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A DESIGN PROGRAMME TO OPTIMISE HIGH RELIABILITY WIDEBAND HYDROPHONES

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INTRODUCTION

General Background

Several years ago DBE Technology became concerned about the reliability, and in particular the immersed lifetime, of some high performance, wideband hydrophones then in use. Devices manufactured by ITC Inc. were showing signs of deterioration after only a few months immersion in an application where a long life is of prime importance owing to high installation and replacement costs. DBE Technology were interested in developing replacement hydrophones, with the emphasis on achieving an acceptable reliability and immersed life.

This early interest opened up the possibility of achieving improvements to the hydrophone design, both in terms of lifetime and performance. In August 1980, DBE Technology began to optimise such hydrophones. This work was carried out over approximately two years, ceasing in October 1982. This report presents a summary of the programme.

CHARACTERISTICS OF EARLY HYDROPHONES AND REQUIRED IMPROVEMENTS

Early Hydrophones

The early hydrophones in use were manufactured by Ithaco Inc., Model No. 605C. These were discontinued, and manufacture of equivalent devices (Model 6050) was undertaken by ITC Inc., at the request of the US Government. Both these hydrophones have a similar performance to the DBE Model OH103 hydrophone.

Principal Characteristics

The full characteristics of the hydrophone under discussion are not presented in this summary. However, information is given on the principal characteristics; polar patterns, sensitivity and self noise.

These parameters are shown for the Model OH103 hydrophone in Figures 1, 2 and 3, which require some explanation. Figure 1 is a plot of the hydrophone sensitivity, but normalised to the element sensitivity by subtracting the pre-amplifier gain. This leads to some error, since the gain and coupling of the element to the amplifier are not constant with frequency. However, the normalisation facilitates the comparison between devices. Figure 2 shows the sensitivity variation caused by deviations to an omnidirectional polar pattern in both the horizontal and vertical plane. The figure is a concise summary of up to 20 separate polar plots. Figure 3 shows the self noise spectrum of the hydrophone, referred to the acoustic pressure level in the water.

As can be seen, the hydrophone possesses a good sensitivity, except above 80kHz, and has a noise performance adequate to detect signals well below sea noise. The polar patterns in the horizontal plane are not ideal, but are acceptable. The patterns in the vertical plane however vary greatly, particularly at the higher frequencies. It is this variation which limits the generally good overall performance of the hydrophone.

Feasibility of achieving the Requirements of Omnidirectional Hydrophones

Major conflicts. It was fairly well-known that no hydrophone then available was able to satisfy the three main requirements simultaneously. There is a conflict between the size required to achieve a good sensitivity (and hence noise performance) and that required for uniform polar response. Furthermore, as the polar patterns improve, the encapsulation materials become increasingly more important, and a secondary conflict exists between polar patterns and long-term immersion capability. These conflicts will now be examined in more detail.

Polar response. The required polar response can be achieved by two basic shapes, a cylinder and a sphere, and in general, the sensitivity and capacitance requirements are best achieved by thin wall devices, typically 1mm.

The diameter of these shapes is constrained by two factors; the resonant frequency and the level of perfection in the manufacturing and encapsulation processes. It is possible to produce spheres of up to 20mm diameter with a satisfactory polar response, even at 100kHz. Larger spheres (or cylinders) would be unacceptable because the resonant frequency would be too low, below 50kHz say.

As far as cylinders are concerned, the size must be small. A length of only 6mm would in theory produce an unacceptable dip in the vertical polar pattern on the axis of 4dB.

Sensitivity. The sensitivity is affected by the ceramic type, method of polarisation and method of shielding unwanted modes. Tangentially polarised cylinders offer the best electro-mechanical coupling factors, and are normally the optimum solution. However, in this case, spheres can offer a greater ceramic volume, and with the development of suitable electroding and connection arrangements, ultimately offer the best solution.

However, usually the best sensitivity from a sphere is around -200dB for 19mm diameter, whereas up to -184dB can be obtained from a 20mm diameter by 3mm long cylinder.

Encapsulation, boot design and screening. The polar patterns and sensitivity discussed above are functions of the ceramic element alone. However, in a practical hydrophone these may be modified by the effects of the encapsulation, oil-filled boots and screening arrangements.

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The hydrophone Model OH103 contains an inner encapsulation and a boot wall thickness which are not small compared to a wavelength at 100kHz. Additionally, the shape of these items is far from ideal, being designed for ease of manufacture. Finally, the electro-magnetic screen is known to disrupt the polar response. Improvements in these areas may be at the expense of submerged lifetime, immunity to interference, strength, robustness, reliability and cost. All these aspects were considered during the optimisation exercise.

