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CHARACTERIZATION OF ULTRASONIC SIGNALS BASED ON WAVELET CROSS SPECTRUM

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***Abstract*— This paper lists the findings of application of wavelet cross spectrum on ultrasonic A-Scan signals obtained by moving across the top surface of the hexcan kept immersed in a tank of water. Wavelet cross spectrum helps to identify the scans which have been acquired with the transducer exactly on top of the object whereas other signals have been acquired when the transducer is slightly away from the object.**

***Keywords*— Wavelet cross spectrum, Continuous wavelet transform, Wavelet coherence, Ultrasonic signals, beam spread,**

I. INTRODUCTION

Ultrasonic testing is an important non-destructive technique. Ultrasonic Testing is based on the vibration of materials caused by the motion of sound waves into the material. Pulse Echo Ultrasonic Testing is a type of ultrasonic technique, which is commonly used for the detection of flaws in the materials and the estimation of size of flaws. [1].This technique is also widely used for the measurement of thickness of objects. Pulse Echo has the advantage that measurement is possible from a single side access to the object under test. In the pulse-echo method, a piezoelectric transducer with its longitudinal axis located perpendicular to and mounted on or near the surface of the test material is used to transmit and receive ultrasonic energy. The ultrasonic waves are reflected by the opposite face of the material or by discontinuities, layers, voids *etc*. Thus in this method, the reflected portion of the waves is used for testing. The display on the CRT screen shows the transmitted wave and the back wall echo. The presence of any defect in the material is seen by another echo before the back wall echo. Proper calibration of CRT screen can give us the information about the location of the defect. Ultrasonic testing can be done in two modes, namely contact mode and immersion mode. In contact mode, the probe is in direct contact with the test specimen with a couplant between the probe and testing material. The couplant is used for better transmission of ultrasonic waves. In the Immersion type, the entire experimental set up is placed in water bath. A waterproof- probe is placed at a distance from the test specimen and the ultrasonic beam is transmitted into the material through a water column or a water path. This technique is largely used in laboratories and in automatic ultrasonic testing. The advantage of this technique is that uniform couplant conditions are obtained. The region of propagation of ultrasonic waves from the transducer is known as Ultrasonic Beam, which comprises of two regions, namely Near Field (also known as Fresnel zone) and the Far field (also known as Fraunhofer zone). In the Near field, the ultrasonic beam converges. In the far field, divergence of the ultrasonic beam occurs, *i.e.*, spreading of ultrasonic beam takes place. This is known as the phenomenon of beam spread.

The motivation behind this research work carried out at IGCAR is to detect the bowing of fuel sub assembly head (FSA) using ultrasonic signals. Bowing is bending of the FSA due to long exposure to high temperature. Currently bowing is detected by analysis of images obtained of the FSA [2]. The research work is split into various modules. This paper deals with the module of identifying the A-scan signals that has been acquired when the position of the transducer was at the centre of the object. This will help in identifying the centre points and by the Circle Fitting technique [3]

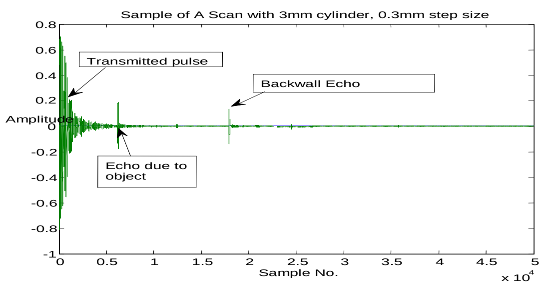
This paper consists of four sections, first section gives the introduction, second section describes the Experimental setup and data acquisition, third section deals with Wavelet Transform and fourth section deals with Results and Conclusion.

II. EXPERIMENTAL SETUP AND DATA ACQUISITION

The experimental setup is an automated Ultrasonic system consisting of an immersion tank, transducer, actuators, stepper motors , programmable logic controller, Ultrasonic Pulser-Receiver, signal conditioning unit, CRO for display and a PC for storage of data.[4.]The object under test in this experiment is Fuel Sub-assembly head, which is also called as hexcan. The ultrasonic transducer is an unfocussed, immersible, normal probe of 10mm diameter of 5 MHz frequency.

