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Application of Synthetic Aperture Focusing Methodology For Estimation of Wall Thickness

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Abstract

This paper deals with estimating the wall thickness of Fuel Subassembly head by using the synthetic aperture focusing methodology. The determination of its thickness would enable to locate the centre of the head which can eventually lead to the detection of bowing. Bowing can be detected by the lateral shift in the position of the centre of the FSA head. All ultrasonic transducers have beam spread due to which the thickness cannot be determined accurately. Synthetic aperture focusing method has been applied on A scan signals and thickness has been estimated with an accuracy of above 90%.

Keywords: Thickness, Pulse Echo, Fuel Sub assembly, Bowing, SAFT, A Scans,

Introduction

The PFBR (Prototype Fast Breeder Reactor) at Kalpakkam, India is a 500 MWe, pool type reactor with liquid sodium being used as the coolant .The core of the PFBR is composed of 181 fuel subassemblies[1]. The fuel subassemblies are of nearly 4.5m in length and are arranged in honeycomb pattern. The topmost portion of the FSA is called its head, which has a wall thickness of 3.2mm. The FSAs are placed vertically in the core of the PFBR and submerged in a pool of liquid sodium.

Due to prolonged irradiation and flow of hot liquid sodium, the FSAs undergo certain dimensional deformations known as bowing, growth or protrusion. Presently, bowing is detected by means of C Scan images obtained by application of Pulse Echo technique. An under-sodium scanner had been developed which would indicate the top view of the FSAs. Appropriate software has been designed to indicate the condition of bowing and growth.[2]

This research is intended to detect bowing from A Scan signals acquired using Pulse Echo. Bowing is defined as the angular bending of the fuel rod, in which one face of the fuel rod is at a higher position than the other face of the same fuel rod. Due to bowing, there is a horizontal displacement of the FSA head, which is seen by a lateral shift of the centre point of the head. To determine the centre, the width of the FSA head is to be calculated which in turn requires the measurement of wall thickness.

Therefore, the main objective of this present work is to estimate the wall thickness of the Fuel Subassembly head. Liquid sodium is transparent to ultrasound and since only a single side access to the FSA is permissible, Pulse Echo ultrasonic technique is the only feasible technique for this measurement [3]. Immersion mode of testing has been carried out here since the FSA is submerged in liquid sodium. For initial testing, the FSA head is placed in a tank containing water and thickness has been estimated. The accurate measurement of the thickness poses a challenge due to the inherent property of beam spread of ultrasonic waves.

Synthetic Aperture Focusing Technique (SAFT) is one of the methods for measurement of dimensions using ultrasonic technique[4]. It has been commonly applied to the A Scans, from which a new B Scan image is reconstructed after application of SAFT. SAFT has been found to reduce the effect of beam spread; hence dimensions can be done estimated within permissible range of errors from resulting B Scan images. This paper deals with synthetic aperture based focusing using A Scan signals. Synthetic aperture focusing involves combining several overlapping measurements of the same point in space by delay and shift methodology to yield a large synthetic aperture with a narrow beam, resulting in increased resolution.

Data Acquisition

The head of the FSA is hexagonal in shape when viewed from the sides and when viewed from the top it is circular in shape as shown in the Figure 1. The head is also called as hexcan, of width 131.3mm , when measured across flat sides and of thickness 3.2mm [5]. It is made of stainless steel SSA.

Figure 1: FSA head

The ultrasonic transducer used is an unfocussed normal beam immersion transducer of central frequency 5MHz. The diameter of the transducer probe used is 10mm. The hexcan is placed in a water tank and the transducer is made to step along a horizontal line, above the top surface of the object. The transducer transmits pulses at every step distance and receives reflected waves from object. The Pulser – Receiver used was model RITEC RPR 4000.The transducer movement is caused by the 4 axis manipulator. It brings about movement of transducer along X axis, Y axis, Z axis and θ or U axis. The 4 axis Stepper motor controller model used is Performax 4CX. The A Scans were displayed on the CRT screen and also digitized to store in the PC. The sampling frequency chosen was 50 MHz and 50,000 samples for each A Scan were stored as digitized signals saved in the form of .txt documents in the PC. The step distance or spatial sampling rate is chosen as 0.3mm and 0.5mm. The transducer is moved from the point of detection of the object till the end of detection of the object.