Requirements of the Improved Omnidirectional Hydrophones

The main design aim requirements for the improved hydrophones are given below.

Element.

Sensitivity:	178dB ± 2dB at 1kHz
Resonant Frequency:	90kHz or above

Overall hydrophone.

Sensitivity:	-156dB
Polar Response:	Omnidirectional ±1dB in the horizontal plane. Omnidirectional +1 to -2dB in the upper half of the vertical plane.
Self Noise:	24dB re 1μPa @ 40kHz
	25dB re 1μPa @ 10kHz
	32dB re 1μPa @ 1kHz
	48dB re 1μPa @ 100Hz

THE OPTIMISATION PROGRAMME

General Outline

The optimisation programme described consisted of three main areas. Firstly, a programme of data acquisition was undertaken to provide sufficient data on candidate materials to enable the design to be carried out scientifically. Secondly, an experimental evaluation programme was performed, to assess the performance of various aspects of the design. Finally, the various element configurations were investigated, both theoretically and practically. Since this is of prime interest, only the latter is described here.

Assessment of Candidate Element Configurations

Theoretical considerations. The major performance aspect of an optimised noise-measuring hydrophone under consideration is the trade-off between polar patterns and self noise and the goal of achieving acceptable performance in both areas. Whilst other frequencies, such as sensitivity, capacitance and resonant frequency are significant, they are of secondary importance.

Taking the OH103 hydrophone as a starting point, it has an acceptable noise performance, but an inadequate vertical polar response, with up to 18dB variation at high frequencies. An aiming point is an element sensitivity of -170dB re 1V/µPa and a polar response within +1 to -2dB at up to 100kHz. This would result in a hydrophone with the same noise performance as the OH103, but considerably better polar response.

The principal parameters of a hydrophone element (as distinct from a complete hydrophone assembly) are sensitivity (m), capacitance (Co), resonant frequency (fr), and polar pattern (determined by size and shape). The calculation of these three parameters, and their effect on the hydrophone noise performance is given in the presentation. A computer programme to evaluate m, Co and fr was written and used in the optimisation process.

OH103 element. The OH103 element is a 19mm diameter by 12.7mm long, tangentially polarised cylinder with 4 stripes, made by Channel Industries Inc. in their material, Channelite 5800. It has a low frequency sensitivity of -178dB re 1V/µPa (minimum), a capacitance of 75pF and a resonant frequency of 57kHz. It is normally mounted on a pressure release former in an "ends-shielded" configuration. The computed results for this configuration are shown in Table 1 for a number of different ceramic materials.

Short cylindrical element. A cylindrical element can be considered to have a polar pattern equivalent to a line array if it is long compared to a wavelength, or to be omnidirectional if its dimensions are small compared to a wavelength. The OH103 element represents 0.85 wavelengths at 100kHz, and clearly falls somewhere between the two above cases.

As a first step, a quick "prototype" was envisaged using available ceramic cut down to only 3mm in length. This was in CH5600 ceramic, and predicted a similar performance to the OH103 element, as shown in Table 1, mainly due to a larger dielectric constant and greater number of stripes. The actual values obtained were -181dB re 1V/µPa and 87pF.

The polar patterns obtained showed significant departures from omnidirectional, and upon later examination, the 8 sections of the cylinder were found to have unequal capacitances, indicating that some depolarisation had occurred during the cutting process. Notwithstanding this, the vertical polar patterns still showed significant directional characteristics, and although generally better than the OH103 element, they were far short of the design aim.

Early spherical elements. When it became clear that the design-aim polar patterns could not be obtained with readily available cylindrical elements, a change in emphasis in the design aim was accepted, and attention was focussed on spherical elements. These were thought to provide good polar patterns, albeit with a much poorer sensitivity and corresponding noise performance, the aim being to consider ways of improving the sensitivity without degrading the polar patterns.

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The first attempt made used a 25mm sphere which was cut into 4 physically separate segments which were bonded together and joined electrically in series. This produced a sensitivity of -186dB re 1V/µPa and a capacitance of 3.5nF. However, the polar patterns were very poor at certain frequencies (70 - 90kHz), and this was thought to be a result of dissimilarities between the hand cut sections, which were free to act independently, particularly troublesome near resonance.

In view of the relatively poor polar response obtained, it was decided to build another prototype, using a 12.7mm sphere, with parallel connected halves. This configuration should produce the optimum polar response, and form a starting point for sensitivity improvements. The element had a capacitance of 14nF, and a measured low frequency sensitivity of -206dB re 1V/µPa. The polar patterns obtained in the horizontal plane plots were very good and entirely acceptable. The vertical plane plots were much better than any previous prototype, but still below the design aim. Much of the deviation shown is attributable to the 5mm wall, "rectangular-ended" boot.

