CONTROL OF RESONANCES IN UNDERWATER HOUSINGS AND BAFFLES

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1. INTRODUCTION

Optimal design of underwater acoustic instruments requires careful control of the interaction between the transducer, the water and the housing for the electronics. High efficiency sound projection can be attained by such instruments because good coupling can be achieved between the transducer and the water. However, good coupling can also exist between the transducer and the housing, either directly or via the water. The whole instrument can then be involved in the radiation of sound. The following discussion will be principally concerned with battery operated acoustic beacons and transponders, such as those used for acoustic telemetry and positioning systems (Fig 1). To achieve the desired beam pattern of sound radiated and received requires careful control of these interactions and any associated resonances.

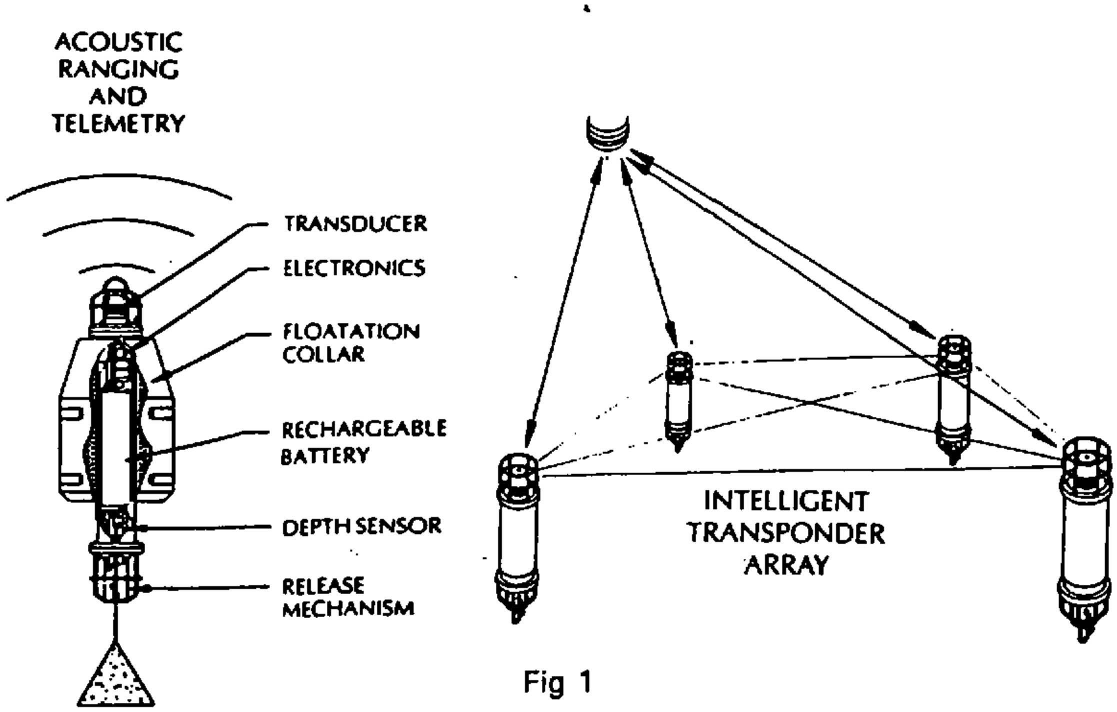

Fig 1

2. SCATTERING BY A RIGID HOUSING

The housing will have an influence even if perfectly rigid, since it reflects and scatters incident sound. Such effects are unavoidable if an omnidirectional beam pattern is required from an instrument with a housing big enough to hold a battery of adequate size. The problem is much less important where directional transducers are used since very little energy is incident onto the housing. Omnidirectional transponders aim to cover an extended hemisphere, so that when positioned close to the sea bed they can communicate with other instruments anywhere in the same locality (typical ranges up to 10km).

