MATERIALS CHARACTERISATION USING IMPEDANCE TUBE TECHNIQUES

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1. INTRODUCTION

As part of materials development performed at DERA, it is desirable to investigate the acoustic performance of a new or improved material over a range of different environmental conditions. It is relatively simple to model the acoustic performance of the material when its chemical composition is known, but it is desirable to verify the modelled data with physical results. The approach of SMC at DERA is to use impedance tube measurement techniques to capture this physical data.

Another problem exists if a material of unknown chemical composition requires characterisation. The sample cannot be accurately modelled as there is insufficient data present. It is under these circumstances that the measurement technique described in this paper is most useful. The sample can be tested for its ability to reflect, transmit and absorb acoustic energy over a variety of pressures and temperatures, and from this information , other relevant, physical data can be calculated.

This paper shows how accurately physical data acquired through impedance tube measurements compares with modelled data for a material of known composition. The methods used to perform the impedance tube measurements and data analysis are given, and further discussion shows routes used to obtain further physical properties.

2. REVIEW OF THE ACOUSTIC WAVEGUIDE

Acoustic measurements may be restricted to one dimension through the application of a waveguide, and thus simplified. A typical waveguide, figure 1, consists of a fluid filled tube, with walls of impedance large compared with the impedance of the fluid, and an aspect ratio of length to internal diameter much greater than 1. This arrangement produces a quasi-plane wave within the tube when the wavelength is greater than 1.7 times the diameter of the bore.

$$f_{max} \approx c_{fluid} / 1.7D$$

The low frequency limit of the wave guide is determined by the distance between any hydrophone and the end of the tube nearest to it.

$$f_{min} \approx c_{fluid} / 2l_{min} \qquad \text{where, } l_{min} = \min[\, l_{H1X}, l_{H2T}, l_{H1S} \,]$$

3. IMPEDANCE TUBE MEASUREMENTS

3.1 The Impedance Tube Apparatus

The Impedance tube apparatus can be separated into two sets. Those making up the physical components, and those concerned with instrumentation.

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3.1.1 Impedance Tube Components. The main tube consists of a thick walled stainless steel cylindrical tube of internal diameter D and length L. This is surrounded by a vessel through which liquid coolant passes, enabling accurate temperature control. The tube is connected to a high pressure water supply, allowing measurements to be conducted at various pressures. The tube is capped with a removable steel lid that provides a pressure seal as well as a means of introducing samples. Acoustic signals are propagated up the tube from a piezo electric source situated at the base of the tube. Hydrophones, H_1 and H_2, recessed into ports in the walls of the tube, are located at distances L/3 from the base and top respectively.

3.1.2 Instrumentation. A short pulselength signal with a smooth frequency envelope and bandwidth matched to the acoustic bandwidth of the tube is produced by a signal generator. The signal length must be of duration such that incident and reflected signals can be time resolved, that is, they do not overlap. The signal is amplified and impedance matched to the transducer by means of a power amplifier with a signal to noise ratio greater than the dynamic range of the tube. A piezo electric transducer is used to produce an acoustic signal, which is the convolution of the amplified input signal and the mechanical response of the transducer. Thus a broad band transducer of low Q is best suited. Low noise hydrophones working below resonance are connected to pre amplifiers, which also serve as anti-aliasing filters. The conditioned signal is transferred to a PC through an analogue to digital data acquisition card.

3.2 Experimental Procedure

An anechoic material was manufactured within DERA, and its expected acoustic performance was modelled. Model performance can be seen in figure 2. This material was then tested using impedance tube techniques to investigate how the materials' acoustic performance compared with the model.

A circular plug of the material was cut out such that its diameter was only slightly less than that of the Impedance tube. This ensures a snug fit when the sample is placed in the tube, and since the shortest wavelength present in the tube is much larger than the gap, it has little acoustic effect. The sample required conditioning to the environmental test conditions, which were initially to be 8°C. To achieve this, the sample was immersed in tap water and placed in an environment of constant 8°C for a period no less than 16 hours and no more than 24 hours. Meanwhile, the impedance tube temperature was also allowed to equilibrate at 8°C.