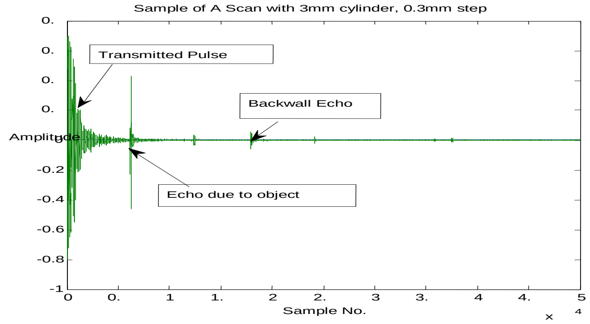
The data is acquired and analysis is done in offline mode. The transducer is automated to move in specified steps across the object and at every step it sends out pulses and receives echo. The starting point, step distance and number of steps is given as input to the PLC, which takes care of the movement of transducer. The A Scan signals that are received are digitised and stored in the PC for further processing. The starting point of the transducer is usually set as little further away from the object, move across the object in steps till it crosses the other end of the object. So while the data is being acquired, it is not known which signal has been obtained when the transducer was on or near the centre point of object. Though it is clear that the signal with maximum amplitude of echo has captured more of object, it cannot be confidently ascertained that the maximum amplitude signal has been acquired at the centre point of the object. For this reason, multiple data is acquired with varying steps of the transducer.

The raw signal that is saved will consist of transmitted pulse and the echoes namely interface echo and backwall echo.[5] A sample signal is shown in Fig.1 and Fig.2



Transducer nearing the object

Fig.1 A-Scan showing the condition of transducer nearing the object.



Transducer on the object

Fig. 2 A-Scan showing the condition of transducer on the object

Our point of interest is the interface echo, hence the portion of echo is isolated from the scan for further analysis.

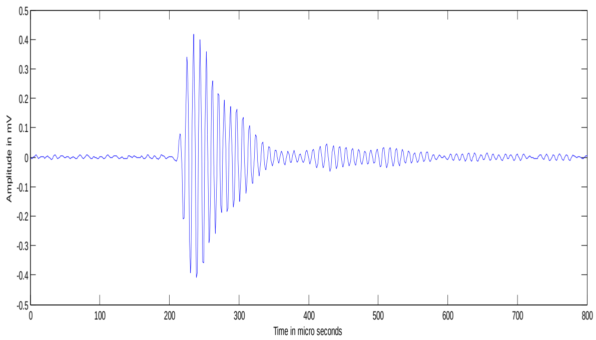


Fig.3. The enlarged interface echo

Each scan is time shifted and differs in magnitude with each other. To determine the amplitude and the phase shift between each signal, wavelet transformation has been applied. It is important to note that the scans which have been acquired while the transducer was focussing more of object rather than the surroundings will be in same phase or its phase difference will be very small. Such scans will hereafter be referred as target scans.

From the acquired data set of 37 A Scan signals recorded with transducer step size of 0.3mm. where the interface echo is more prominent than the back wall echo is taken for further analysis. Keeping this in mind, 14 A –scan signals are used in this module, namely F14 to F27. Among this reduced set, A-Scan signals F20 and F21 have high magnitude of amplitude, indicating these could be the target scans.

To confirm that they are the target scans, wavelet cross spectrum is determined.

III. WAVELET TRANSFORMATION

Cross correlation is a measure of similarity between two waveforms. Application of CWT to two time series and the cross examination of the two decompositions reveal localized similarities in time and scale. [6] Application of Continuous wavelet transform followed by Wavelet cross spectrum and wavelet coherence has been discussed in this paper.

The Continuous Wavelet Transform compares the signal to shifted and compressed or stretched versions of a wavelet. The mother wavelet chosen is Morlet wavelet as it provides a good balance between time and frequency localization.[7]

