RBE. VOL.7 N.1 1990

A MEASUREMENT CELL FOR ULTRASOUND ATTENUATION ESTIMATION IN LIQUIDS

E.T. COSTA[1] and S. LEEMAN[2]

ABSTRACT -- This paper describes a measurement cell for assessing ultrasound characteristics in liquids, such as attenuation and velocity. Attenuation estimation is carried out using a "diffraction-insensitive" (DI) hydrophone inside the cell and immersed in the liquid under test. The hydrophone allows measurements to be made in the near field of ultrasound transducers without diffraction correction for the data and experimental results of the attenuation in silicon oil are presented.

INTRODUCTION

Attenuation of ultrasound waves is an important parameter for the description of the properties of the medium in which they propagate. Jones and Leeman (1984), in a detailed review on tissue characterization, showed that there is an established correlation between pathology and attenuation, and that attenuation measurements play a major role in ultrasonic tissue characterisation schemes. Attenuation can be readily measured in the laboratory via transmission techniques. So, in vitro measurements of tissue samples, liquids and solids can be easily carried out under laboratory conditions. However, if in vivo data are required, attenuation estimation relies predominantly on pulse-echo methods.

In a review on attenuation and ultrasound wave velocity measurements by Breazeale et al. (1981) the sources of error in measurements of attenuation and velocity are described as mainly velocity dispersion, the transducer/material coupling medium, phase cancellation effects and beam diffraction. Solutions to these problems are also described. It is noted that even in this relatively recent review, there is no mention made of using large aperture receivers to reduce diffraction. In fact, the contrary is advocated, to minimise phase cancellation.

This paper describes a measurement cell for assessing ultrasound attenuation and velocity dispersion, using a large aperture hydrophone as receiver, in order to provide measurements in the near field of the transmitter without need for diffraction correction. The

[1] Departamento de Engenharia Biomédica-DEB/FEE, Centro de Engenharia Biomédica-CEB, UNICAMP, Caixa Postal 6040, CEP 13081, Campinas-SP, Brasil.

[2] Department of Medical Engineering & Physics, King's College London, Dulwich Hospital, East Dulwich Grove, London SE22 8PT.

measurements were carried out in laboratory, using a transmission technique. We have presented previously (Costa et al., 1987a,b; Costa, 1989) the theory and experimental verification that supports the use of this large aperture "diffraction-insensitive" (DI) hydrophone and it will not be repeated here. The DI hydrophone is made with a piezoelectric plastic membrane (PVDF), 25 Ôm thick, 50 mm diameter active surface, and is able to intercept the entire ultrasound field produced by the transmitter.

ATTENUATION ESTIMATION AND THE MEASUREMENT CELL

The cell consists of one inner and one outer tanks. A transducer is fixed at the bottom of the outer tank and is immersed in some coupling medium (usually water). The smaller tank is made of anodised aluminium and is designed to contain the liquid under test. A membrane separates the coupling medium from the liquid inside the inner tank. The inner tank is covered with a top plate that holds an accurate measuring device (to 0.01 mm) that is moved up and down by a lead screw. A steel plate is held at the bottom of the screw lead. The DI hydrophone is clamped to this steel plate and then can be moved up and down the inner tank with its position determined very accurately. A schematic diagram of the whole experimental set-up for measuring attenuation is shown in figure 1. The same cell can be used in the study of non-linear propagation in different liquids, and allows velocity dispersion to be assessed quite easily. For measurement of attenuation, an electrical tone-burst is applied to the transducer and the output of the DI hydrophone is measured in the steady state portion of the signal. The hydrophone is moved some distance away and its output is read again. For precise determination of the centre frequency of the tone-burst, a Fourier analysis is performed on the waveform after it is digitised and transferred to a computer (Compaq 386-20). To improve the signal to noise ratio, computer controlled averaging is performed and the measurements are made with the averaged waveform.

The attenuation in silicon oil was determined in the frequency range 2-4 MHz. The transducer was driven off-resonance with tone-bursts of approximately 10 [Equation: mu]s duration at discrete frequencies. The hydrophone was moved in steps of 2 mm over a total distance of 2 cm. The temperature was kept at 20 oC ± 1 oC. The driving voltage was 700 mV inputted to a 50 dB wideband linear power amplifier. The received signal was amplified by a tuned signal amplifier with appropriate filters for each tone-burst centre frequency. The signal amplifier is part of a commercial ultrasound scanner (Diasonograph model NE4102). The amplification factor varied from 50 dB to 70 dB in order to obtain the best signal to noise ratio without causing saturation of the amplifiers. There was no variation of the amplification factor within a series of measurements. One hundred waveforms were averaged for each position. The mean value of the envelope within a stable portion of the averaged waveform, as well as of its centre frequency, were determined off-line. The envelope was calculated via the Hilbert transform (Oppenheim and Schafer, 1975). The frequency dependence of the attenuation coefficient was calculated via the following equation:

$$\alpha(f) = (20 \log (menv(d_1)/menv(d_2))) / (d_2 - d_1) \quad (1)$$

where:
.. menv(d): mean of the envelope at distance d (d in cm).