Before the sample is introduced to the tube, a calibration measurement for the incident signal at the second hydrophone, H_2, is required. To achieve this, the pressure of the tube was set to 0 psi, and numerous pulses were recorded at H_2, averaged, to increase signal to noise ratio, and then stored. This measurement was repeated at 50 psi, 100 psi, 200 psi and 400 psi. The change in pressure is instantaneous, and as such some time is required for the sample to become conditioned to the change.

The sample was suspended in the tube immediately below hydrophone H_2. Care must be taken not to trap any air on the surface of the sample when it is introduced into the tube, as this will significantly effect performance. This can be achieved by ensuring the surface of the sample is fully wetted, and inserting the sample at a slight angle.

Using the same number of pulses as were used in the calibration measurement, data was recorded at both hydrophone H_1, for incident signal and for signal reflected off the sample, and at hydrophone H_2, for the signal transmitted through the sample. Again, the signals were averaged to improve the signal to noise ratio. This measurement was made at 0 psi, 50 psi, 100 psi, 200 psi, and 400 psi.
Using the same method and pressures, the sample was conditioned and tested at 15°C and 20°C.

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4. ANALYSIS

Whilst still in the time domain, the captured signals were windowed using a 10% cosine taper in order to separate the signals from one another and from any nuisance signals or tube artifacts. This provided separate waveforms for the incident and reflected signals at H_1, figure 4.1, and the incident and transmitted signals at H_2, figure 4.2-3.
Each of these waveforms was then padded with zeros to an equal length in order to improve resolution. Fourier analysis was then applied to each of the waveforms to obtain frequency information. After the transformation to the frequency domain, the different signals retain the same number of points. From these complex signals, it is possible to calculate numerous physical properties. The experiment provides values for the Echo Reduction, Transmission Loss, and Fractional Power Dissipation as required in order to effect a direct comparison with the modelled data.

On comparison of the modelled data, (figure 2), with the experimental data, (figure 3.1-3), it can be seen that there is a good correlation of loss levels and position of characterisic peaks. The data does deviate toward the upper and lower frequency limits. The reason for this is apparent given the bandwidth of the signal used. Figure 4.

For normally incident sound waves;

Reflection coefficient,	R = Reflected Signal Amplitude (ω) / Incident signal Amplitude (ω)
Transmission coefficient,	T = Transmitted Signal Amplitude (ω) / Incident Signal Amplitude (ω)
Echo Reduction,	$ER = -20\ \log_{10}(R)$
Transmission Loss,	$TL = -20\log_{10}(T)$
Fractional Power Dissipation,	$FPD = 1 - [(R)^2 + (T)^2]$
Characteristic Impedance,	$Z = Z_{water}\,(1+R)/(1-R)$

Phase velocity, c, can be obtained from the transmission coefficient.

5. ERRORS AND IMPROVEMENTS

The system as described deviates from the characteristics of a perfect waveguide, and allows scope for improvement. An approximation has been made that the walls of the tube are totally rigid. This is not the case. For a wall of thickness t, the sound velocity in the tube relative to free space is,

$$c'/c = \{1+(2E_0/E_w\ .\ D/2t)\}^{-1/2}$$

Where E_0 = Elastic modulus of the fluid, and E_w= Elastic modulus of the wall material. This limits the maximum frequency supported by the geometry to;

$$f_{max} = c'.\beta_{0,1}\ /\pi D \qquad \text{where } \beta_{0,1} \text{ is the first root of } dJ_0(z)/dz = 0$$

The tube is of a finite length, L, and thus acoustic signals are able to propagate up and down the tube, both in the fluid and in the walls, after undergoing reflections at each end. These multiple reflections can temporally overlap with subsequent reflected, transmitted and incident signals. The pulse rate must be low enough such that these reflections have decayed to a low level so that signals can be windowed cleanly. By making the pulse repetition pseudo random the multiple reflections are cancelled out during time averaging. Reflections can also be suppressed by topping the tube with an anechoic boundary.

By measuring the response of the transducer and power amplifier, it is possible to generate a signal at the generator such that the convolution of the signal and system response is an acoustic signal with a bandwidth matching that of the tube, and a constant amplitude over that bandwidth.

Another variation in the method to achieve values of echo reduction or reflection coefficints, is to use two separately recorded time domain signals. The first being the incident signal at hydrophone H_1 with no sample present, and the second the incident and reflected signal at H_1 with the sample in place. By subtracting the first of these signals fron the second an improved reflected signal is obtained since any coherent noise present in the two signals is removed.

