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The Dispersion and Resolution in Guided Wave Testing

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Abstract

The work reported in this paper is focused on the experiments conducted with guided waves propagated on sheets to study the dispersion, beam spread and its effects on resolution. Unlike acousto ultrasonic technique, here angle beam is attempted, as it is possible to have an activation zone completely enclosed for lower phase velocity values. Unique characteristic behaviour of guided waves of longer distance and its practical implications are analysed. Compared to the bulk waves, guided waves also are found to have similarity in its spreading pattern, energy dissipation, wave structure across the thickness etc. Depending upon the phase velocity, points of dominant can be either in plane displacement or out of plane. This aspect is studied in this paper as it decides the sensitivity of testing. But unlike the bulk waves, guided waves lose its resolving power as the distance increases. The increase in wave pulse duration causes decrease in wave pulse resolution. This limits the length of guided wave testing for detecting a particular size of defect. Experiments shown in this report indicate the need to fix a testing distance for guided wave inspection when looking for a specific size reflector. Multiple defects are detected simultaneously by changing the distance or by changing the angle and frequency. These effects of guided wave are studied and the experimental observations are compared and reported.

(Key Words: Guided Waves, Dispersion, Pulse Duration, Phase Velocity, Group Velocity, Resolution.)

Introduction:

The application of ultrasonic waves in Non Destructive Testing is innumerable. But using Ultrasonic bulk waves is not always a wise solution especially in case of thin sheet testing, tube testing and loaded laminates. Alternatively a variety of guided wave technique has been developed for various materials and products. Their merits and demerits are published in many articles. The main advantage of guided wave testing is that they can travel long distances. A single scan with guided waves can cover a huge area and length there by indicating its potential for lengthy product testing. But works on guided waves are very limited and so guided wave applications are very rare in industry.

The basic need for guided wave analysis is the wave dispersion relationship expressed in terms of material thickness, elastic property of the material or wave velocity. Solving the dispersion equation (R1to R9), a set of curves can be obtained that shows the relationship between phase velocity and frequency. Guided waves consist of many frequencies and the waves oscillating at different frequencies travel at different speeds and so their phase velocity is function of frequency. Though the broadband signals are attractive as they contain more information over the range of frequency band, it will be convenient to use tone burst signals. Here the signals retain their shape through their travel path. In guided waves the different propagating modes are grouped into symmetric and anti symmetric modes represented normally by S and A respectively. For guided wave generation either wedge tuning technique or frequency match tuning technique is adopted. In this experiment angular insonification method of turning is adopted for guided wave generation. The basic principle of this technique and the characteristic properties of such generated waves are well-studied (R2).

One of the characteristic property of Guided waves is their disperse nature, meaning that waves oscillating at different frequencies travel at different speeds. In other words the phase velocity is not a constant value but a function of frequency. The effect of dispersion is that the energy in a pulse travels at different speed depending upon the frequency. This itself is an indication that the wave(pulsewidth) will spread as it propagates through a structure.

Background:

Based on a plane, uniformly emitting ultrasonic source, the profile of an ultrasonic beam, in case of bulk waves, will be diverging. If the beam spread is measured as Ø, then based on diffraction theory

$$\sin Ø/2 = 0.56\ \lambda/D,$$

(beam width to half the centreline intensity)

The effect of beam spread influences the flaw sizing techniques based on intensity drop. The beam spread mapping using an IOW block is one of the practical approaches for beam spread estimation. In case of guided waves the energy pulses propagates at different speed causing dispersion, which is similar to beam spread. The dispersion represented in graphical form with respect to distance is space-time map. In case of bulk waves the parameter for beam spread estimation is a pre fixed dB drop whereas in guided waves the parameter normally used is out of plane displacement of the surface of the plate. As this parameter is a function of time trace, that itself is measured for constructing the space-time map. One such map constructed using the measured data of this experiment is shown in figure (1b).

The effect of increasing pulse duration and decrease in pulse amplitude due to increased travel distance results in poor sensitivity and resolution in guided waves. As the testing length increases the sensitivity and resolution will be reducing and so it is desirable to fix up a reasonable test length.

Many numerical modelling of disperse propagation are being published. The numerical prediction of disperse propagation using Fourier decomposition (R3 to R8) forms the basis for predicting disperse propagation. Though relations are derived, they are not suitable for absolute predictions because it depends highly on bandwidth of the input signal. Alternatively, another approach, for a test set up, based on pulse duration and rate of signal spreading is attempted here to predict the reasonably resolvable distance between flaws.

