.

Beams of plane waves are a mathematical fiction, however, it has been shown that provided the beam-width of the primary source is no greater than that of the end-fire array the mathematical argument is still valid.

6. CONSLUSIONS.

A prototype has been tested at pressures greater than would be experienced at sea and proved that the mechanical design is sound. Circle diagrams show little variation in performance with increasing pressure. The mechanical 'Q' of a row of three prototype elements is somewhat higher (about 8) than desirable but this may decrease when the stacks are correctly glued with a strong, slow setting epoxy. There remain two areas of uncertainty:-

What mutual interaction there will be between elements and between rows.

How to calibrate the instrument.

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7. REFERENCES.

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