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AMPLITUDE AND PHASE FLUCTUATIONS OF ULTRASONIC WAVES PROPAGATING IN INHOMOGENEOUS MATERIALS

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Introduction

A considerable portion of the materials subjected to ultrasonic methods of non-destructive testing exhibit inhomogeneity to a greater or lesser extent: granular metals, fibre reinforced plastics, concrete, animal tissue. Whereas the inhomogeneity is usually discussed in relation to the degree of ultrasonic scattering produced - and many successful applications measure this scattering as a diagnostic index - another (related) phenomenological aspect of the presence of inhomogeneities is the occurrence of phase and amplitude fluctuations in the waves propagating through the specimen[1,2]. The degree of fluctuations induced will depend, as for the scattering, on the linear scale of the inhomogeneities in relation to the wavelength, and on the magnitude of the inhomogeneities (i.e. the extent to which the local acoustic parameters - density, elastic moduli - vary). In addition the fluctuations tend to increase with the distance traversed through the material.

It has been suggested[3] that one of the effects of phase fluctuations across the front of the wave is to produce very significant systematic errors in the conventional attenuation measurement systems employing piezo-electric receivers, due to 'phase cancellation' effects. It is also true, although it has received little attention in the literature, that phase fluctuations will lead to errors in velocity measurements if piezo-electric receivers are used, while phase fluctuations are theoretically linked to amplitude fluctuations[2] - which will further influence the attenuation measurements. It may be expected that the significance of the effects on velocity measurements will be a compromise between their increasing importance as the specimen thickness is decreased, and the simultaneous reduction in their magnitude.

To date evidence for the existence of such fluctuations has been largely circumstantial, and appears to have been limited to tissues. The evidence that exists[4-8] is almost exclusively devoted to demonstrating a lower measured attenuation when a piezo-electric receiver is replaced by a phase insensitive detection device (i.e. calorimeter, radiation force device or CDS transducer), with the implicit assumption that the lowest apparent attenuation has the highest probability of being correct. The conclusion that phase disturbances are present in the waves emerging from the specimens is probably valid, the origin of the disturbances is less certain. They may originate from the inhomogeneities in the specimen, from the inevitable phase irregularity involved in irradiating the specimen with a diffractive source, or from variations in the thickness of the specimen.

The present work describes an experimental arrangement for measuring the fluctuations due to inhomogeneities in the specimens themselves and presents what appear to be the first direct measurements of such effects in bulk materials.

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Materials

The specimens used have been described in detail in the previous paper[9]. They are suspensions of glass spheres in silicone rubber moulded into rectangular blocks (3cm x 4cm x 5cm) with parallel sides. The ball diameters ranged from 50 μ m to 600 μ m and concentrations from 0% to 17.2% by weight. For the present experiments measurements were made through the 3cm thickness.

Method

Measurements of amplitude and phase were taken as a function of lateral movement relative to the transmitting probe axis using a 1.0mm diameter element needle-type hydrophonewith an integral pre-amplifier. The transmitter was a nominal 2MHz 15mm diameter plane disc driven at 2.066MHz with 20 cycle bursts. Measurements of amplitude were made on an oscilloscope and of phase using a technique previously described[10,11] based on the 10th zero crossing of the pulse. Investigation of the field (phase and amplitude distributions) of the transmitter [12] revealed that at 70mm from the face of the element the waves bear a good approximation to the irradiating plane waves ubiquitously assumed in theoretical analyses[10]. The measurements were performed 0.5mm from the side of the specimen further from the transmitter, in lateral steps of approximately 150 μ m. (The precision mechanical movement permitted 7.5 μ m resolution). The temperature of the water was maintained at $20 \pm 0.2^\circ\text{C}$ for the duration of the experiments.

Results

Figure 1 shows typical results of amplitude and phase distributions obtained with four concentrations of the largest scatterers used, ranging from 0 to 17.2% by weight. The absence of scatterers confirms the close approximation to incident plane waves achieved. The minor irregularity of the phase distribution has been identified as a slight ($\approx 2\mu$ m) eccentricity of the driving screw thread[13].