The value of the attenuation coefficient at each frequency is an average value, obtained by finding the attenuation for 6 measurement separations (d2 - d1). The frequency dependence of the attenuation in silicon oil can be seen in Figure 2.

The technique allows absolute values of attenuation to be obtained, at very close range from the transmitter, without the need for diffraction correction since these effects are not observed in the waveforms. As an example, figure 3 shows the time domain signals (cw field in silicon oil), obtained with the DI hydrophone at two relative distances from the transducer face. The respective envelopes are shown in Figure 4. Even at very close ranges, no diffraction is observed. Due to homogeneity of the liquid, no scattering is observed and thus there are no interference effects observed either.

DISCUSSION

Limitations of the equipment did not allow measurements to be carried out at all frequencies. The main limitation was due to the transducers used not being able to operate well off their resonance frequency, with the consequent drop in amplitude of the waves being generated. Another factor is the lower sensitivity of the large aperture hydrophone (50 mm active diameter), compared to that of a point-like hydrophone. Very weak signals were not capable of being amplified outside the amplifier/filter bandwidth of the Diasonograph. Increasing the power to the transducer in order to compensate for its poor performance off-resonance could lead to generation of non-linear propagation, an undesirable side-effect that was avoided at the cost of a reduced measurement frequency range. Apart from these problems, the system that was constructed for measuring attenuation and used for measuring velocity as well, is quite accurate in regard to the positioning of the DI hydrophone and the transmitting transducer. The cell did allow direct measurement of ultrasound attenuation in liquids (in the present case, silicon oil) to be carried out in the near field of the transmitter without diffraction correction. Measurements of ultrasound velocity are not shown in this paper, but the cell allows direct assessment of velocity dispersion in liquids, and experimental results will be shown in a later paper.

ACKNOWLEDGMENTS

E.T. Costa wishes to thank CAPES (Coordenaç o de Aperfeiçoamento de Pessoal de Nível Superior), from the Brazilian Ministry of Education, as well as UNICAMP, for the study leave and financial support.

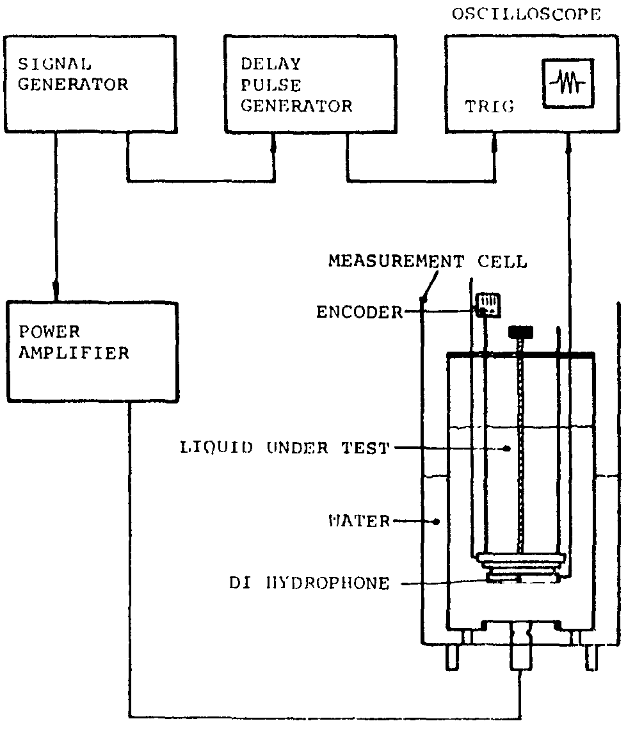

Figure 1. Diagram of the experimental setup for measuring attenuation.

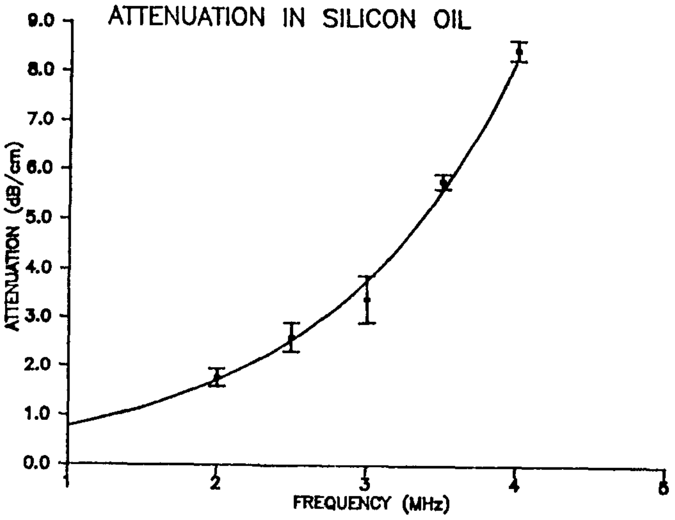

Figure 2. Frequency dependence of the attenuation in silicon oil.