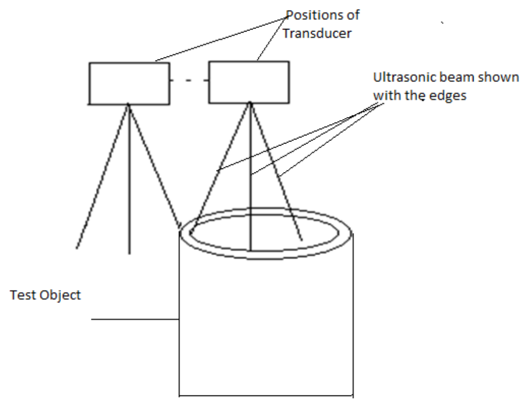

Figure 2: Movement of Transducer.

23 A scans were acquired with step size of 0.5mm and 37 A Scans were acquired with step size of 0.3mm. Sample of A Scans recorded have been shown in Figures 3to 6.

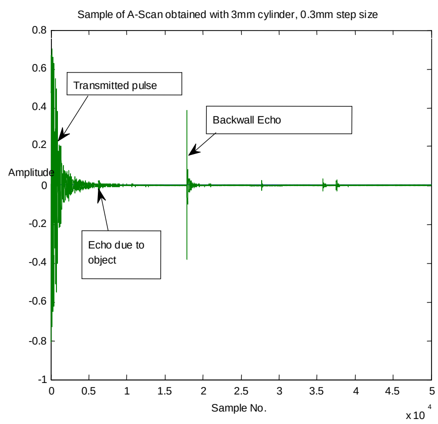

Figure 3: Transducer just detected the object

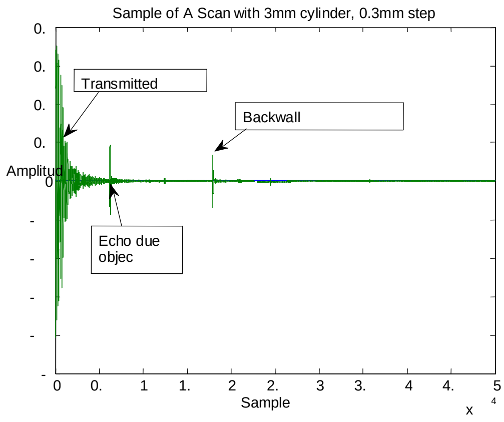

Figure 4: Transducer nearing the object

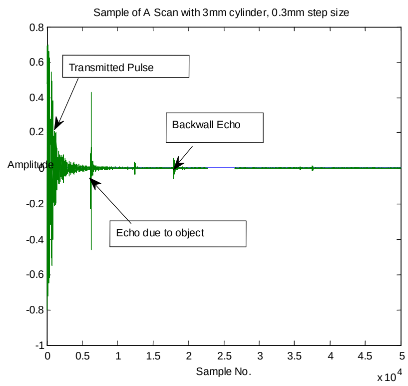

Figure 5: Transducer on the object

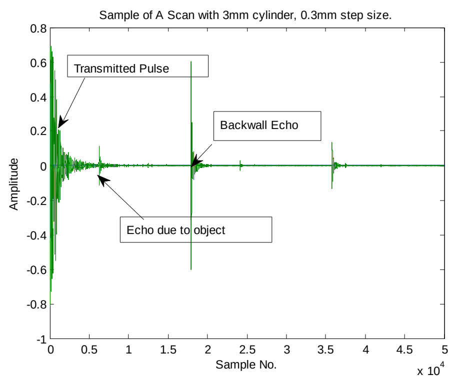

Figure 6: Transducer moving away from the object

While acquisition, it is noticed that the A Scan has a minimum of three distinct patterns seen on it. The first distinct pattern is the transmitted beam. The other distinct pattern is the reflected beam from the bottom part of the water tank, which is called the back wall echo. The other distinct pattern is the echo which is the reflected beam from the top surface of the object, which can be termed as the interface echo.