6. REFERENCES

E.G.RICHARDSON, 'Technical Aspects of Sound', Elsevier 1953.
L.E.KINSLER, A.R.FREY, A.B.COPPENS, J.V.SANDERS, 'Fundamentals of Acoustics', Wiley 1982.

Figure 1 Typical Impedance Tube.

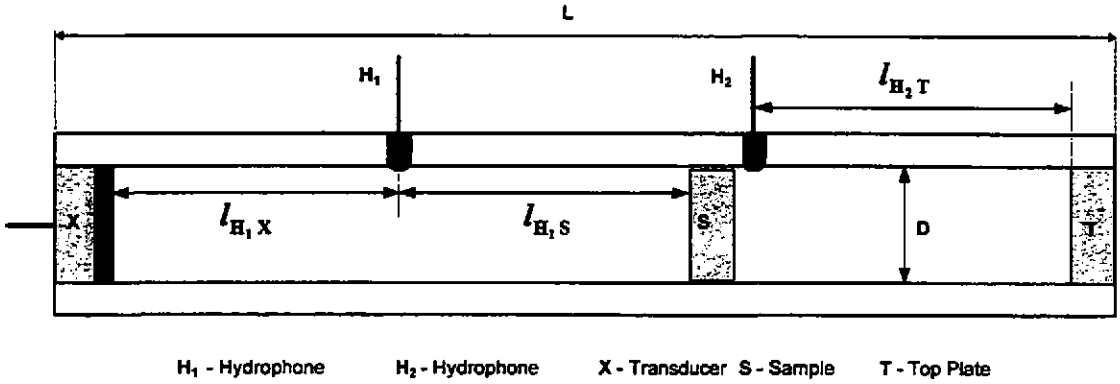

Figure 2

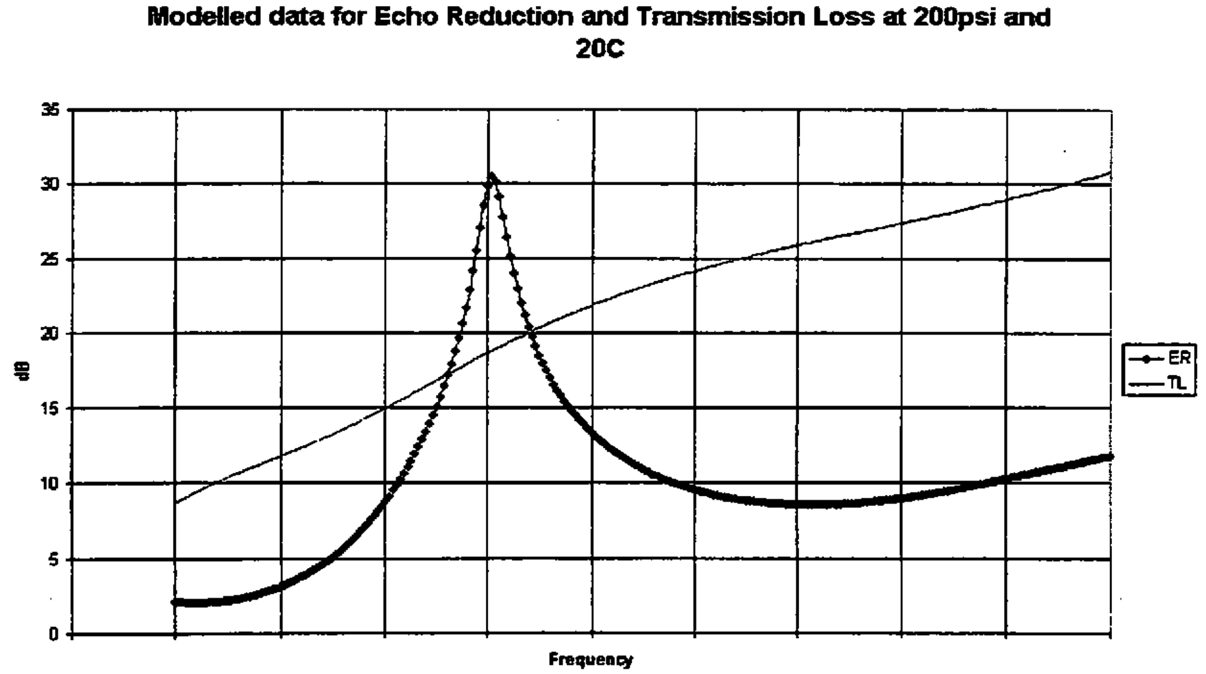