<u>Small sphere with improved sensitivity</u>. Having obtained some encouraging polar patterns with small spheres, a programme was undertaken to bring about sensitivity improvements without degrading the polar response. Three devices were produced and their characteristics fully measured.

The first of these, contained 12.7mm hemispheres, connected in series, giving a capacitance of 3500pF and a sensitivity of -206dB re 1V/µPa. The hydrophone was constructed with a full standard packaging, including an inner polyurethane encapsulation, screen, oil filling and neoprene boot. Polar patterns were good.

The second device was similar, but contained a quadranted sphere, as shown in item 3 of Figure 4. This element was specially made by Channel Industries, and was designed to realise an 18dB improvement in sensitivity over the plain, parallel-connected sphere, by using 8 segments in series. Based upon a measured sensitivity of -206 for series connected hemispheres, this device should have realised a sensitivity of -194dB re 1V/µPa, and a capacitance of 220pF. In fact, a sensitivity of 200dB re 1V/µPa and a capacitance of 320pF were obtained. Upon subsequent examination, a high stray capacitance between sections was found, in effect shorting out some of the gathered charge. The resulting loss in sensitivity was increased by the asymmetry of the device, since the stray capacitance across the first and last segments has a greater effect than say the first and second.

The final element configuration, item 4 of Figure 4, used a "hooped" electrode pattern, to overcome the asymmetry. Five hoops were used on a 14mm sphere giving a 14dB improvement over the plain, parallel connected hemispheres, and a theoretical sensitivity of -188dB re 1V/µPa. The theoretical capacitance is 220pF. The electrode pattern was applied by DBE by hand to plain hemispheres from Vernitron Ltd, and the uniformity between sections of the resulting prototype was poor. However, excellent polar patterns were obtained, in conjunction with an element sensitivity of -192 to -194dB re 1V/µPa. As evidence by the low sensitivity (compared to theoretical) and high capacitance of 400pF, stray capacitance is still significant. However, the result is an improvement of 6 - 8dB over the previous device, only 1dB of which is due to the increased element size.

CONCLUSION

The history of the development of an optimised wideband hydrophone has been described, proving the advantages of using a striped spherical element for this special type of hydrophone. The presentation will give further details, including the methods used to calculate the optimum sensitivity obtainable from this technique. The striped spherical element has now been employed in over 100 production hydrophones, and is the subject of a UK patent.

Table 1. Theoretical predictions for large diameter cylinders

CERAMIC GRADES	SAMPLE 1 19 OD x 16 ID x 12.7 L			SAMPLE 2 20 OD x 18 ID x 3 L		
CH5400	55.1	-174.9	74.8	50.8	-176.0	42.8
CH5500	52.2	-175.0	100.7	48.1	-176.1	57.6
CH5600	52.2	-176.4	149.6	48.1	-177.4	85.5
CH5700	50.9	-177.5	184.2	46.8	-178.5	105.3
CH5800	58.1	-175.2	63.3	53.5	-176.3	36.2
	fr (kHz)	m (dB re	Co (pF)	fr	m	Co

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Figure 1. OH103 Hydrophone Sensitivity (Normalised)