As the transducer is traversed across the object, the amplitude of the interface echo and the back wall echo changes. The amplitude of the interface echo is found to initially increase, reach a maximum and then found to decrease. The amplitude of the back wall echo is initially maximum, decreases as the transducer moves closer to the object and then increases again as the transducer moves away from the object. The A Scans have been collected and post processing is done on them to get the required dimension. It is also noticed that the A Scan acquired with the position of the transducer exactly on the object has the interface echo with maximum amplitude occurring at the shortest time of flight and all other A Scans acquired at different positions are scaled and delayed version of the above scan.

Besides the three distinct echoes in the above A Scans, echoes of smaller amplitudes are seen. These are the echoes due to multiple reflections. The difference in time of flight between the interface echo and the back wall echo is indicative of the depth (height) of the object. If the transducer is placed on its sides, then the difference in time of flight would indicate thickness. Since the object is not accessible from the sides, alternate techniques are required for this measurement.

Methodology

The concept of synthetic aperture is performing multiple measurements over a required region and post-processing these measurements to synthesize a large effective aperture by combining them [6]. Synthetic aperture can be unfocused or focused. If each A Scan is shifted in time to contribute for the delay due to beam spread, then the resulting synthetic aperture is of focused type. If the scans are combined without taking into account of the time delay, then it is unfocussed type[7].

Since the step size of the transducer is small and the width of the object is comparatively larger, there could be more than one signal which could indicate the exact position of the transducer on the object. The number of A Scans to be included under the aperture is always a tough decision to make. In this work, the size of synthetic aperture is varied to determine the effective synthetic aperture. Therefore a known size of synthetic aperture is chosen and the scan in the central position of this aperture is chosen as reference scan.

The signals are delayed and summed with respect to the reference signal within the aperture. The time shifted scans within the aperture are stacked to get a single value of amplitude in a manner similar to obtaining a B Scan. The synthetic aperture is then moved to cover the entire set of data and the above procedure of delay and sum is repeated in each aperture. From the obtained B Scan values, a threshold value is chosen. The values of B Scans above the threshold value are selected for calculation of the thickness. The number of values of B Scan above the threshold value is multiplied by the step size of the transducer to obtain the thickness of the object. The size of the synthetic aperture is now varied and the entire procedure is repeated. The results have been tabulated below.

Results and Discussion

No. of A Scans Acquired	Step Size	Synthetic Aperture (mm)	Thresholded scans	Estimated Thickness (mm)
23	0.5mm	3.0	14	6.5
		4.0	13	6.0
		5.0	11	5.0
		6.0	10	4.5
		7.0	8	3.5
		8.0	6	2.5
37	0.3mm	5.4	19	5.4
		6.0	15	4.2
		6.6	11	3.0
		7.2	11	3.0
		7.8	9	2.4

The thickness has been estimated for varying sizes of the synthetic aperture. It is found that there exists an optimum size of synthetic aperture for which resolution is high. The high resolution is indicated by the reduced error in thickness measurement. When the size of the synthetic aperture is varied above and below the optimum size, the error in thickness measurement is found to increase, indicating low resolution.

The optimal length of synthetic aperture in this case is in the range of 7.0mm to 7.2mm, where the thickness is found with an accuracy of 90%. When the length of synthetic aperture is larger than the optimal level, under sizing occurs and when the length of the synthetic aperture is smaller than the optimal length over sizing occurs.

Conclusions

Synthetic aperture focusing methodology has been very effective in estimation of thickness with reasonable amount of accuracy. There exists an optimal length of the synthetic aperture where the lateral resolution is high. It is also found that the resolution does not depend on the step size of the movement of the transducer. The thickness estimated depends on the step size of the transducer.

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