Suitable surface coatings applied to the housing can reduce the scatter, but need to be thick to provide significant absorption. In practice, the housing is often surrounded by foam block buoyancy, so that the instrument can be released from its anchor and float to the surface for recovery (Fig 1). The buoyancy collar isolates the tubular housing from the water, but must itself be considered for its scattering potential, and suitably shaped.

The most intense scattering is due to the endcap fitted to the tubular housing on which the transducer is fitted. The design of these endcaps and their associated securing systems thus receive very careful attention at the prototype stage. Rather than absorb the incident power it is found to be possible to reflect it to good use. However, the energy distribution must be such as to avoid destructive interference between the direct and scattered beams.

In practice good distributions can be achieved by suitable choice of housing shape and size (Fig 2). These choices are made by a combination of experience (the "black art") and theory. The main development tool is the means to quickly test prototypes over a range of frequencies. Automated polar plotting plays a very important role(1).

3. THEORETICAL BOUNDARY ELEMENT ANALYSIS

Theoretical modelling is becoming increasingly important as computer costs fall and the software improves. A "brute force" approach to model every detail remains uneconomic, but useful enlightenment can be obtained by the use of simplified models. This work is still at an early stage but some results from such a model are shown (Fig 3). These theoretical polar plots have been calculated by Boundary Element Analysis (BEA) software on a 486 PC with software purchased from PAFEC Ltd (see the following paper). This development of Finite Element Analysis can predict the acoustic pressures in the far field where the whole instrument can be considered to be a point source.

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The model for Fig 3 is of a rigid cylindrical housing, similar (but not identical) to the housing measured in Fig 2. The transducer is simulated by a point source lying on its axis at different distances from the end. Perhaps the most surprising feature is the narrow beam seen in the direction behind the housing. This solid, rigid housing is seen to act as a "lens", focusing energy in this direction. This feature can be observed in Fig 2, albeit with much less intensity. It shows how energy can be diffracted by objects whose size is comparable to the wavelength of sound in water. It seems to be related to the "bright spot" measured behind a circular baffle which obscures a source on its axis of symmetry (2).

When the housing is close to the point source a reasonable beam pattern is predicted. There are no directions in which serious destructive interference occurs. However, if the housing is too far away, deep nulls can be found where the scattered energy can completely obliterate the signal.

