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# Analysis of Ultrasonic Signals based on Wavelet Cross Spectrum

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**Abstract**—This paper discusses the results of application of wavelet cross spectrum on Ultrasonic A-Scan signals that have been acquired by moving across the top surface of a cylindrical object placed vertically and immersed in a tank of water. Due to the phenomenon of beam spread, the ultrasonic transducer detects the object even when the transducer is slightly away from the object. As the transducer traverses across the object, the peak amplitude of the A- Scan signals increase and then decrease. Wavelet cross spectrum is found to be successful in identifying the signals that have been acquired with the position of the transducer exactly focusing the object.

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

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## I. INTRODUCTION

Non-destructive testing helps in detection of flaws or defects in a material without destroying its structure and properties. Among many techniques, Ultrasonic testing is an important non-destructive technique. Ultrasonic Testing uses high frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection helps in flaw detection and evaluation, dimensional measurements, material characterization. Ultrasonics is particularly attractive for non-destructive testing because it can be used with most types of materials, and it can be used to investigate both their outer and inner surfaces. 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].The Ultrasonic technique involves sound waves transmitted into a test object. The ultrasonic waves can undergo reflection, refraction or diffraction. The Pulse echo mode transmits sound in the form of pulses into the object and uses the reflected sound waves to study or analyze the internal structure of the material. The reflected pulses are called as echoes, hence the name Pulse Echo .This technique is also widely used for the measurement of thickness of objects. In the pulse-echo method, a piezoelectric transducer with its longitudinal axis located perpendicular to the object may be mounted on or near the surface of the test material. The same transducer is used to transmit as well as receive ultrasonic energy. Pulse Echo has the advantage that measurement is possible from a single side access to the object under test. Ultrasonic waves get reflected at boundaries where there is a difference in acoustic impedances of the materials on each side of the boundary. Whenever there is a change in the density of the material, the ultrasonic waves undergo reflection. When a steel object is placed under water and ultrasonic waves are transmitted into the water, a part of the ultrasonic waves get reflected at the boundary of the water and steel. The remaining part of the ultrasonic waves gets transmitted into the steel. It propagates through steel material and reaches the back wall of the steel material. At that interface, a part of the transmitted wave gets reflected back and the remaining part gets transmitted into the water-steel interface. Inside the steel material if there is any crack or void, due to change in density, waves get reflected at those points.

The transmitted and reflected waves are displayed on the CRT screen. If the display is of ultrasonic signals , then display is called A-Scan. If it is an image, it may be B or C or D- Scan. An object without any flaw or defect in it shows the transmitted wave and the echo from the back wall. 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. When the ultrasonic probe is placed in direct contact with the test specimen, it is termed as contact mode, though a couplant is used between the probe and testing material, for better transmission of ultrasonic waves. In the Immersion type, the entire experimental set up is placed in a liquid bath, most often in water. A waterproof- probe is placed at a convenient distance from the test specimen and the ultrasonic beam is transmitted into the material through a water column or a water path. The immersion mode, due to its uniform couplant conditions, is largely used in laboratories and in automatic ultrasonic testing.

This research work was carried out at Indira Gandhi Centre for Atomic Research ( IGCAR), Kalpakkam. The work deals with application of pulse echo technique in immersion mode. The test object is an open cylindrical object placed vertical in the water tank. The transducer is placed above the open end of the cylindrical object. The aim of conducting this experiment is to determine the shell thickness of the cylindrical object through A- Scan signals. The motivation behind this research is to detect the bowing of fuel sub assembly head (FSA) using ultrasonic signals. FSAs are immersed in liquid sodium at high temperatures. Due to long exposure of FSA to high temperature, a phenomenon termed as Bowing occurs. Bowing is bending of the FSA, where the axis of the FSA undergoes a tilt. Currently bowing is detected by analysis of images obtained of the FSA [2].

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 apply 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

### *A Experimental Setup*

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 immersion tank and the actutator is shown in Fig.1.