Figure 3.1

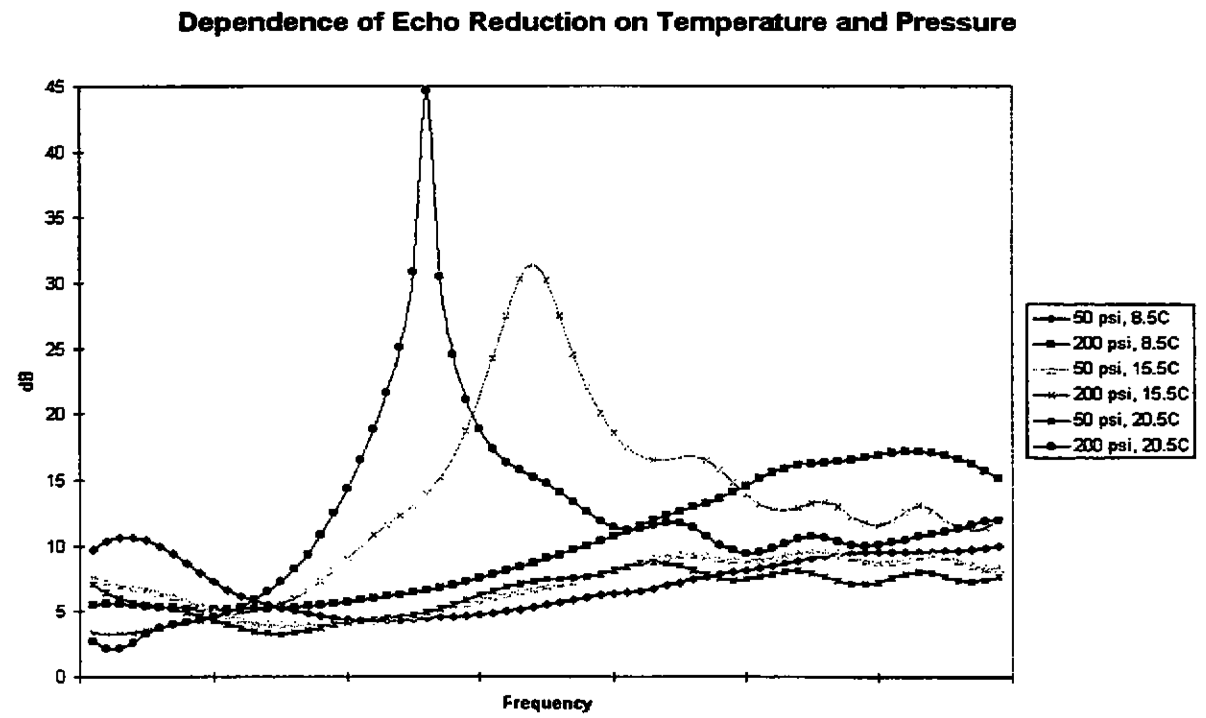

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Figure 3.2

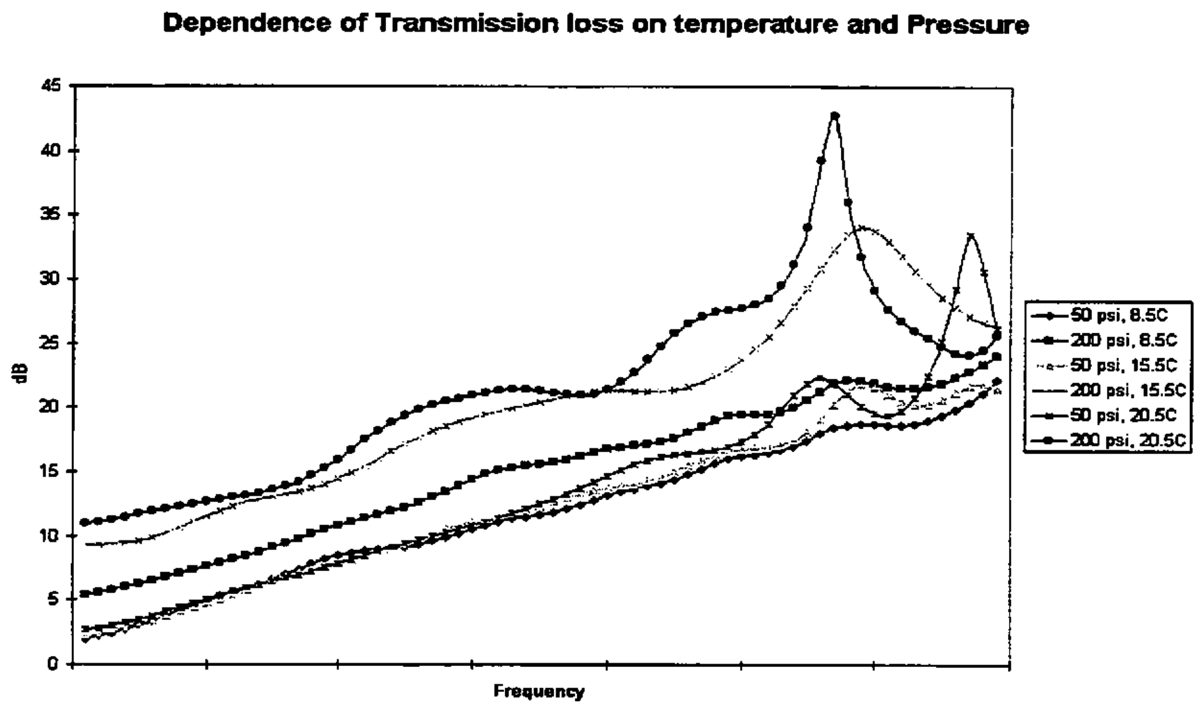

