72·44

BRITISH ACOUSTICAL SOCIETY
Meeting on Tuesday 6th June, '72
Gloucester Hotel, Weymouth.

Underwater Acoustic Test Facilities
and Measurements.

ACOUSTIC FIELD MEASUREMENTS USING A COMPUTER-POSITIONED PROBE

W.G Welsby. University of Birmingham

INTRODUCTION The design of any underwater system involving radiation, propagation or reception of acoustic waves must inevitably be concerned, directly or indirectly, with the spatial distribution of the pressure and particle velocity of an acoustic field. This paper outlines some reasons why a study of spatial field structures is of interest and shows what parameters have to be measured. Measurement techniques are discussed, referring particularly to the use of the computer-controlled facility recently installed in the Acoustic Division of the University of Birmingham.

VECTOR ACOUSTIC ADMITTANCE A familiar idea in acoustic engineering is that of acoustic impedance, defined as the ratio of pressure to particle velocity. A much more useful concept can be developed however by considering the reciprocal of this ratio; i.e. the acoustic admittance. This has the vector velocity in the numerator, divided by the scalar pressure, so that the admittance itself is a vector quantity. Both velocity and pressure are time-alternating quantities so their ratio can be represented by a complex number, the real part containing the in-phase component of the velocity and the imaginary part containing the component of velocity which is in time-quadrature with the alternating pressure. The two components of the admittance, at any point in the field, are themselves vectors. In simple cases; in uniform planar or spherical waves for example; both vector components point in the same direction. In general however they do not do so; the particles of the medium then oscillate in elliptical orbits and not in straight lines as is often imagined. Simultaneous measurement of both pressure and velocity yields much more information about the local behaviour of the field than could be obtained from a knowledge of either parameter alone.[1] A very useful device therefore is a vector admittance meter, capable of measuring the amplitude and phase of the pressure and velocity, in any chosen direction, and of displaying their complex ratio. This can be demonstrated quite neatly by combining a pressure-sensitive transducer and a pressure-gradient transducer in a single hydrophone unit and using the respective outputs to provide the X and Y deflections on a CRT screen. The resulting Lissajous figure gives an immediate visual impression of the magnitude of the admittance and of the relationship between its real and imaginary components in the direction in which the composite hydrophone is arranged to point at any given time. Orientation of the device enables the absolute magnitude and direction of either component of the admittance to be determined. For more exact work the quantities are of course recorded numerically. It is usually the real component which is of most interest because its direction always coincides with that of the time-averaged power-flow in that particular locality. An admittance hydrophone can be used therefore to trace out, point by point, the form of the power-flow field, Such information is of considerable interest for example in the design and testing of multi-element transmitting arrays. Another interesting fact is that since the phase angle of the admittance near a boundary differs from its value farther out in the medium, a fixed admittance hydrophone can be used to indicate the approach of a moving "target" object or, alternatively, a moving hydrophone will give readings indicating that it is approaching a fixed boundary. Furthermore, reading close to a boundary will be influenced by the properties of the material of which the latter is composed; this may sometimes be practically useful.

EQUI-PRESSURE SURFACES Another property of the power-flow vector is that its direction is always perpendicular to pressure equi-phase surfaces; i.e. surfaces drawn in the medium in such a way that the alternating pressures are cophasal over each such surface; (see Appendix). The surfaces are also known variously as wavefronts or phase-fronts. The magnitude of the powe-flow vector is proportional to the pressure phase-gradient. The pressure amplitude-gradient, on the other hand, is perpendicular to pressure equi-amplitude surfaces and gives the direction of the imaginary component of the acoustic admittance. So here we have another method of studying the structure of the acoustic field; by sampling the alternating pressure at a sufficiently large number of points and using the results to trace out the form of the phase-fronts and of the flux lines of the power-flow field, which intersect them at right-angles. Any possible infinitesimal-amplitude underwater acoustic field can be expressed in terms of scalar potentials. It is sometimes an advantage to tackle problems by this approach, making use of the powerful tools of potential field theory and subsequently translating the results back into terms which are generally more familiar to engineers and are more easily interpreted physically.