It can be seen that, as anticipated, an increase in the number of scatterers increases the fluctuations and that both amplitude and phase fluctuations increase together, as predicted theoretically. There is clearly a reservation necessary concerning the spatial frequency of the fluctuations that can be detected which, for the hydrophone used, cannot be greater than about 2 per mm. What is surprising is the high concentration of large scatterers needed to produce very significant fluctuations, suggesting the need for the cautious interpretation of the experimental results mentioned above. A factor that may influence the magnitude of these fluctuations is the relatively high attenuation in the materials investigated which, intuitively, would be expected to have some moderating effect on the fluctuations observed. Apart from the need for further theoretical development in this area, the results indicate both the importance of careful experimentation and the extension of such measurements to inhomogeneous materials tested routinely with ultrasonics.

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Relative amplitude
(arbitrary linear scale)

Relative phase (degrees)

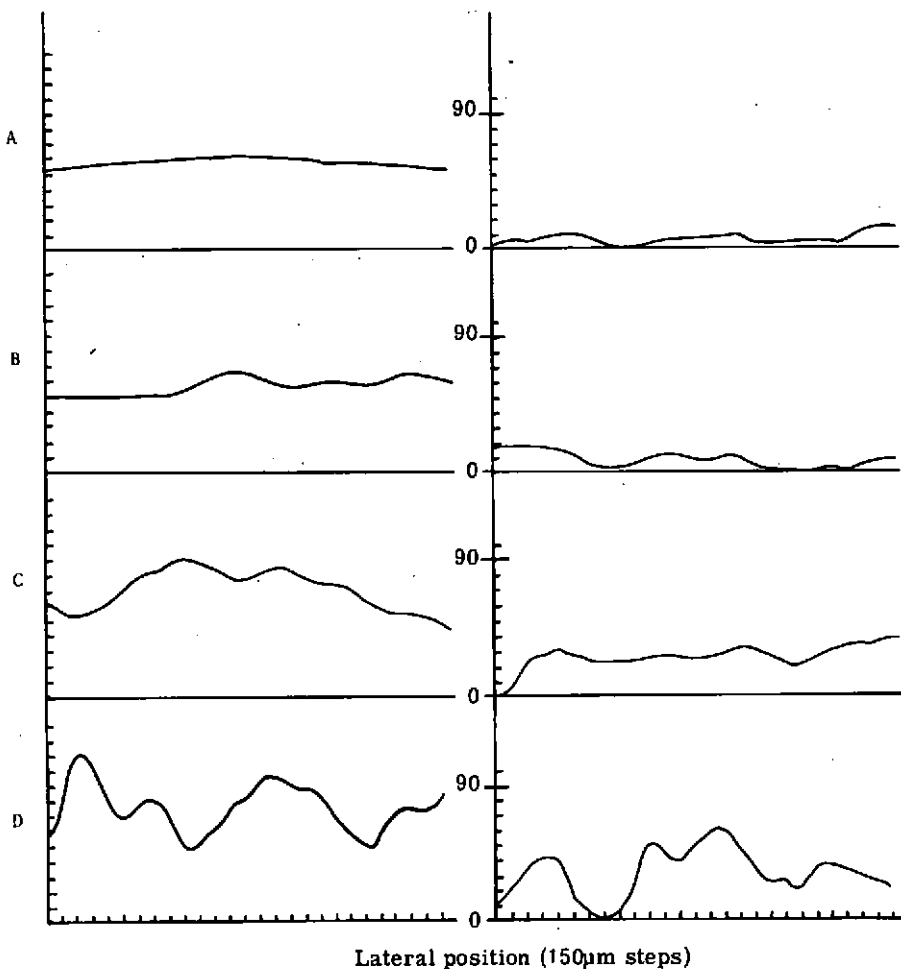


Figure 1. Amplitude and phase distributions of plane waves traversing 3 cm of silicone rubber with A) 0%, B) 2%, C) 7.5% and D) 17.2% of 500-600μm diameter glass ballotini by weight.