Proceedings of The Institute of Acoustics

ULTRASONIC STUDIES OF SUSPENSION SYSTEMS

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One of the aspects of the proliferation of analytical techniques in ultrasonics - both analogue and digital - is a growing use for materials of predetermined ultrasonic parameters: velocity and absorption for homogeneous materials; velocity, attenuation and scattering for inhomogeneous materials. In medical ultrasonics there is a particular need for materials with differing controlled ultrasonic propagation parameters that can be used to imitate the behaviour of human soft tissues. The purposes of such modelling in medical ultrasonics have been discussed more fully elsewhere (1) and can be summarised as: the development of systems for the empirical assessment of commercially available real-time grey-scale B-scan machines, and a means of obtaining insight on the mechanisms that may be of particular importance in the propagation of ultrasound in tissue (2).

Although a suspension system has obvious advantages in terms of the number of independent parameters that may be varied, it is necessary to adopt a systematic approach to the matching of material parameters. A liquid matrix has some advantages (3) but is generally very temperature sensitive. A matrix that is solid but strongly attenuates shear waves is preferable, while transparency permits visual assessment of the evenness of the distribution of the suspended particles. The essence of a systematic approach can be seen in the way that experimental data is displayed. The traditional display of the variation of a parameter with frequency or temperature is useful but limited. It is often more appropriate to work at one temperature, or frequency, and in this case the VA (velocity, attenuation) diagram shown in Figure 1 is more useful. Any particular matrix material at a particular frequency and temperature will have unique properties of velocity (V) and attenuation (A), defining a point on the diagram such as P. The inclusion of suspended particles of a particular size, shape and material will change the attenuation and the velocity (if the concepts of coherent and incoherent scattering have experimental validity (4)). Increasing the concentration of the scatters will cause the point P to move along a locus such as PR to R where the suspension is saturated. Changing the particles gives a different locus PS and changing the matrix, a different set of loci based on P'. For any matrix it is possible to reach any point within the region PRS by suitable mixtures of particles. The diagram may be extended to a third dimension by the inclusion of a third variable such as scattering (S) temperature or frequency. Although functional dependence is not necessarily implied by VA, AS or VS diagrams the latter two should give interesting information on absorption and the importance of coherent scattering to the propagation velocity.

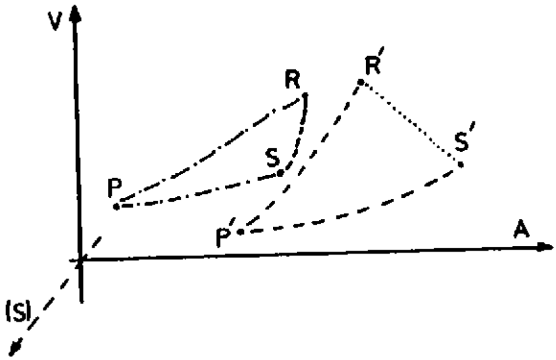

Figure 1 : A VA(S) diagram for inhomogeneous systems

The detection of this latter effect depends essentially on the precision of the measurement system, while the matching of properties of a specified tissue, for example, depends on the accuracy both of the original measurements and of those used to define the properties of the suspension system. The problems of measurement are severe. There appear to be no relevant theories for accurate measurements of velocity or attenuation where scattering is involved, and scattering measurements, even on the simplest theories,have as prerequisites measurements of velocity and attenuation, and the inaccuracies are compounded (5). Furthermore with conventional large area receivers the errors in attenuation measurements can be excessive (6), while the time errors in velocity measurements may be as great as one period of the wave, and thus their significance depends on the frequency used and the size and material of the specimen.

For fitting theory to experiment to identify interaction mechanisms, these considerations are of vital importance. However, if subsequent visualization is involved, it may be possible to relax the stringency of the matching that is required. Thus, for example, if a conventional linear B-scan, (whether mechanically or electronically scanned) is used, exact matching of the velocity is not important since it affects only one axis of the display, and this can often be compensated by adjustment of the display controls (some commercial machines even have an adjustable calibrated velocity control). Similarly most B-scan machines concerned with imaging lossy materials have adjustable swept gain. Thus provided the velocity and attenuation of the suspension system are known and lie within the range of adjustments available, representative visualization can be achieved.

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Some visualizations of model suspension systems, taken on a commercial scanner with settings typical for diagnosis are shown in Figure 2. The variation of image with scatterer concentration is of particular interest. At the lower concentrations the scattering appears to increase with concentration.

Above some threshold the scattering visualized is reduced in both amount and granularity, and as the concentration increases further the scattering increases again but the very high attenuation introduced close to saturation prevents visualization of the deeper parts of the specimen. It is suggested that the threshold occurs at the concentration for which the mean inter-particle spacing is of the order of the pulse length. Further studies on this are in progress, and on the quantitative assessment of the scattering with a commercially available image analyzer (7).

Acknowledgements Funding from the D.H.S.S. (R.A.B.), the S.R.C.(R.J.P., J.D.A.), and the University Research Committee is gratefully acknowledged.

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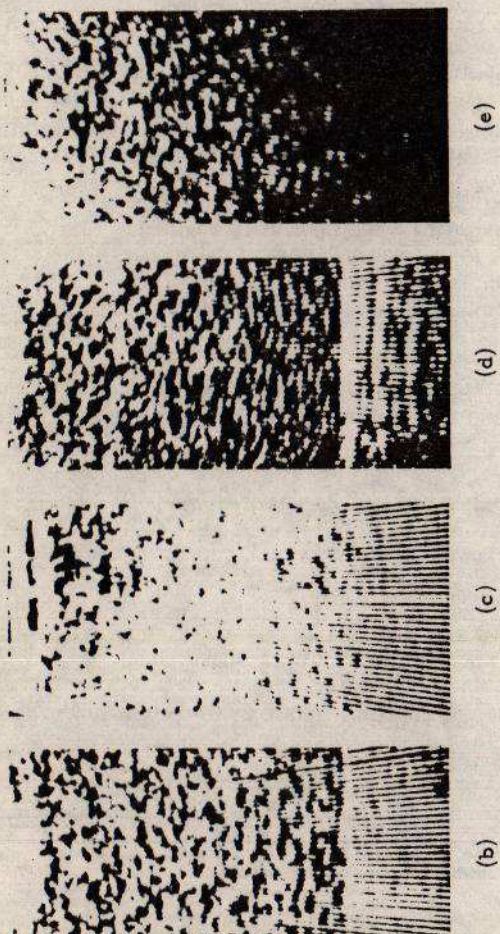

Figure 2 : Visualization at 2. 5MHz of $\frac{1}{4}$ mm diameter spheres in a rubber matrix at different concentrations: (a) 0. 5%, (b) 1%, (c) 2%, (d) 10%, (e) 25% (saturation). The velocity of the matrix was approximately 1100 m/s.