Experiment:

For the experimental trials a stainless steel sheet of size 1280-mm length, 140mm width and 2.35mm thick was selected and three holes of size 0.5mm dia and 0.5mm depth were drilled on the surface at distances as shown in fig (1a).

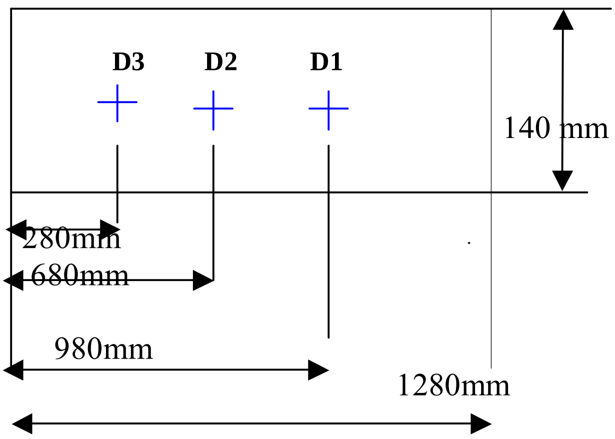


FIGURE: (1a) SPECIMEN WITH DRILLED HOLES

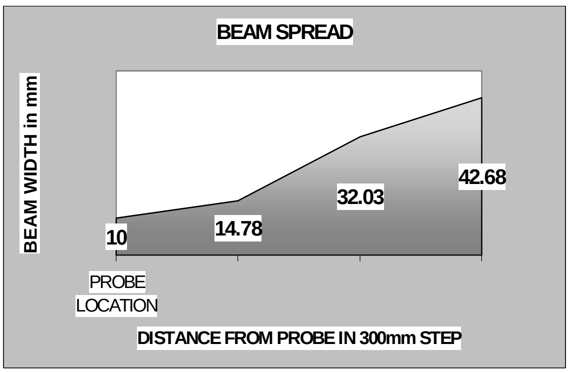
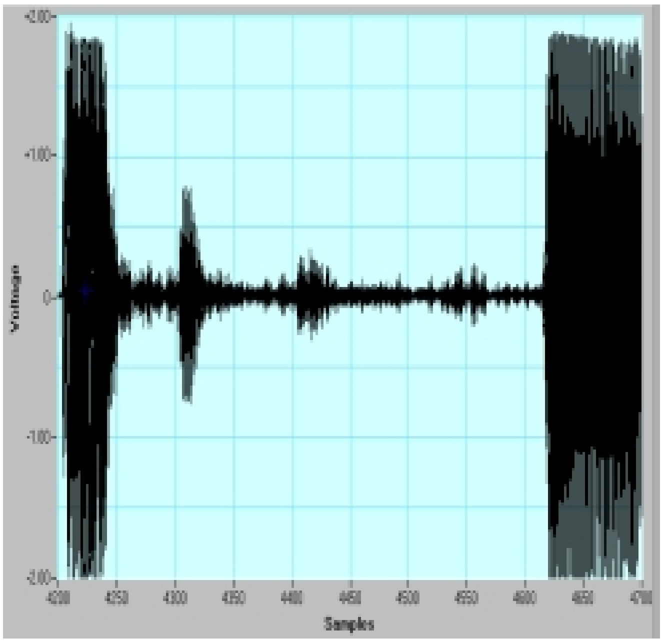
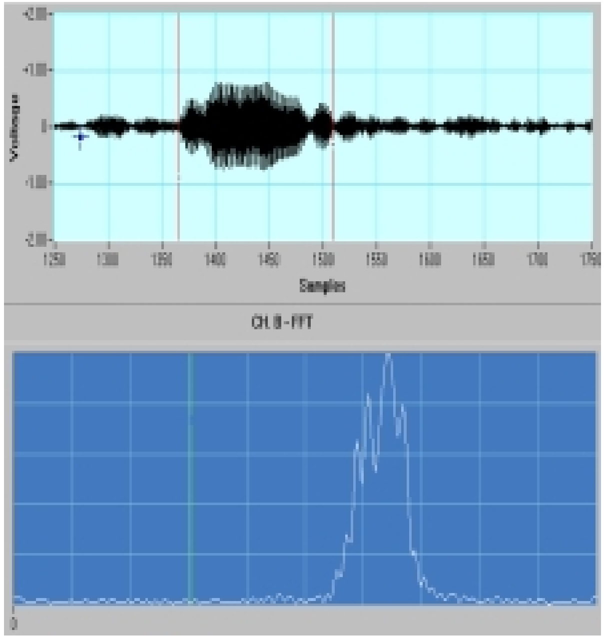