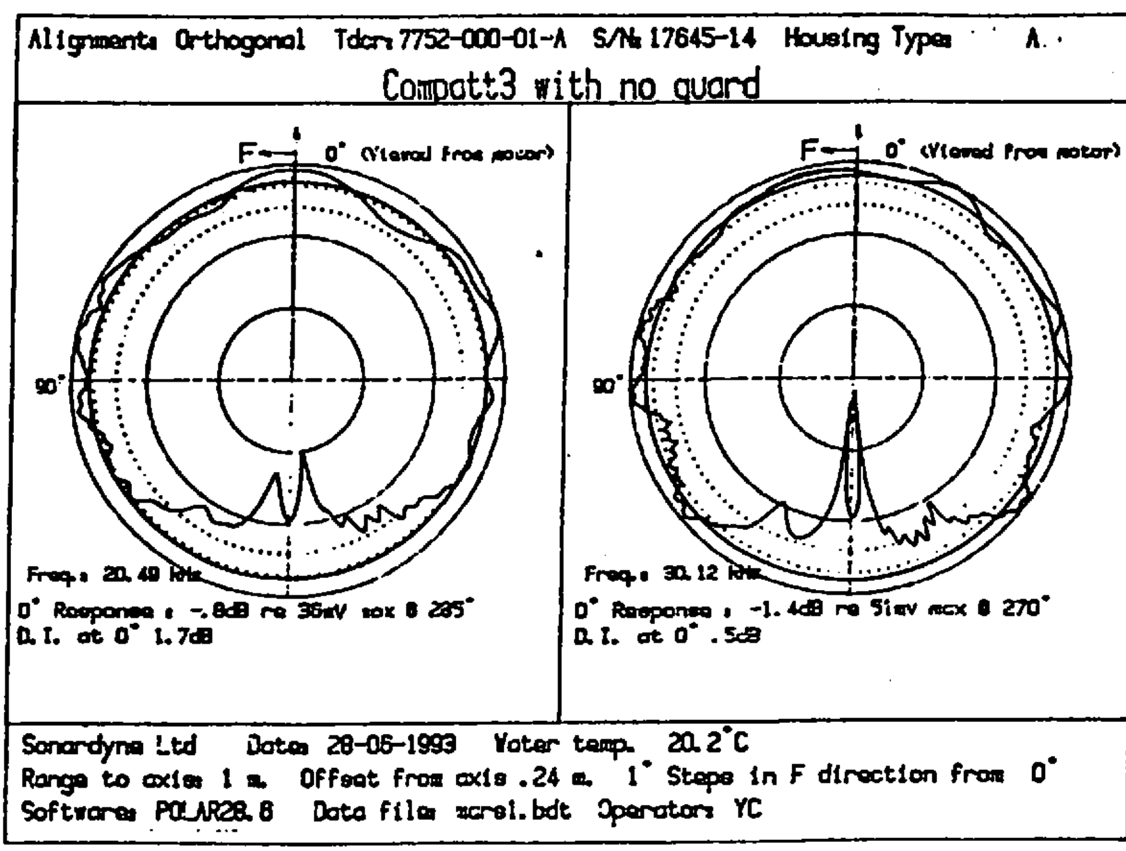

Fig 2

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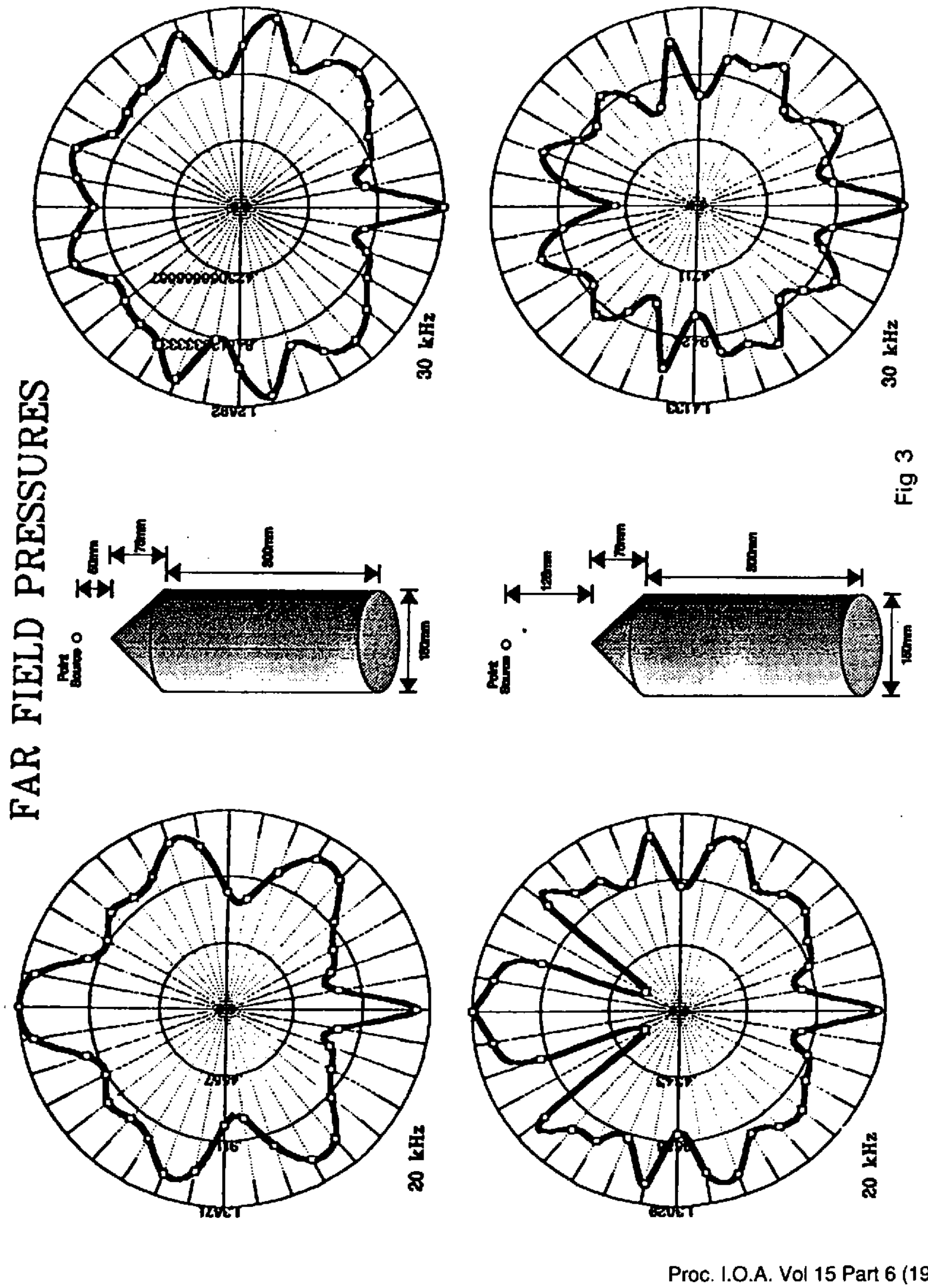