FAR-FIELD PREDICTION The classical theory of Kirchhoff and Helmholtz shows that if an imaginary surface is drawn so that it completely encloses any transmitting array then it is theoretically possible to reconstruct the whole field, at all points in the region outside that surface, from a knowledge of both the pressure and the pressure gradient over the whole of the surface. This desirable process is mathematically elegant but practically impossible to realize. The real problem is essentially one of compromise; of finding out how best to choose the reference surface and how best to distribute over it some reasonable finite number of sampling points, One convenient approach is to choose part of the surface to be a planar "window" and then to contrive that the contributions from the rest of the surface are negligibly small. The window then becomes the aperture of a hypothetical array which, it is hoped, has a far-field pattern which is acceptably close to that of the original array. One advantage of choosing a planar sampling surface is that it is then not necessary to measure both pressure and pressure-gradient; it can be shown that either will suffice to enable the result to be computed. It is however sometimes appropriate to depart from this and to adopt some other simple geometrical form; e.g. a cylinder, for the sampling surface. Even then it is often possible to arrange that the radius of curvature of the cylinder is large enough to justify assumptions which still enable the pressure-gradient measurements to be avoided. Care has always to be taken to ensure that the sampling surface is placed far enough away from the physical boundary of the array for the effects of the boundary field associated with it to have fallen to a negligible value. This explains why the sampling operation is not carried out at the face of the array itself. The "evanescent" waves which make up the boundary field cannot propagate into the far-field but they can interfere with the sampling process.

USE OF POSITIONING MACHINE Practical investigations of the spatial distributions of acoustic fields require some means for placing a sampling probe accurately in any desired position and then causing it to move along some pre-determined path in a test tank. At the same time it is necessary to measure both the amplitude and relative phase of the alternating pressure at each point and to store this information for subsequent processing. The basis of the equipment which we have developed at the University of Birmingham for this purpose is a travelling gantry machine, running on rails above a tank roughly 10 X 5 metres in area and 3 metres deep, capable of positioning a probe or even a complete array, with an accuracy of ± 1 mm in three dimensions.[2] Positional control is achieved either manually, by setting the required numerical values of the co-ordinates or automatically, by feeding the required programme into the PDP8 digital computer which is linked to the machine. Pulsed acoustic signals are used to avoid interference by tank-wall echoes. The complex amplitude of the alternating carrier within the received pulse is measured by a pair of quadrature-connected phase-sensitive detectors which produce sine and cosine coefficients. These are punched out on paper tape. The system is usually worked in an open-loop condition but we have experimented with a feedback method in which the phase information from the received signal is fed into the control circuits of the machine in such a way that the latter is made to trace out automatically loci on which the pressure phase is constant. From the previous paragraphs it can be seen that this can be of interest in studies of the power-flow field near an array.

APPENDIX The particle velocity $\underline{u}$ in a sinusoidally oscillating field is given by $\underline{u} = -\frac{1}{j\omega\rho}\nabla p$

where ρ is density and p is alternating pressure.

$$p = |p|e^{j\theta}$$

$$\nabla p = \nabla|p|e^{j\theta} + j\nabla\theta|p|e^{j\theta}$$

so admittance is $\frac{\underline{u}}{p} = -\frac{1}{\omega\rho}\nabla\theta + j\frac{1}{\omega\rho}\frac{\nabla|p|}{|p|}$

The real part of the admittance is proportional to the pressure phase-gradient $\nabla\theta$ and also to the time-averaged power-flow. The phase-gradient at any point is perpendicular to the equi-phase surface at that point. Hence power-flow flux lines always intersect pressure equi-phase surfaces at right-angles.

REFERENCES

1. V.G.Welsby, "Pressure and Displacement sensors used simultaneously in underwater sonar" Nature, Vol. 218, p 890-1 1 June 1968.
2. V.G.Welsby, "New facility at University of Birmingham for underwater sound research". Paper read at ULTRASONICS conference, London 1971