Proceedings of The Institute of Acoustics

PARTIAL SPHERE TRANSDUCERS - FURTHER DEVELOPMENT

M HOLLAND

PLESSEY MARINE RESEARCH UNIT TEMPLECOMBE

At the 1978 Specialist Meeting of the Underwater Acoustics Group at Birmingham, Dr P Brazier-Smith presented a paper entitled "Partial Sphere Transducers". In it he explained the theory behind a mathematical model, which the Plessey Company had developed, that could be used, in association with finite element analysis, to predict the in air and in water modes of vibration of partial spherical shell transducers. The modelling requires data about the geometry and material constants of the shell, together with a stiffness tensor for the shell support ring, obtained from static finite element analysis.

In this paper I will present to you the results of extending this work, together with practical examples to show the feasibility of 'partial spheres' as a practical transducer concept.

Whilst the model, outlined in the previous paper, is capable of predicting the performance of a particular design, it was considered essential to be able to design a practical partial sphere from a given set of requirements. It was not possible to reverse the theory directly, so several analyses were conducted and the results compiled in a series of design charts.

Since no two configurations of shell support will have the same stiffness components it was considered better not to try and compile design data based on a particular stiffness tensor. Instead two cases were considered comprising the two extremes of an infinitely stiff support (relative to the shell in question) and no support at all (free edge case). This was done and the data was accumulated from many computer runs and design charts were created for the two cases. It was found that the variations in resonant frequency between the two cases, for a particular shell, were small. From these charts, for a particular resonant frequency a size of shell could be estimated, with sufficient accuracy, to enable successful designs to be achieved with a typically proportional support ring and a minimum of tuning.

The charts were prepared with the dimensionless resonant frequency on one axis, and the ratio of shell thickness to semi chord on the other. The remaining variable required to fully define a shell, the cap semi angle, was plotted incrementally as a series of lines on the chart, Figures 1 and 2.

It was realised that two distinct groups of partial sphere transducer were likely to evolve as the most practical. The first group were those using a shell whose cap semi angle was, say, 45° or less. These are usually referred to by the ceramic manufacturer as a focal bowl. The second group of transducers appeared to be those utilising readily available ceramic hemispheres (ie. semi cap angle 90°). Charts were prepared for these two groups of transducer designs.

The two configurations are very different in their performance. The 'flat spherical shells, as in the first group, exhibit modes of resonance spaced widely apart, and are useful as active devices requiring a single resonance at a particular frequency. The latter, hemispherical, group exhibit a different pattern of behaviour. Their resonances occur much closer together and this enhances their role as a broadband device.

The charts for the first group were designed to consider only the first mode of resonance, whilst the charts for the second group considered also the higher modes of resonance.

The charts have been used as a basis around which several successful practical transducers have been designed at both low and medium frequencies of operation.

LOW FREQUENCY SINGLE RESONANCE TRANSDUCERS

Several low frequency designs have been built. The charts were used to find the sizes of ceramic shell necessary to provide resonant frequencies in air of nominally 6 and 3 KHz.

When received from the manufacturers the ceramic focal bowls were not precisely to the required radius of curvature. Full analyses were conducted on the 'new' dimensions, and the results are given in the table,

Figure 4, compared with practical results obtained after building the transducers. The errors that exist between theory and experiment are in all cases less than 5%. It must be noted that as the ceramics had the same chord diameter, the stiffness tensor calculated for the 6 KHz transducer support ring (incorporating a 10 mm thick ceramic focal bowl) was also used for the theoretical analysis of the 3 KHz transducer (which used a 5 mm thick ceramic). This introduced an error in the theoretical assessment and is the 4.2% error shown in the table of results.

Back masses of approximately ten times the ceramic mass were used with these designs, giving an overall transducer weight of 4-5 kg for the 3 KHz design. The design has been driven, at resonance, with an electrical input of 80-100 Watts, for more than 20 x 10^6 cycles, without failure. As a passive device the transducer has a receive sensitivity at low frequency (well below resonance) of +56 dB re 1μv/Pa.

BROADBAND TRANSDUCER

A broadband (multi mode) design of transducer, which again was initially conceived using the set of charts, is shown in Figure 3. It consists of a 3 mm thick lead zirconate titanate ceramic hemisphere, mounted on a stainless steel backmass. Before construction of the prototype, the design was checked using the full analysis method described by my colleague in his paper. The backmass/support ring was analysed using the finite element method and the resulting stiffness tensor and shell geometry input to the suite of analysis programmes.