Figure 3.3

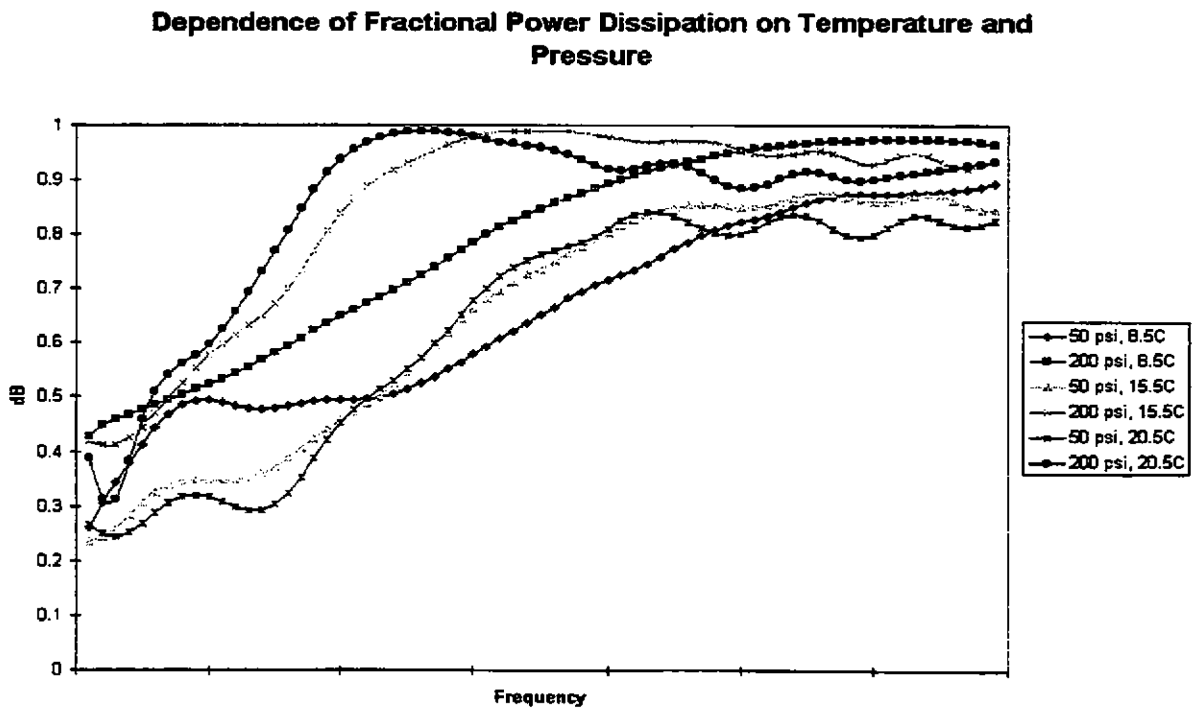

Figure 3.4

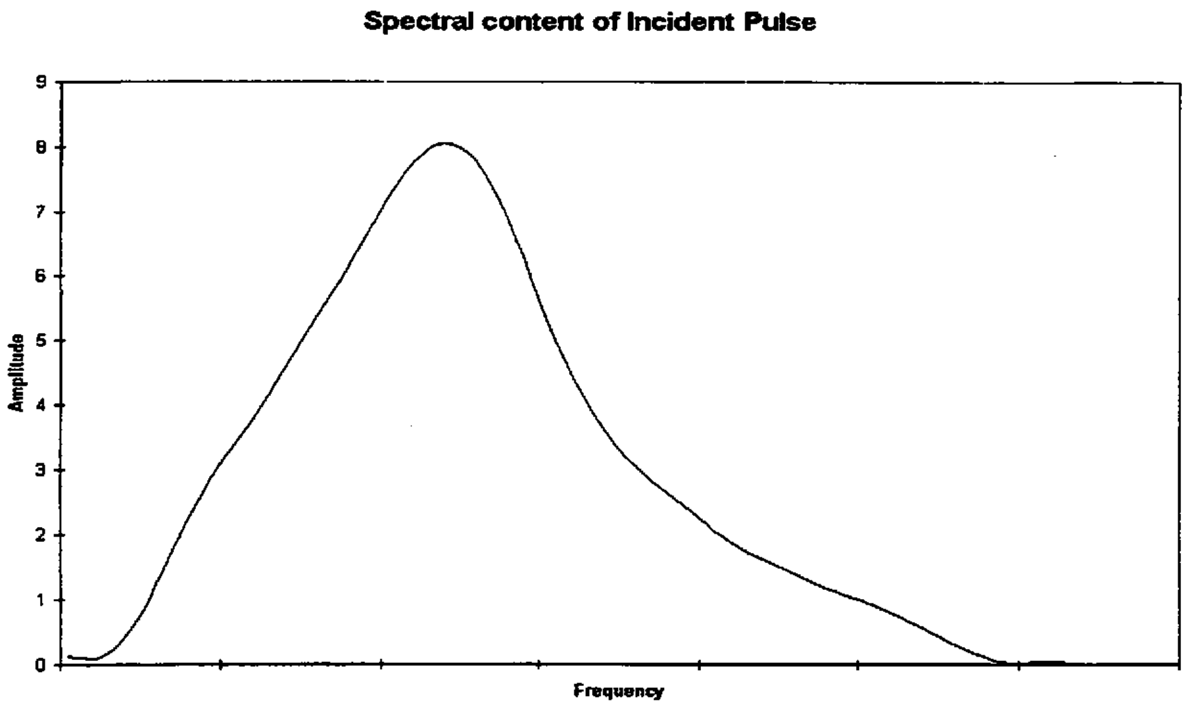

Figure 4.1