Fig 3

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4. INFLUENCE OF RESONANCES

Significant additional complications arise if the housing can resonate. A full analysis is very expensive in time and equipment, and often impracticable. However, where measured results fail to match the nonresonant expectations simplified modelling can again be made to good effect.

The simplest indication of the effects of resonances occur in large ("infinite") plane baffles. Plane wave analysis is then applicable. When the thickness of the baffle equals half a wavelength for sound in the material, a strong resonance occurs. In contrast to thicker or thinner baffles, this thickness baffle can be almost transparent if there is little intrinsic damping. Noise reduction enclosure design must take account of this important effect, especially if using foam materials with low speed of sound and relatively short wavelengths.

However, for metals the speed of sound is high ($c \approx 6000$m/s for aluminium), and even a 10mm thick aluminium sheet will resonate at about 300 kHz. The resonant frequency rises for thinner sheets, so this simple mode can thus be ignored for most pressure housings at frequencies below 100 kHz.

A more troublesome mode is that of flexural waves. These are typically much lower in frequency, as commonly experienced in the design of bells. Tubular bells exhibit relatively simple modes if the ends are unrestrained. Typical simple aluminium tube housings can have resonances in the audio region if unrestrained. These modes are eliminated when the endcaps are fitted, but others remain at higher frequencies.

5. APPLICATION OF DAMPING

The choice of housing structure and any acoustic damping is complex and interlocks with issues of strength, weight and corrosion. Sonardyne has used aluminium, aluminium bronze, stainless steel and mild steel for different applications, none of which have much intrinsic damping, and such housings depend on the additional damping provided by other components to avoid problems. Where the depth rating is not onerous, typically 300m or less, plastics are also used (UPVC or acetal), which have the advantage of good damping and corrosion resistance. However, for deeper applications metal housings are generally used. Glass spheres can provide an alternative, cost effective, high strength solution, but also have rather low intrinsic damping, and do not provide the adaptability of tubular housing designs.

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Some damping can be achieved by external or internal coatings, but it is not yet clear whether this is sufficient to eliminate the destructive acoustic interference of a driven resonance. In air, resonances of typical bells can have a mechanical quality factor, Qm, over 1000. When struck, they continue to ring audibly for many thousands of cycles. Very little damping is then required to produce a dramatic loss of their ringing quality but this may still leave a Qm well over 10. This will sound "dead" to the ear, but still vibrate strongly if driven by a tight coupled resonant driving force.