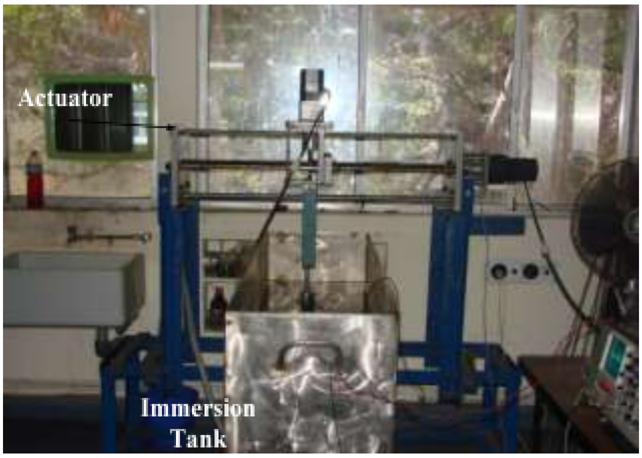



Figure 1: Immersion Tank with the Actuator (Courtesy: IGCAR, Kalpakkam)

The Pulser –receiver and the dislay unit is shown in Fig.2.The ultrasonic transducer is an unfocussed, immersible, normal probe of 10mm diameter of central frequency5 MHz.


Figure 2: Recording and Display system (Courtesy: IGCAR, Kalpakkam)

The transducer probe is also kept immersed in the water but at a certain height from the object, such that the object is in the far field of the transducer. The test object is the hexcan which is shown in Fig.3 is placed vertically in the immersion tank and kept submerged in water as shown in Fig.4. The transducer is not placed at the curved side of the object in the experiment because the FSA in the reactor is not accessible from the sides.

Figure 3. Hex can (Courtesy: IGCAR, Kalpakkam)

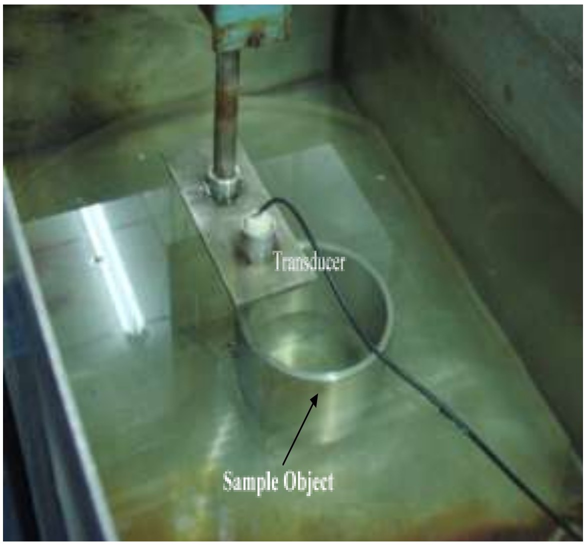
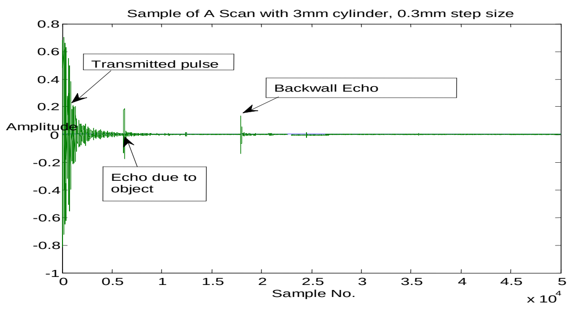



Figure 4: Cylindrical Object Immersed (Courtesy: IGCAR, Kalpakkam)

### *B Data Acquisition*

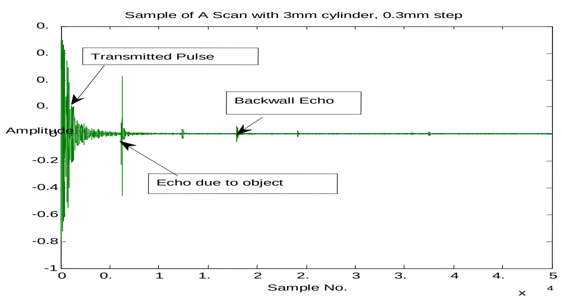
The data is acquired and analysis is done in offline mode. The starting point, step distance and number of steps is given as input to the PLC, which takes care of the movement of actuator. The transducer is attached to the actuator, thus the transducer is automated to move in specified steps across the object and at every step it sends out pulses and receives echo. The A -Scan signals that are received are digitized 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. [5]. Therefore 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 back-wall echo.[6].

A sample signal acquired at different stages of movement of transducer is shown in Fig.5 and Fig.6. Our point of interest is the interface echo, hence the portion of echo is isolated from the scan for further analysis. 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 focusing 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.