FIGURE:(1b) BEAM SPREAD (IN 6dB)

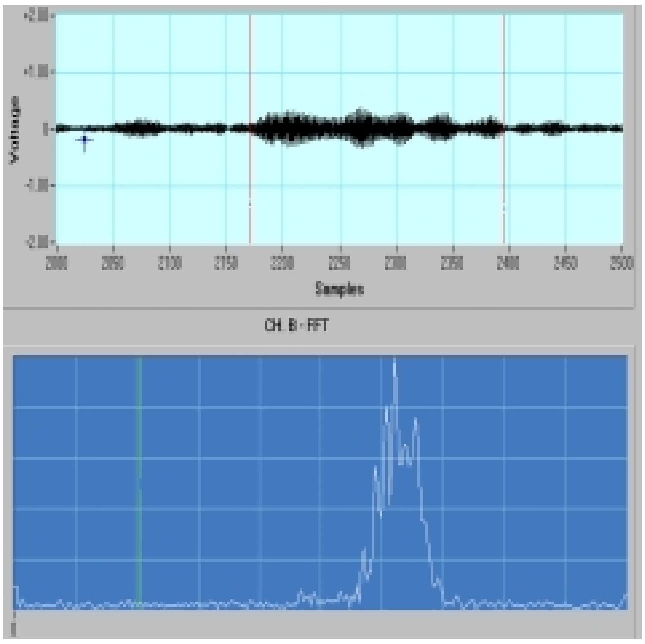
Another test specimen of length 1200 mm and width140mm is also included in this experiment. Two small holes of diameter 0.5mm and depth 0.5mm 200mm away from the edge are drilled with 25mm separation distance between them. The signals from these holes are sensed with guided waves and their RF waveforms with corresponding FFT are recorded as shown below in figure 2 & figure 6.

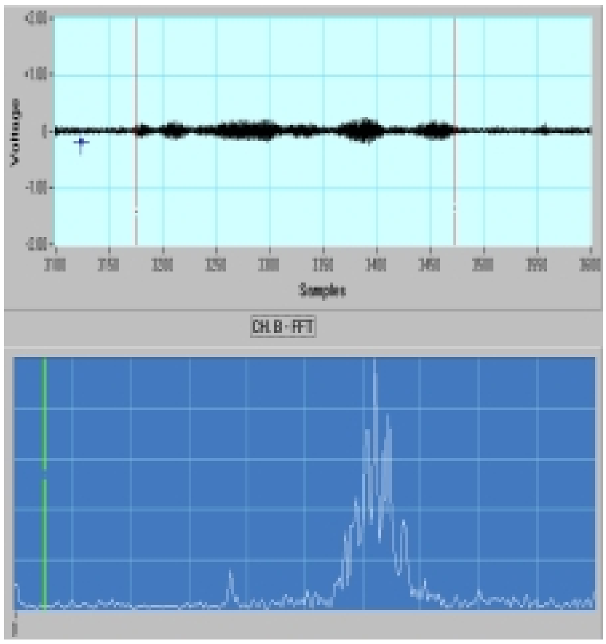




D1 D2 D3 BE **D1-DEFECT IN RF FORM & FFT**

A-SCAN IN RF WAVE FORM





D2 - DEFECT IN RF FORM & FFT **D3 - DEFECT IN RF FORM & FFT**

Figure 2

Results and Discussion:

By observing the defect signals from the holes at different distances it can be seen that the pulse duration increases with distance of the defect from the probe. The prime reason for the extended pulse duration is dispersion (R10 to R13). Though the frequency content of the pulses remain same for the entire defects signal, different frequencies are getting dispersed bearing a relation with its distance from the probe. This is evident from the figure (2a). and also from their respective FFT figures.