Underwater housings are already damped by their coupling to the water, and to avoid undesirable radiation, any extra damping must exceed this by a good margin.

This leads to two questions - How much damping is required to overcome unwanted re-radiation, and what systems are adequate to provide it?

6.NOISE BAFFLES AND ANTIVIBRATION MOUNTINGS

A closely linked topic is the provision of noise and vibration baffling for directional systems. Typical under hull acoustic systems need isolation from water borne and structure borne interference. Absorptive baffles surrounding the typical planar transducer elements or arrays need to be assessed for their noise reduction indices. Heavily loaded rubber (especially butyl) baffles can provide a useful combination of noise reduction, vibration reduction and mechanical protection.

Where metallic support systems are required for strength and security, damping can be used to avoid flexural wave vibration coupling. It is then relatively straightforward to eliminate compressional wave coupling by suitable design.

The constrained layer metal sandwich structure has the virtue of being immune to pressure effects. There is an urgent need to reduce the hydraulic noise generated by remote operated vehicles (ROVs). Such noise has been found to be critical is many acoustic positioning systems around the world. Noise surveys conducted by Sonardyne on behalf of the client (typically oil companies) have clearly demonstrated the need for noise control. Whilst some practical work has been done, this is an area where considerable improvements are still required.

7.DAMPING PERFORMANCE

Sonardyne has used various commercially available damping materials, as well as its own rubber mouldings and foam components. it has been found difficult to obtain damping data which can be readily applied to to design needs encountered.

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What was required was a simple test to compare different materials. The findings presented below do not represent any advanced techniques, but rather illustrate a need for simple and economic tests, and comments would be welcomed from others with more specialist knowledge.

The ASTM E-756 standard for measurement of damping properties uses the Oberst bar test. A specially machined test specimen has an integral thick root section by which it is firmly clamped. Non contact driving and receiving transducers drive the bar at frequencies of interest, plotting the variation of amplitude with frequency. There will be many resonances, and at each one the mechanical Qm is calculated from the half power bandwidth. Results are presented as the Young's modulus and the associated damping factor.

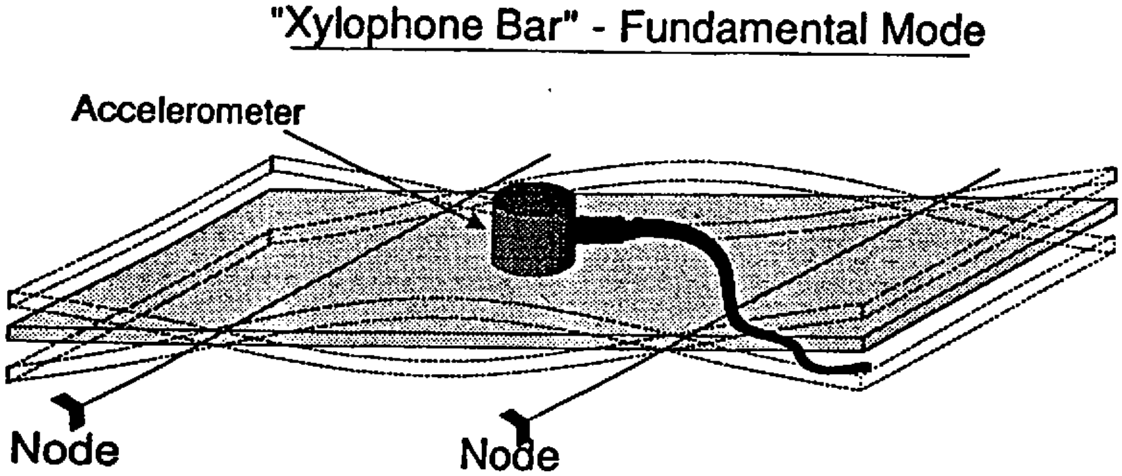

Fig 4

A simpler alternative used in recent tests was to make up unclamped bars with an accelerometer bonded to the centre (Fig 4). These were supported using transparent adhesive tape, and excited with a tap from a rubber ended pencil. After a little practice, clean traces of the exponential decay of several modes were obtained (Figs 5-8).