Transducer nearing the object

Figure 5: A-Scan showing the condition of transducer nearing the object




Transducer on the object

Figure 6: A-Scan showing the condition of transducer on the object

From the start of detection of the object to the end of detection of the object, the transducer was made to move with step sizes of 0.5mm and 0.3mm.With step movement of 0.5mm, 52 A Scans had been acquired. From these 52 A Scans, only those scans where interface echo amplitude is more prominent than the back wall echo are taken for further analysis. Keeping this in mind, 23 A –scan signals are used in this module, namely f1 to f23. Among this reduced set, A-Scan signals f9 and f10 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 TRANSFORAMATION

Cross correlation is a measure of similarity between two waveforms. Application of Continuous Wavelet Transform 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 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]. 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 given by

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

$C_x(a,b)$ 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 two signals is determined and analyzed. The reference signal is chosen as the A-scan signal f10 as this signal has the highest peak amplitude. The highest amplitude is indicative of the position of the transducer exactly above the object.

The wavelet cross spectrum gives the output in three windows, with the first window showing the analyzed signals. The second window indicates modulus part of coefficients of WCS and the third window indicates that of angle part. Red color in the modulus and angle indicates maximum value. In angle red color indicates 180° and blue indicates minimum value or 0°. The WCS obtained between signals f9 and f10 has been shown in Fig.7.

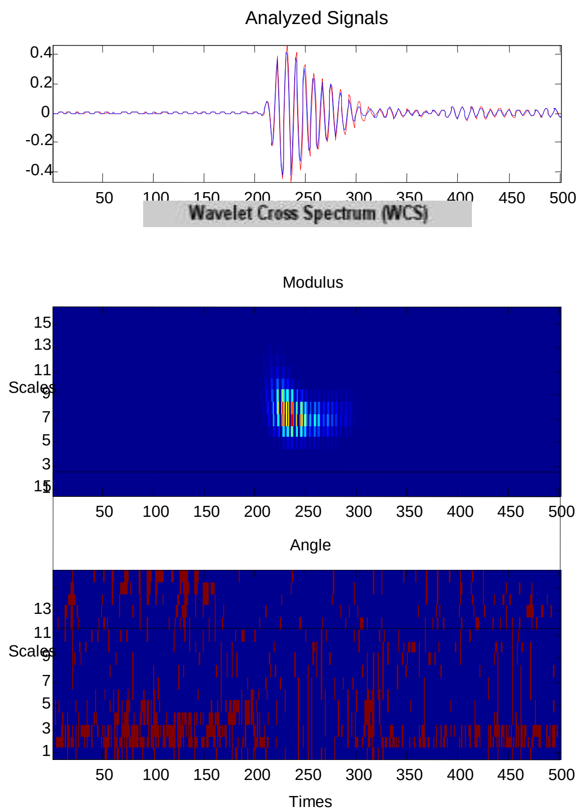



Figure 7: Wavelet Cross Spectrum of f9 and f10

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## IV. RESULTS AND DISCUSSIONS

The maximum power and minimum angle is seen in the region of 200 to 250 at the scale of 8 as seen from Figure 7. Similarly the wavelet cross spectrum. The values of WCS coefficients for different signals have been obtained. The modulus values at scale of 8 for different signals have been plotted in a graph and analyzed.

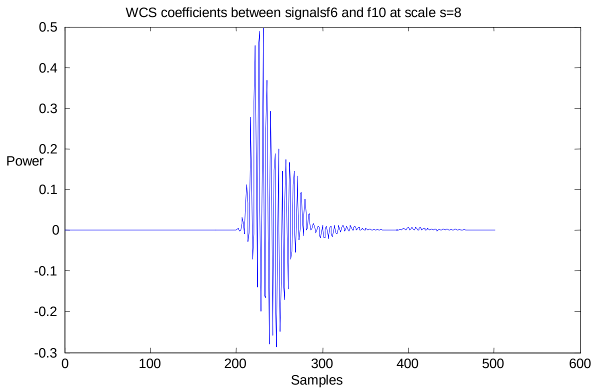


Figure 8: WCS coefficients between signals f6 and f10.

The Wavelet cross spectrum applied between signals f6 and f10 is shown in Fig.8. From the figure, it is noticed that the power values are both positive and negative, which means that the two signals are out of phase with each other. The negative values is found to decrease as signals closer to f10 are applied.