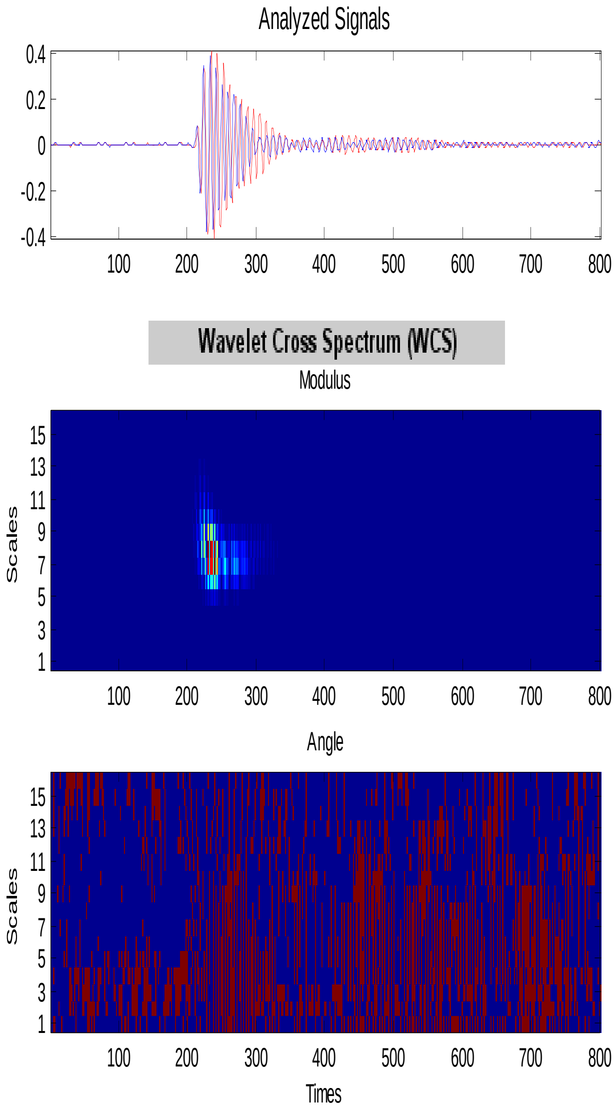


Fig.4. WCS of F14 and F20

The wavelet cross- spectrum is a measure of the distribution of power of two signals. The wavelet cross spectrum of two time series, *x* and *y*, is:

$$C_{xy}(a,b)=S(C_{*x}(a,b)C_y(a,b)) \qquad (1)$$

$C_x(a,b)$ and $C_y(a,b)$ denote the continuous wavelet transforms of *x* and *y* at scales *a* and positions *b*. The superscript * is the complex conjugate, and *S* is a smoothing operator in time and scale.

The wavelet cross spectrum between the signals F14 and F20 has been shown in Fig.4:

The wavelet cross spectrum indicates maximum power in the region of 200 to 300 at the scale of 8. The region of maximum power is indicated by red colour. The values of power at the scale of 8 have been selectively displayed below in Fig.5.