Results from three samples are compared, all the same size , 188mm * 61m *3mm. Sample 1 is a solid undamped piece of stainless steel, chosen to give a well separated fundamental "xylophone" mode. Fig 5 shows the fundamental 490Hz resonance, which is a flexural mode with two nodes, aand a central antinode (Fig 4). The accelerometer, bonded by cyanoacrylic adhesive, provided some mass loading,(8 gms in 300gms) but insignificant damping. Its internal resonant frequency is above 100kHz allowing it to be useful throughout the ultrasonic bands of interest. The print is from a bubble jet printer attached to a digital oscilloscope.

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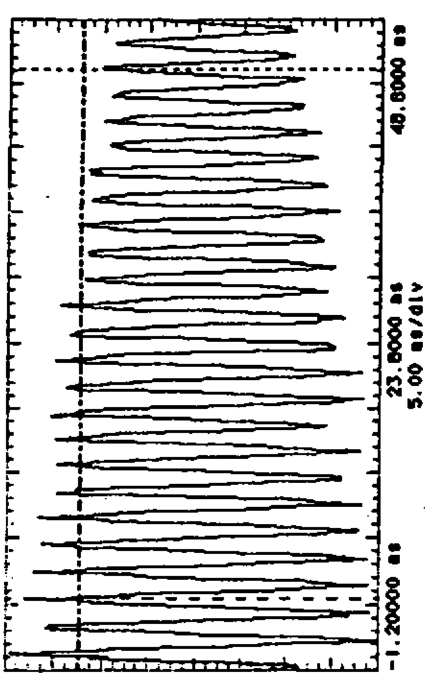