The results for the first five in vacuo modes are given in the table, Figure 5, together with the practical figures obtained from an admittance plot of the prototype transducer. The first mode of resonance is within 3%. The predictions for the higher modes become progressively more erroneous.

This is accounted for by the use of a static stiffness tensor, obtained from the finite element analysis. It is fully expected that a prediction for even the first mode of a high resonant frequency device would be in error for this reason. This has not to date been proven.

The in water results for a broadband device are also given, both theoretically and practically, in Figure 5. Again the predictions for the higher modes become erroneous, in this case not only due to the 'static' stiffness tensor. In order to solve theoretically the effect of water loading, it is necessary to consider the partial sphere set in a spherical rigid baffle of radius equal to the ceramic shell. This enables the Helmholtz equation for the radiated pressure field to be sufficiently well defined for a solution to be obtained. The practical partial sphere transducer however, is usually tested in a free field condition, except for its own backmass and housing.

Figure 6 shows the variation of pressure, on the axis of symmetry of the transducer, with frequency as predicted by the theoretical model.

It had always been considered necessary, as with quarter wave piston transducers, to incorporate a large back mass (relative to the ceramic shell). In this instance the development programme required a reduction in the weight of the prototype transducer (2.7 Kg). The backmass was progressively lightened and the transmit and receive performance of the device monitored. It was found that the reduced backmass did not derate the performance of the transducer, and an [illegible]t overall weight of 1 Kg was achieved. This incorporated an alloy housing in place of the stainless steel used with the prototype.

In the design the ceramic shell/backmass assembly was located in a tubular alloy housing, and the radiating face potted with a polyurethane encapsulant. During environmental testing at low temperatures ceramic shell failures were found to occur. Initially this was thought to be the result of two features. Firstly a locating collar around the backmass support ring was found to be nipping the edge of the hemisphere during assembly. An undercut was provided to eliminate the interference. Secondly it was thought that differential contraction, between the ceramic and the backmass, was causing the locating collar to pinch the edge of the hemisphere. An annular clearance was provided between the collar and the shell. Neither of these measures were found to be effective.

The contraction of ~~the alloy~~ housing was next considered. It was realised that the reduction in diameter at low temperature, combined with the high bulk modulus of the potting compound at low temperature was stressing the ceramic shell to sufficient extent to cause failure.

At the completion of this design phase the front part of the outer housing was eliminated, and the transducer encapsulated using a removable mould tool. This proved totally successful and the design has completed a full set of environmental tests, including low temperature and pressure, and at pressures up to 350 $lbF.in^{-2}$. It has been tested to acoustic outputs in excess of 150 Watts, a power rating of better than 80 Watts/lb.

Summarising, it has been shown that the concept of the partial sphere transducer is feasible. Prototypes at low and medium frequencies have been constructed, and shown to perform as predicted. They provide the designer with a lightweight high power transducer comprising a minimum number of parts resulting in ease of manufacture and low cost.

ACKNOWLEDGEMENTS

Thanks are due to my colleagues at Plessey Marine Research Unit in particular Mr C. McClellan, P. Brazier-Smith and W. Craster for their major contribution for this work and in preparation of this paper.