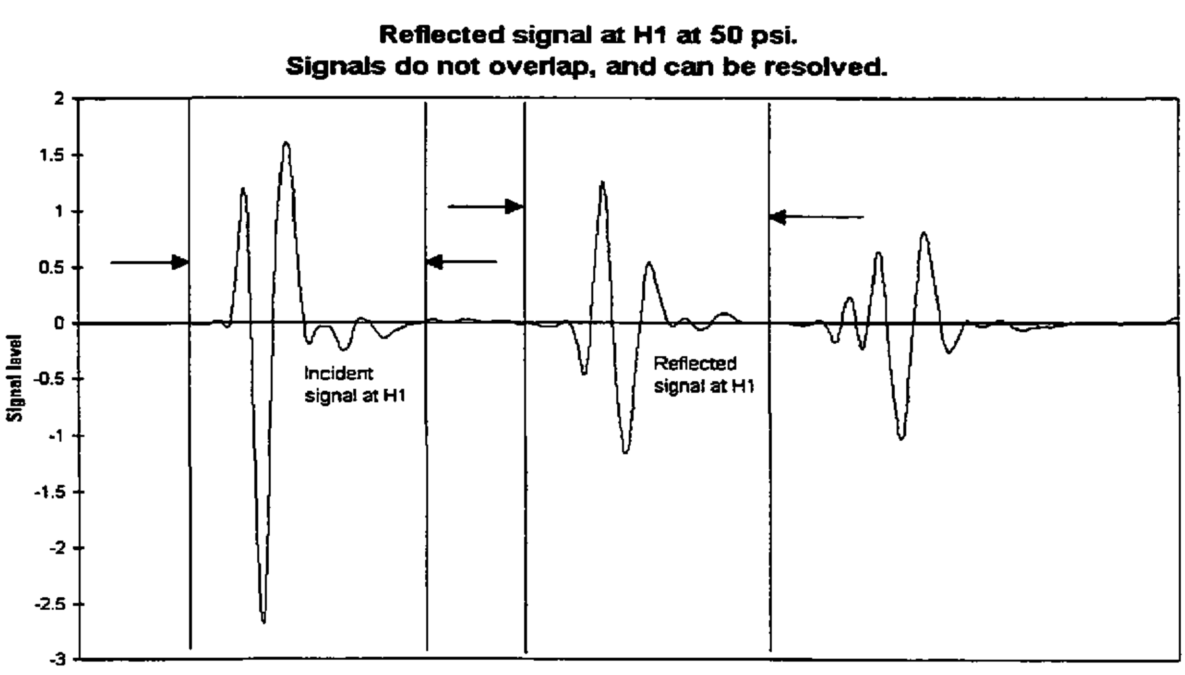

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Figure 4.2

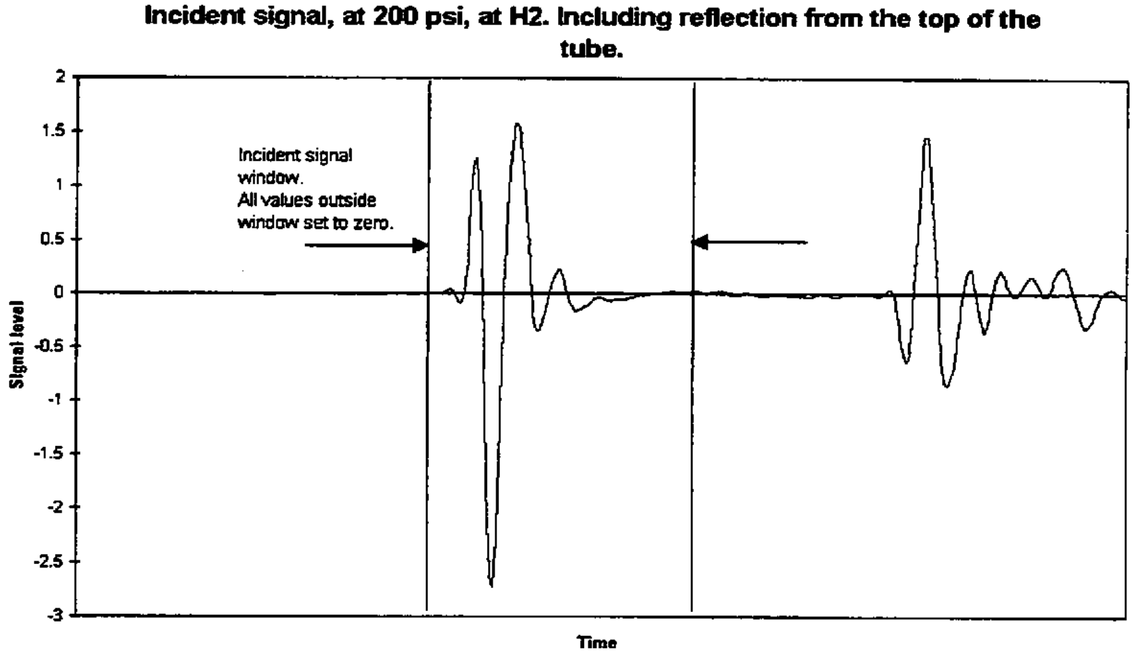

Figure 4.3