Fig 5 Undamped Bar - Fundamental

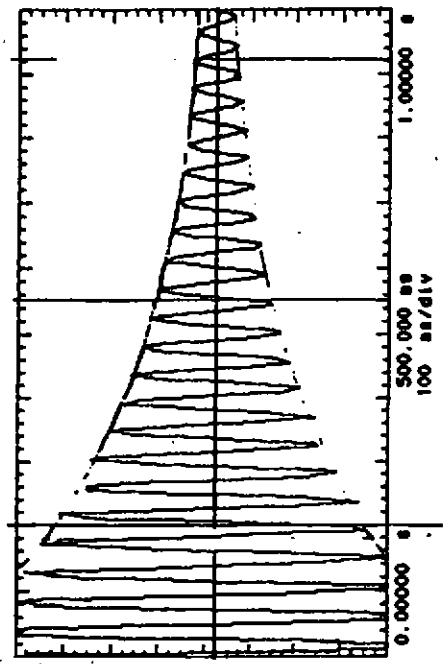

Fig 6 Undamped Bar - Envelope

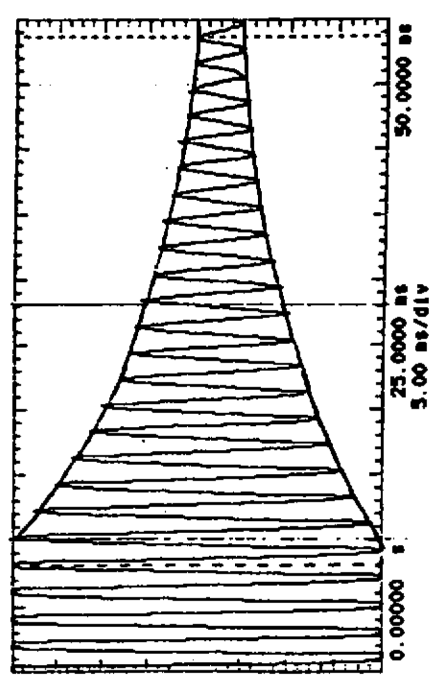

Fig 7 Unconstrained layer damping

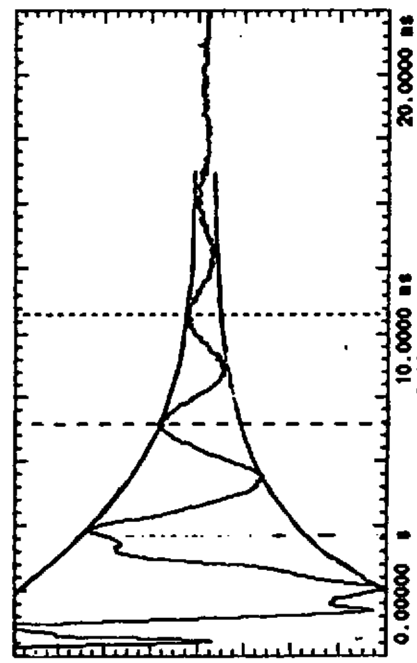

Fig 8 Constrained layer damping

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The signal envelope in Fig 6 shows the exponential decay of peak voltage V over 1 second, but the sine wave shown is a beat frequency (aliasing) between the fundamental and the sampling frequency.

$$V(t) = V(0) \exp(-2\pi fkt)$$

where f is the resonant frequency and k the damping factor. The envelope shows a decay time of 360 milliseconds for an amplitude ratio V(t)/V(0) of 1/e (36.8%) and 720 milliseconds for a ratio $1/e^2$.

This decay period T can then be used to calculate the damping factor k and the mechanical Qm factor (4)

$$k = 1/(2\pi fT) \qquad \& \qquad Qm = \pi fT$$

Samples 2 and 3 are unconstrained layer and constrained layer damped samples. The unconstrained layer is a modified PVC layer fixed to a replica of sample 1 with pressure sensitive adhesive supplied (Fig 7). The constrained layer lies between two stainless steel sheets each half the thickness of sample 1 (Fig 8). The resonant frequency is thus reduced.

As can clearly be seen, the damping of the constrained layer is far superior to that of the unconstrained layer. This is largely due to the imposition of mainly shear stresses on the damping material. The applications are, however, limited to sheet material, and the unconstrained layer has the advantage of being easily fixed to curved surfaces, such as the inside of cylindrical housings. It should be noted that both damped bars sound "dead" to the ear, but that the measured damping factors are very different.

Damping	Damping period (cycles to 1/e)	Loss factor k	Mechanical Qm
Undamped	176	9 E-4	553
Unconstrained layer	8.5	0.02	27
Constrained layer	≈1	≈0.2	≈3

It should be noted that these simple results refer to a room temperature of approx 20^{O}C, and audio frequencies of a few hundred Hz.

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8.DAMPING REQUIREMENTS

As discussed above, the levels of damping required to avoid re-radiation from driven systems is not well characterised. Thin walled tubes couple well to water, and this is the basis for many underwater transducers. The mechanical Qm of such transducers must drop dramatically in water if a wide bandwidth (often over an octave) is to be achieved. Qm factors well below 10 are typical. It thus seems likely that reductions to less than 10 are required. On this basis, the use of constrained layers is advisable where possible.

There is much scope for further modelling of these coupling factors. However, realistic data will be required for the available damping materials and techniques, with loss factors associated with both shear and Young's modulus.

9. CONCLUSIONS

A full understanding of the acoustics of underwater instruments is extremely complex, and simplistic analyses will remain essential for some years. However, the recent improvements in acoustic modelling software now present opportunities to improve these analyses.

Inclusion of realistic damping data for the material data files is very important, and it is hoped that wider promulgation of results can be encouraged to assist in the future exploration of "inner space" in the deep ocean.

10.REFERENCES

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