Indian Journal of Science and Technology, *Vol 7(4), 396–400, April 2014*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Application of Synthetic Aperture Focusing Technique for Estimation of Width using Pulse Echo Ultrasonic Testing

Sujatha Kumaran* **and B. Sheela Rani**

Sathyabama University, Jeppiaar Nagar, Rajiv Gandhi Road, Chennai 600 119, India;
ksujatha71@ gmail.com, kavi_sheela@yahoo.com

Abstract

The condition of bowing of fuel rods in nuclear reactors is often detected through imaging of sub-assembly tops using C-Scans obtained from Pulse Echo Ultrasonic technique. The detection of bowing by means of post processing of A-Scan signals is discussed in this paper. Techniques have been initially developed on hollow cylinders, which mimic the sub-assembly tops. A-Scans are collected by placing the unfocussed ultrasonic transducer at the top of the hollow cylinder, kept in the water bath. The beam spread causes the object to be detected even when the transducer is not exactly above the object. This results in over sizing of the object. The objective is to estimate the width precisely by means of which, condition of bowing could be detected. Synthetic Aperture Focusing Technique is applied on these A-Scans to estimate the width. The width of the object can be estimated at different positions on the top surface of the object, from which centre points at each position can be obtained. If these centre points form an ellipse or a deformed circle, then bowing condition is detected, else normal condition is indicated. Two hollow cylinders of known width 5 mm and 3 mm have been used here. Application of this technique with a synthetic aperture of 14.4 mm, has given a minimal error of 1.4 mm and 0.3 mm for the 5 mm and 3 mm cylinders respectively.

Keywords: A-Scan, Bowing, Pulse Echo, SAFT, Width

1. Introduction

One of the most common techniques for Non–Destructive Testing (NDT) is the Ultrasonic technique, in which quality of materials or objects is examined without damaging the object. Ultrasonic Testing is normally used in determination of thickness of the material, detection of faults and to specify the physical characteristics of the defect such as its dimensions, type of defect etc. Different methods of Ultrasonic Techniques exists namely Pulse Echo technique, Through Transmission technique and Pitch–Catch Technique. Each method has its own advantages and disadvantages. A particular method has to be selected based on the application. When only single side access is possible, Pitch–catch and Pulse echo techniques can be used. When both sides of the object can be accessed then through transmission can be used.

In the pulse-echo ultrasonic technique, a single piezoelectric transducer is used to transmit and receive ultrasonic energy. The transducers could be contact type or immersion type, angle beam or normal beam transducer. The transmitted ultrasonic waves get reflected at top surface of the material or at defects within the material. The reflected waves are called echoes. The echoes are seen on the CRO screen. The display on the CRT screen shows the transmitted wave, reflected wave(s) and the back wall echo. The presence of any defect in the material is seen by another echo before the back wall echo. The reflected wave can be displayed in the form of A-Scans, B-Scans and C-Scans. The A-scan signifies the distance travelled

**Author for correspondence*

by the ultrasonic wave till the point of reflection at a surface or discontinuity. The B-scan presentations provide a side-view of the test specimen. The C-scan presentation provides a top view of the location and size of test specimen features. The Pulse Echo Ultrasonic Technique has been commonly used in thickness measurements. This technique directly gives the depth information, i.e. the total height (thickness) of the object or the depth at which a defect is located. When the transducer is placed above the object, details of depth could be determined. The thickness can be measured by placing the transducer at the sides of the object. This paper deals with placing the transducer above the object to measure thickness of the object because access to the side of the object is not feasible. Hence the word width is used instead of thickness or depth.

A pulse-echo sensor is positioned at a particular height from the top surface of the object, such that the object receives the far region of the ultrasonic beam. The sensor is made to step along a horizontal line, above the top surface of the object. The sensor transmits pulses at every step distance (Δx), and receives reflected waves from object[1–4]. As the ultrasonic wave propagates through the material, it spreads out. This phenomenon is known as beam spread. Due to the effect of beam spread, the transducer detects the object much before the instant when it is actually over the object[5–6]. Hence this gives the impression of enlarged width of the object. The aim of this work is therefore to estimate the correct width of the object.

The Pulse Echo sensor has been used in the nuclear reactor to get the image of sub-assembly tops for measurement of bowing or growth that may occur due to irradiation damage. The extent of bowing can be assessed by measuring the distance between the centre points of adjacent sub assembly heads. C-Scans from Pulse Echo Ultrasonic transducer have been used to estimate bowing[7]. This paper attempts the possibility of detection of bowing from A-Scans. By measuring the width of the sub assembly head, centre points can be identified, from which bowing could be detected. If the centre points form a circle, then no bowing is detected. If the centre points form an ellipse or a deformed circle, then bowing is indicated. Algorithms have been developed to eliminate the effect of beam spread and estimate the correct width of the hollow cylinder, which resembles a sub assembly head.