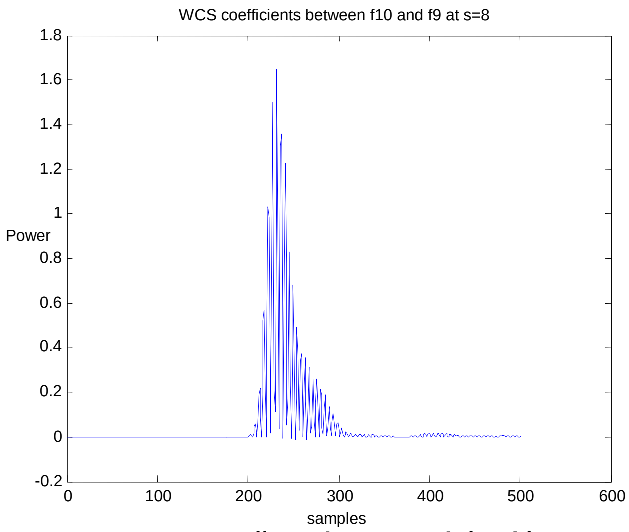


Figure 9: WCS coefficients between signals f9 and f10.

The power coefficients between signals f9 and f10 and also f10 and f11 are completely positive, indicating they are in phase with each other as shown in Fig 9 and. Fig.10 respectively.

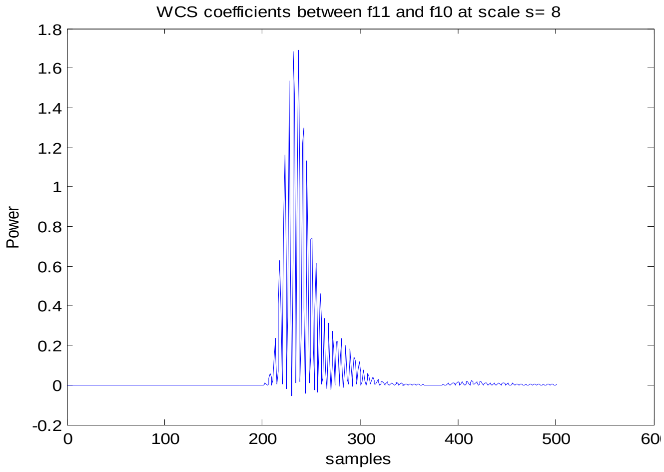


Figure 10: WCS coefficients between signals f11 and f10.

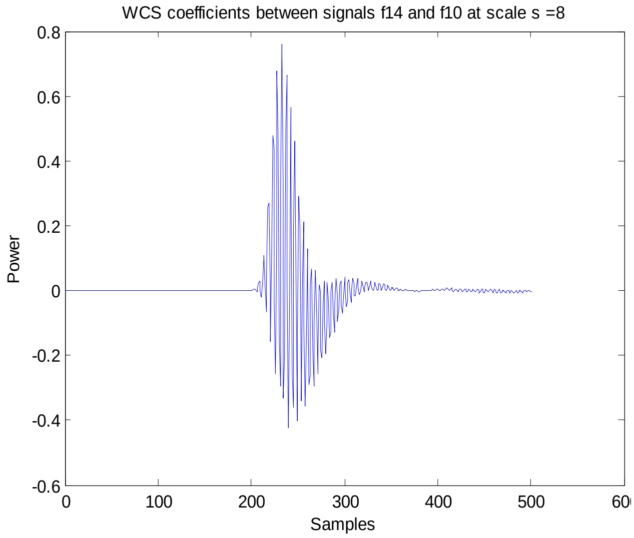


Figure 11: WCS coefficients between signals f14 and f10

For the signals beyond f11, the positive values of WCS coefficients are found to be to reduce and negative values found to increase as shown in Fig.11.

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.

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 f9, f10 and f11 are the signals that have been acquired with the transducer exactly on top of the test object. It is quite probable that f10 has been acquired at the centre point of the object. Hence signal f10 is chosen as reference for estimating the shell thickness of the cylinder.

Thus rather than relying only on the peak amplitude of the A –scan signal to identify the reference scan, wavelet cross spectrum has been applied to determine more effectively.

The future work would be to identify the exact number of scan signals acquired on either side of the reference scan ( f10) that could contribute in estimating the shell thickness of the object .

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