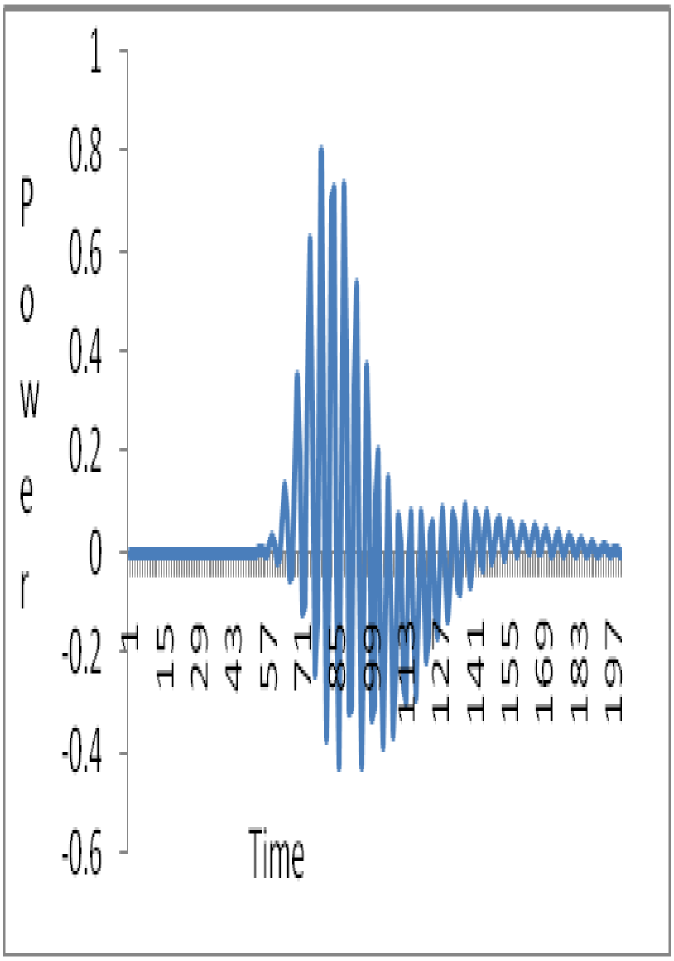


Fig.5. WCS between F14 and F20 at scale=8

In the above figure, only the time period between 150 and 350 has been shown. It is seen that power is both positive and negative, which indicates that the two signals are in phase during positive power and out of phase during negative power. The negative power decreases as we move towards signal F20. The signal F18 shows very little negative power and the magnitude of positive power continuously increases. The signals F19 and F21 show only positive power which is shown below in Fig.6 and Fig.7 respectively:

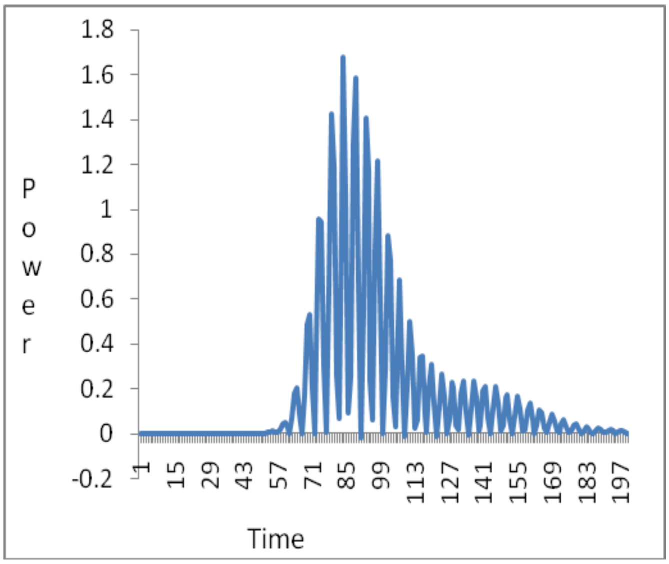


Fig.6. WCS between F19 and F20 at scale=8

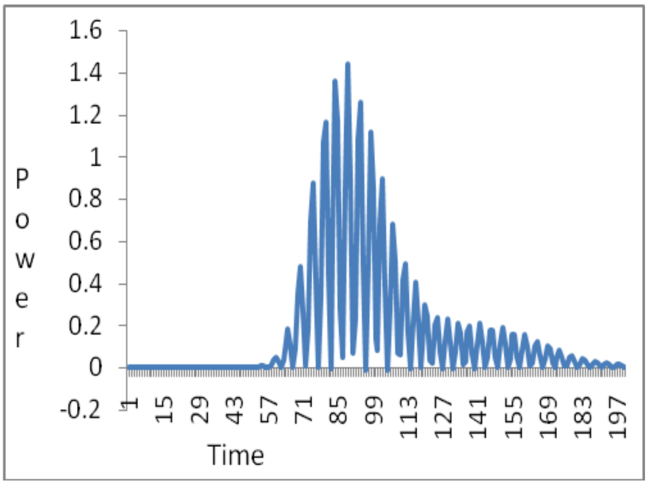


Fig.7. WCS between F21 and F20 at scale=8

The power is fully positive and maximum with F19 and F20. The positive power is seen with signals F21 and F20 but the amplitude is smaller. The power slightly goes to the negative from F22 onwards and the negative power steadily increases as we move towards other signals. It is noticed that as the transducer approaches the object but far from it, the common power is more negative. As the transducer gets nearer to the object, the negative power reduces and certain stages , the power is fully positive. Again as the transducer moves further away from the object, the negative power increases.

IV. RESULTS AND CONCLUSIONS

Power has negative and positive values when there is a phase difference between the two signals. The power is only positive when the two signals are in phase. When there is no phase shift it indicates that the signals have been acquired with the distance between the transducer and the object almost same. From the information obtained from the graphs on wavelet cross spectrum, we are able to reach to a conclusion that F19, F20 and F21 are the signals that have been acquired with the transducer exactly on top of the test object. It is quite probable that F20 has been acquired at the centre point of the object.

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