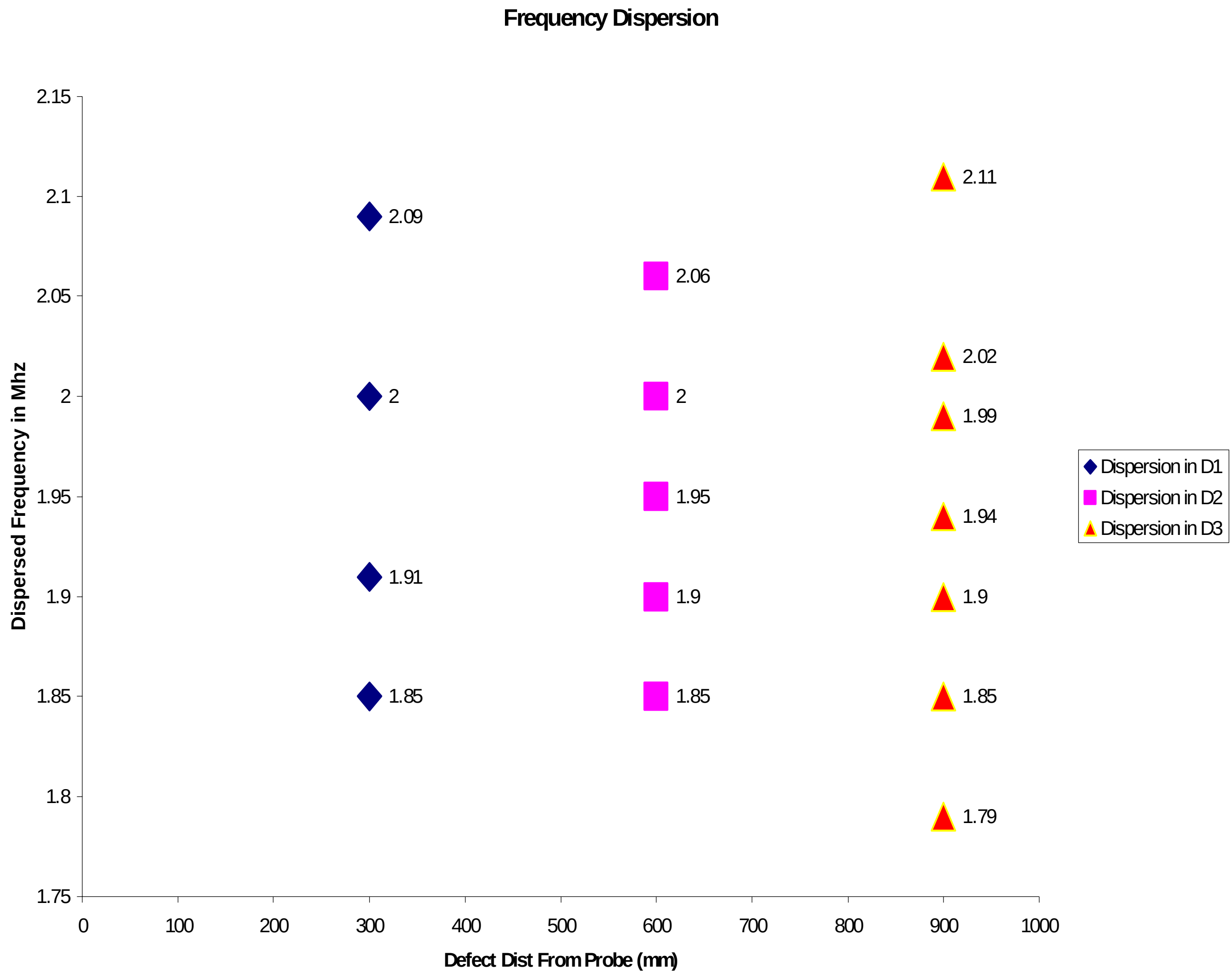


Figure 2a

The exponential relationship of the energy content and the distance is depicted in figure (3) as below. It is seen from the graph that the energy received from the defects is decreasing with increase of distances in its position. The energy decay is in exponential form and the following mathematical relation can represent it,

$$Y = \mathrm{Exp}(0.6x - 1.1317),\ \text{see figure (3).}$$

As the defect distance increases its pulse duration increases and its energy content decrease. It leads one to conclude that there could be a relation between the energy content and the pulse duration. The figure (4) Shows that the frequencies of the pulses at D1, D2 and D3.