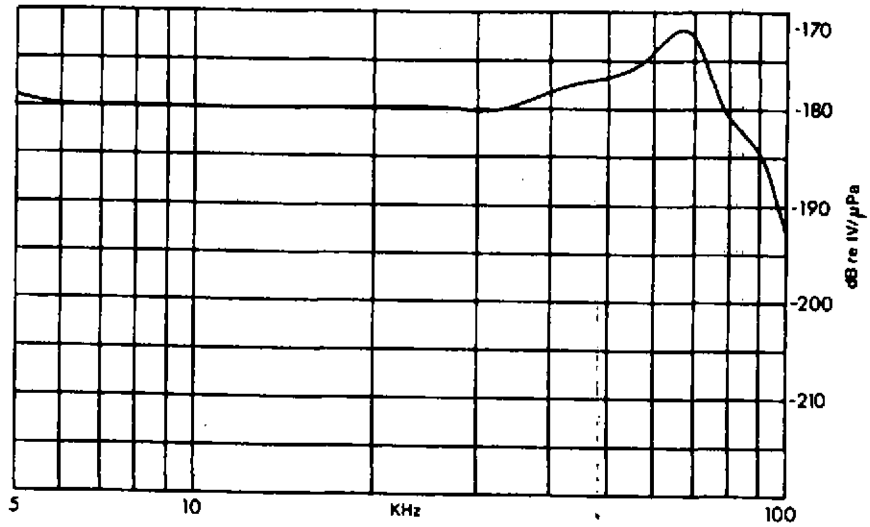
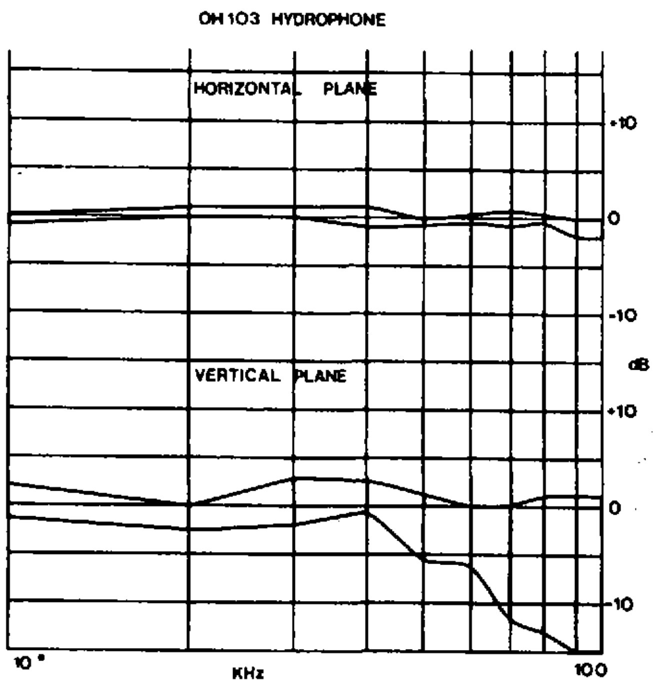


Figure 2. OH103 Polar Pattern Summary



*Polar patterns not measured below 10kHz, but assumed to be satisfactory.

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Figure 3. OH103 Self Noise Spectrum

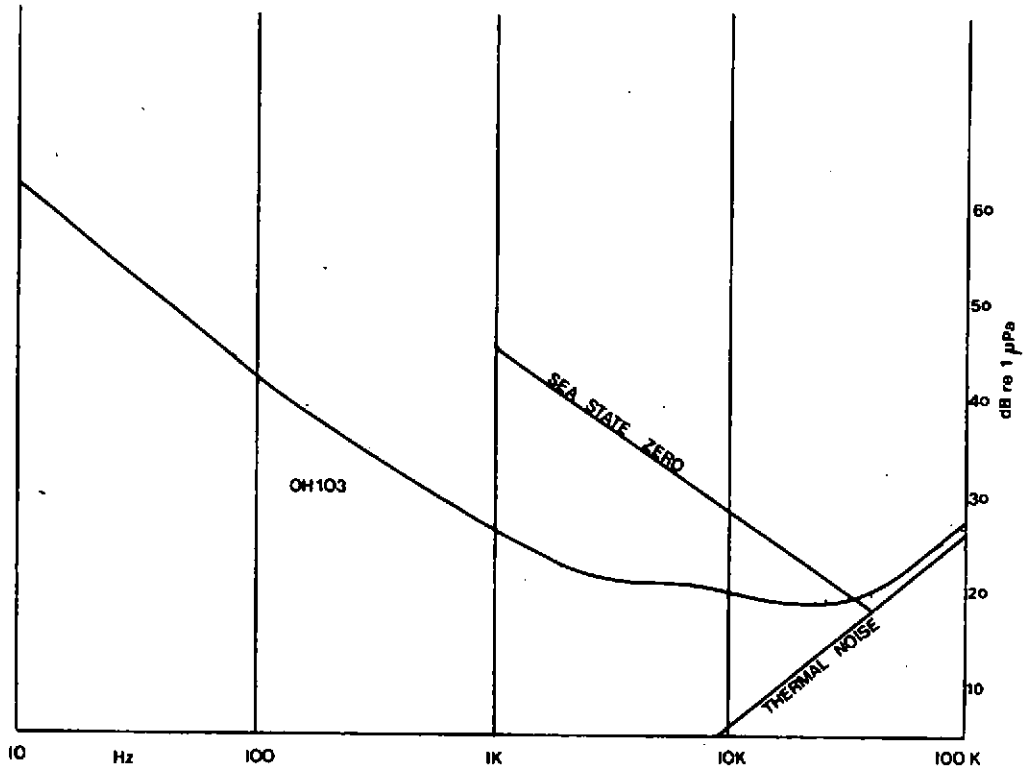

Figure 4. Candidate Element Configurations