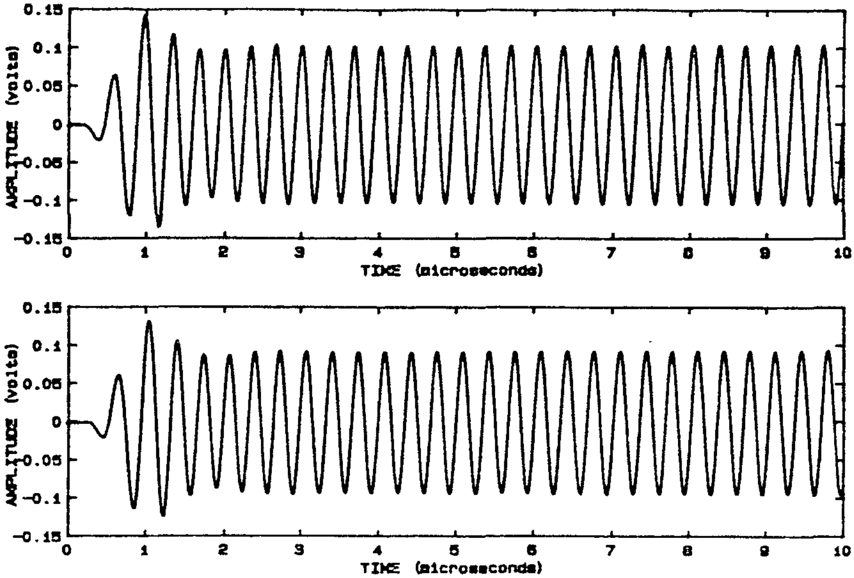

Figure 3....... Output waveforms as measured by the DI hydrophone at two relative distances from the transducer face (continuous wave field in silicon oil).

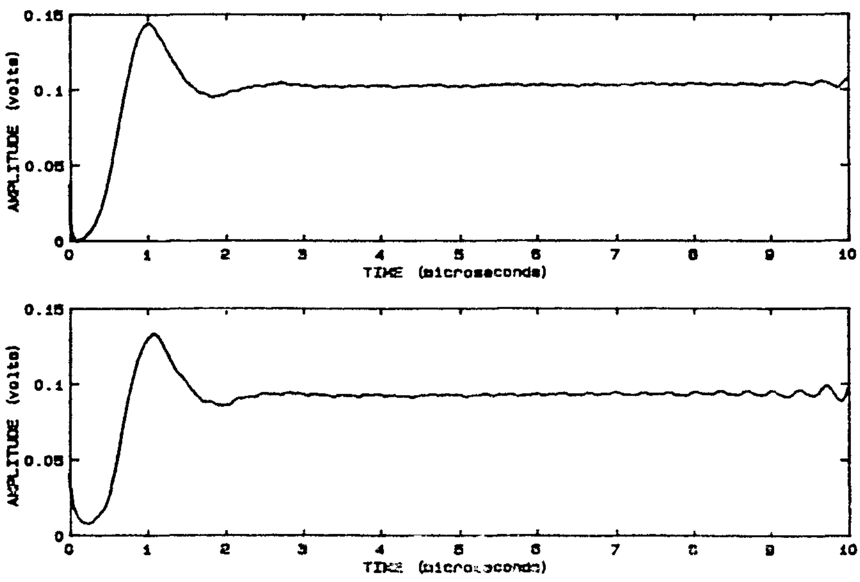

Figure 4. The corresponding envelopes of the waveforms shown in Figure 3

REFERENCES

BREAZEALE, M.A., CANTRELL, J.H. and HEYMAN, J.S. (1981) Ultrasonic wave velocity and attenuation measurements. In: Methods of Experimental Physics - 19 , Ultrasonics. P.D. Edmonds (ed), Academic Press, New York.

COSTA, E.T., LEEMAN, S. and HODDINOTT, J.C. (1987-a) Overcoming the ultrasound diffraction artefact. I. Theory and experimental verification. Revista Brasileira de Engenharia, Caderno de Engenharia Biomédica, vol.4, no.1, pp.38-46.

COSTA, E.T., LEEMAN, S. and HODDINOTT, J.C. (1987-b) Overcoming the ultrasound diffraction artefact. II. Attenuation estimation, characteristic impedance and nonlinear propagation. Revista Brasileira de Engenharia, Caderno de Engenharia Biomédica, vol.4, no.1, pp.47-57.

COSTA, E.T. (1989) Development and application of a large-aperture PVDF hydrophone for measurement of linear and non-linear ultrasound fields. PhD. Thesis, University of London.

JONES, J.P. and LEEMAN, S. (1984) Ultrasonic Tissue Characterization: a review. Acta Electronica, 26,1-2, pp.3-31.

OPPENHEIM, A.V. and SCHAFER, R.W. (1975) Digital Signal Processing. Prentice-Hall, New York.