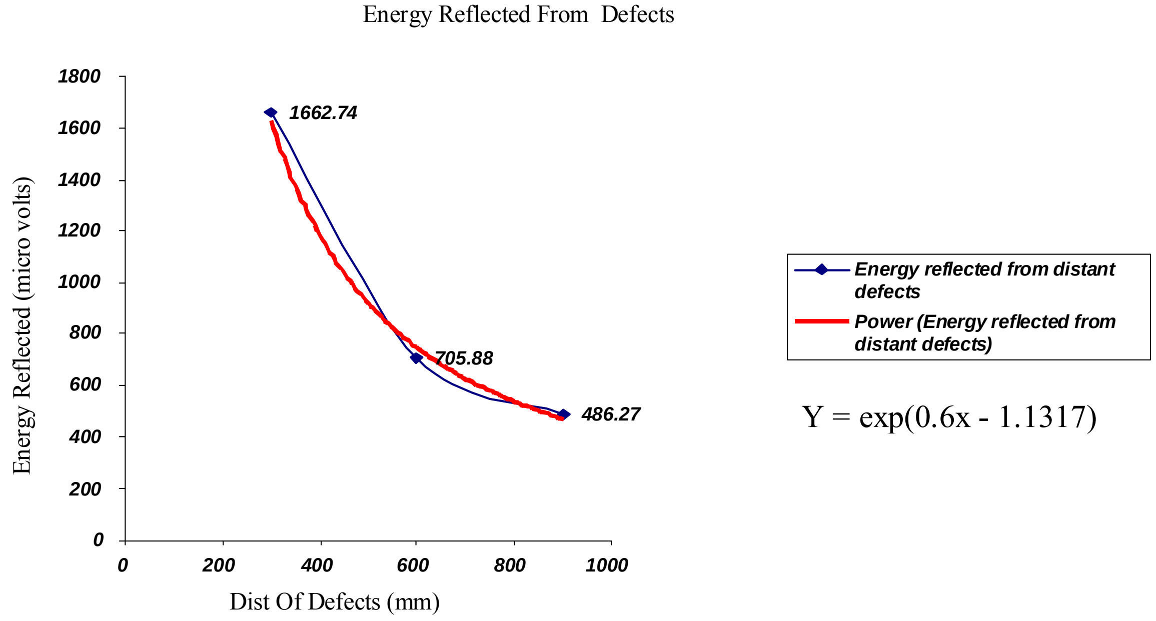


Figure: 3

As the distance of the defect increases more frequency components, especially lower frequency components are getting dispersed (R10,11).