LEGEND

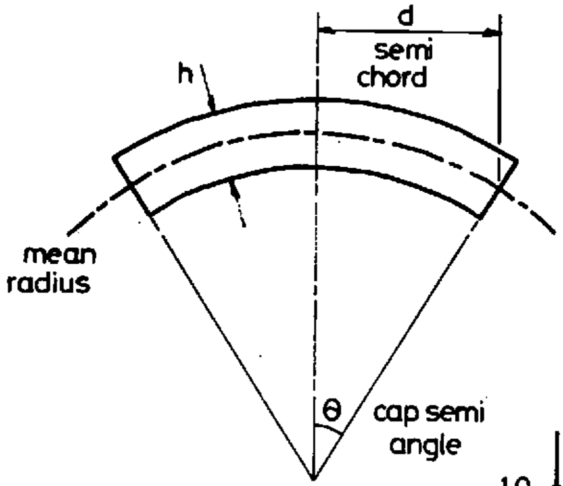

FIGURE 1

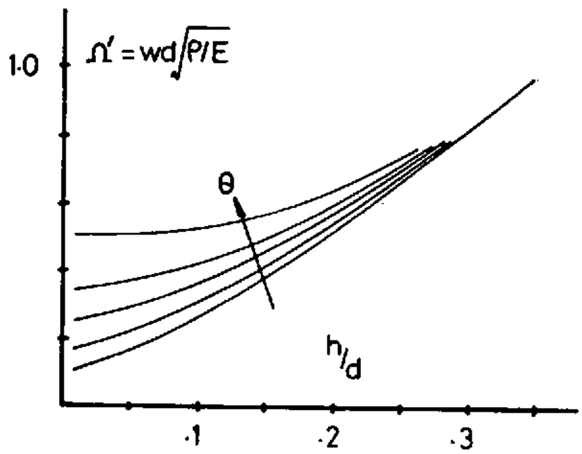

FIGURE 2

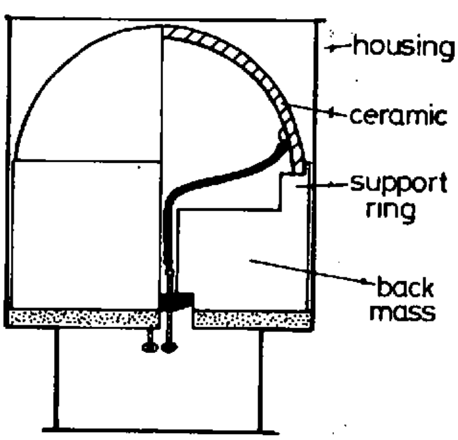

FIGURE 3

FIGURE 4

Theoretical Resonant Frequency		Practical Resonant Frequency		Error %	
Vacuo	Water	Air	Water	Air	Water
3.395 5.546	2.811 5.097	3.544 5.584	2.765 5.659	4.2 0.7	1.7 2.0

FIGURE 5

Mode	Theoretical Frequency		Practical Frequency		Error %	
	Vacuo	Water	Air	Water	Air	Water
1	14.94	12.25	14.57	12.26	2.7	0.1
2	22.48	19.5	20.98	18.31	7.2	6.5
3	28.86	26.4	26.25	23.35	9.9	13.1
4	37.49	33.8	32.79	30.34	14.3	11.4
5	48.68		36.75	35.50	32.5	

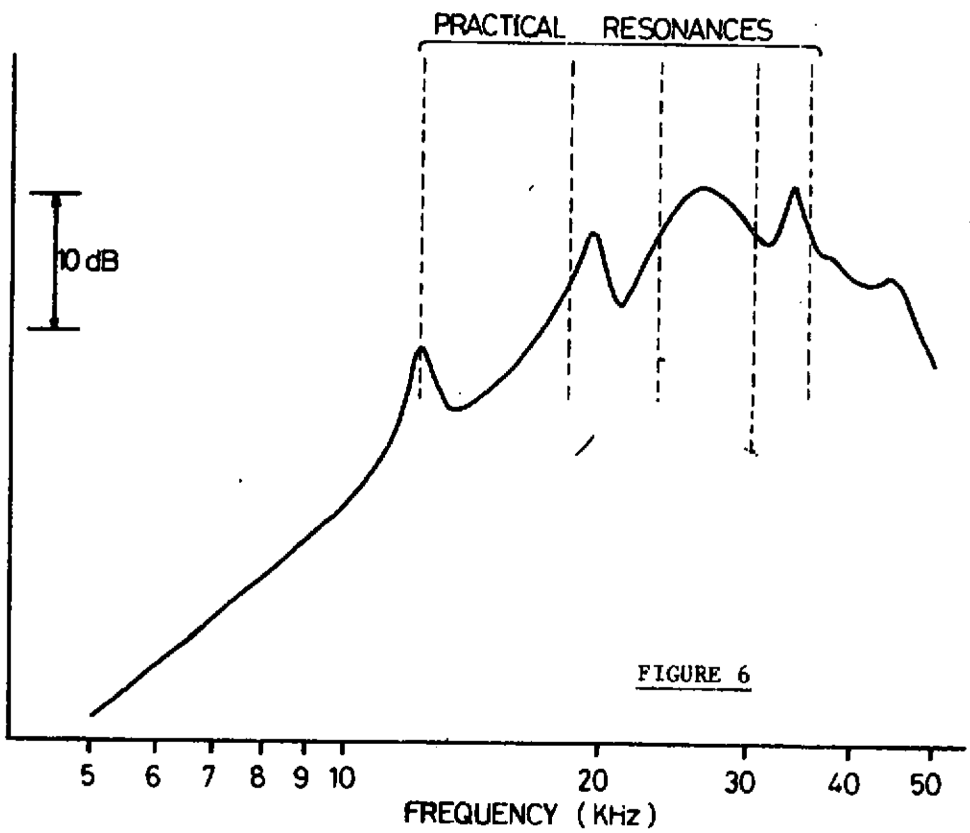

FIGURE 6