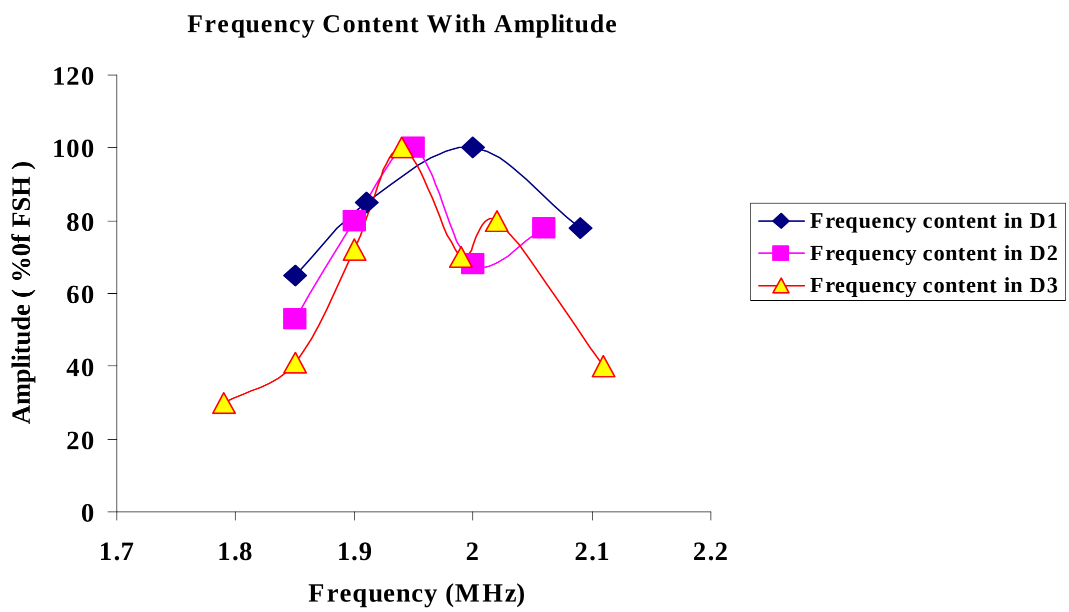


Figure: 4

It can be seen, in figure (4), that the as the defect distance from the probe increases the amplitude of lower frequency components are getting increased compared to higher frequency components. As the attenuation of sound energy increases with increase in frequency the lower frequency components are dominating for longer distance defect signals. Comparatively the velocity of lower frequency components is low and hence the pulse duration is getting increased for distance defects. Figure (5) shows the linear relation between pulse duration and its distance from the probe.

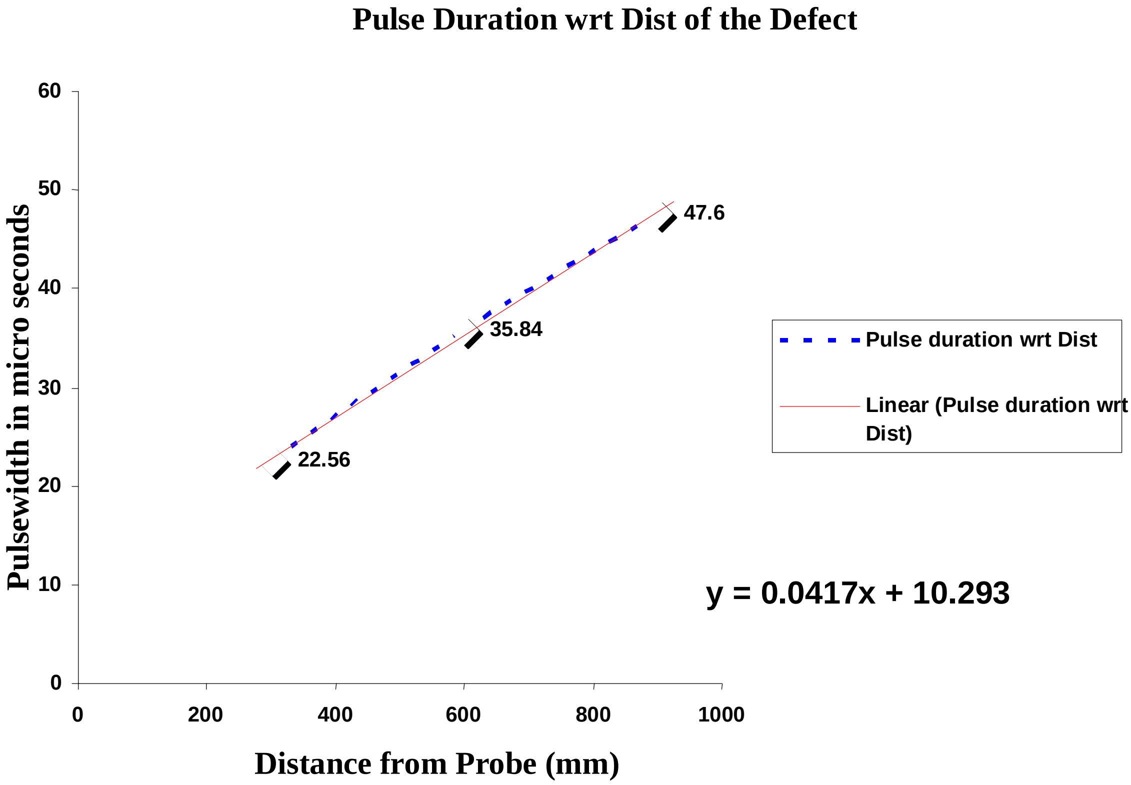
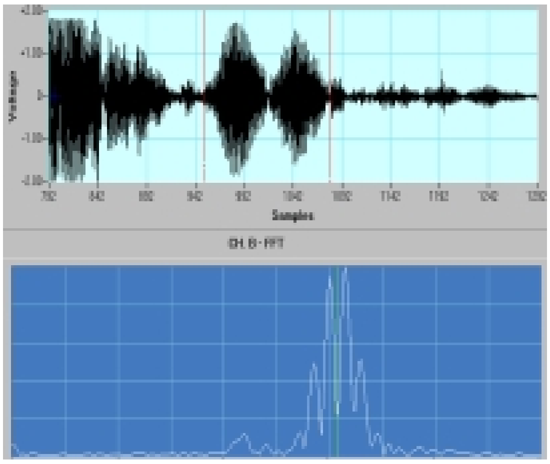


Figure: 5

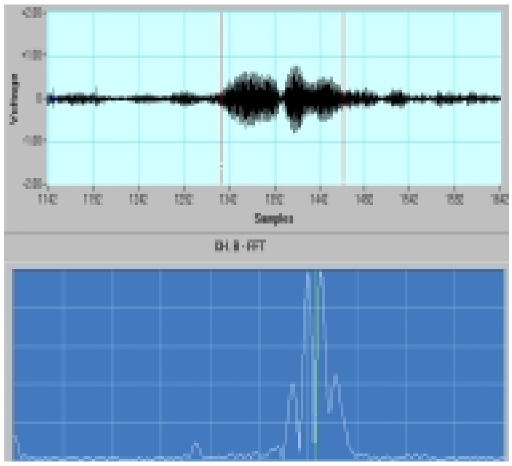
Mathematically the pulse duration and the defect location can be stated as

$$Y = 0.0417x + 10.293$$

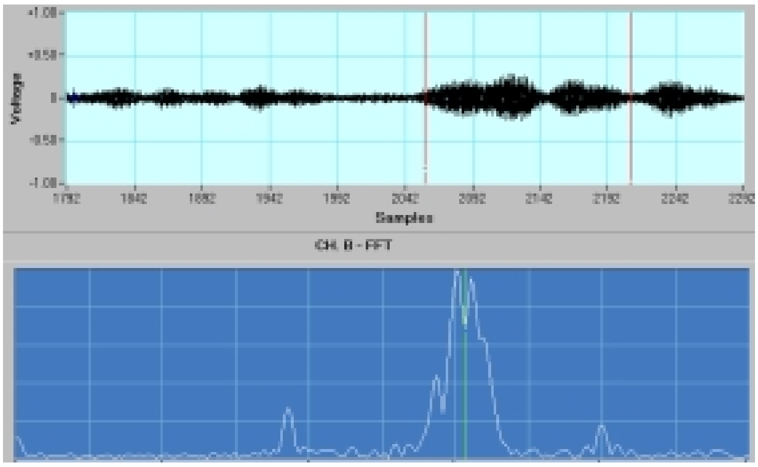
Hence if the defect location is known it is possible to find out the pulse duration at that location. But knowing the pulse duration at different locations may not be useful directly. But the testing limitation such as the resolution obtainable at different distances is definitely a useful data for an effective testing with guided waves. Once the pulse duration and group velocity is known then the product of these two will give the reasonably resolvable distance for that length range. In this experiment, for example, the reasonably resolvable distance between defects of size 0.5mm diameter and 0.5mm depth is calculated to be 23.7mm even at close distance. Here the group velocity is taken as 4610 mtr/sec as calculated in earlier reported study (R5). To verify experimentally the second test piece is tested and the observations are tabulated. In second test plate the holes are on same line and are 24mm apart. When these holes are sensed at distances 130mm, 250mm and 500mm they are well separated there by establishing the validity of the above equation shown in figure (5). The defect signals sensed at different distances are shown below. It is seen that the defect echoes are separated by 500 nano seconds at 130mm and it is gradually increases to 1.12 microseconds at 250mm then to 2.40micro seconds at 500mm distance. Also it is seen that as the distance increases pulse width gets increased and additional dispersion is taking place. As more and more dispersion is taking place for distant pulse, the resolution is affected much with wide band frequencies in such cases.



DEFECT SENSED AT 130mm



DEFECT SENSED AT 250mm



DEFECT SENSED AT 500mm

Figure: 6

Conclusion:

The beam spread in normal bulk wave does not affect spatial flaw resolution. In case of guided waves for a set frequency, thickness, flaw size and test range a minimum distance of separation is required between flaws and that depends on beam dispersion and spread. These experiment details a method to estimate the minimum flaw separation required for resolving defect signals. It is also observed that more beam dispersions take place as the distance between probe and flaw increases. As the defect distance increases its pulse duration increases and its energy content decreases. The experimental observations shown in this paper verify the aspects explained. Experiments shown in this report indicate the need to fix a minimum testing distance for guided wave inspection when looking for a specific size single reflector.

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