Synthetic Aperture Focusing Technique (SAFT) is the one of the most common signal processing tool used in sizing techniques[8,9]. Time domain SAFT involves time-shifting of A-Scans and coherent summation of the time shifted A-Scans within a synthetic aperture. Constructive interference of A-Scans would yield higher amplitude and destructive interference would yield lower amplitude of the A-Scan. SAFT is basically a post–processing technique of ultrasonic data. The effect of the beam spread of the transducer is taken into consideration and application of SAFT produces a more focused response. Length of the Synthetic aperture is defined as the product of number of samples taken during a scan along x-direction and spatial sampling length[10]. In other words, length of synthetic aperture is defined as the distance moved by the transducer for acquiring N number of A-Scans with sampling distance of Δx. Thus length of synthetic aperture is the product of N and Δx. The maximum length of synthetic aperture also depends on distance R between the reflector and transducer, wavelength λ of the transducer and the diameter d of the transducer[11]. Thus for a certain transducer the value of λ and d are constants. Hence the length of synthetic aperture depends on R. Higher the value of R, larger is the length of synthetic aperture.

$$L_{eff} \approx \frac{R\lambda}{d}$$

As the transducer scans across the object, A-Scans are obtained. By joining the peaks of these A-Scans, a curve in the shape of a hyperbola is obtained. The span of hyperbola will be larger for larger values of depth. By use of the SAFT, the span of the hyperbola is reduced and from the reduced hyperbola, the width of the object is determined.

2. Data Acquisition

The ultrasonic system comprises of an immersion tank coupled with sensor and the accessories required to move the sensors with precision. This system is interfaced to a computer for storing the A-Scans in the digital form. The sensor system comprises mainly of the transducer, actuators and stepper motors to move the transducers. The movement of transducer with the help of stepper motors is controlled using a Programmable Logic Controller. The captured A-Scans are passed through signal conditioning unit, converted to digital form, making it easy for storage and also for displaying it on a Cathode Ray Tube. Based on the size of the movement of the transducer required, the number of pulses is fed in through the computer[12]. The transducer can be moved in horizontal and vertical direction by means of a stepper motor for each direction. The vertical position of the transducer is kept constant while acquiring the data. The single normal beam transducer used is a 5 MHz piezoelectric crystal, which is attached to the actuator. The diameter of the transducer is 10 mm. The transducer is made to move in constant steps in horizontal direction along the surface of the specimen immersed in water bath (Figure 1). At each step, it sends ultrasonic pulses and receives the reflected echoes in the form of A-Scans. The electrical signals are digitized with sampling frequency of 100 MHz and stored (Figure 2). Initially the transducer is positioned at a place where it just detects the object. The transducer is moved towards the object with three different values of spatial resolution of 0.3 mm, 0.5 mm and 0.7 mm. The transducer is moved laterally till it stops detecting the object. Two samples of hollow cylinders of width 3 mm and 5 mm have been used. For the sample of 3 mm width, the number of A-Scans recorded for each step size is 75, 45 and 32 A-Scans respectively. With 5 mm sample, the transducer was moved with step sizes 0.3 mm, 0.5 mm and 0.7 mm, and the number of A-Scans recorded is 78, 52 and 36 A-Scans respectively.

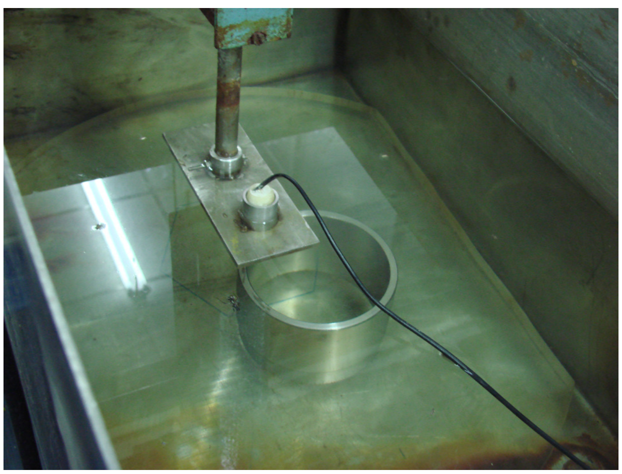

Figure 1. Specimen in water bath and transducer.

Figure 2. System hardware for data acquisition.

3. Methodology

The technique of SAFT involves selection of few data under a synthetic window (aperture). Choosing one of the A-Scan as reference, the other A-Scans are time shifted and the resulting data is added. A single data is obtained which is equivalent to a pixel of the B-Scan. For the same aperture size, the reference A-Scan is shifted left and right of the initial reference scan. A pixel is obtained for each reference A-Scan. If the reference A-Scan is exactly indicating the presence of the object then the value of the pixel is high otherwise it is low. Same procedure is repeated by varying the aperture size. By plotting the pixels so obtained we get a hyperbola whose span is very much less than the initial hyperbola. The value of the pixels above a threshold value is indicative of the presence of the transducer exactly above the object[4]. Hence, these values would contribute to the calculation of width.

4. Experimental Results and Discussion

Two hollow cylinders of width 3 mm and 5 mm have been used as samples. With 3 mm sample, the transducer was moved with step sizes of 0.3 mm, 0.5 mm and 0.7 mm, and the number of A-Scans recorded for each step size is 75, 45 and 32 A-Scans respectively. With 5 mm sample, the transducer was moved with step sizes 0.3 mm, 0.5 mm and 0.7 mm, and the number of A-Scans recorded is 78, 52 and 36 A-Scans respectively. First the A-Scan with the highest peak is chosen as the reference and all the other A-Scans within the aperture are time shifted and the amplitudes are added up to obtain a single pixel. Different A-Scans are chosen as the reference scan and SAFT is applied to obtain pixels. If there is a constructive interference of A-Scans, then the value of the pixel is high and if destructive interference occurs, low pixel value is obtained. The pixel values are plotted. The total numbers of Scans which have amplitudes greater than the threshold are chosen for estimation of width. The threshold is chosen as μ-σ, where μ is the mean of the pixel values and σ is the standard deviation of the pixel values. The results obtained after application of SAFT algorithm has been tabulated below.

Table 1. Results of SAFT on 5 mm ring

Step size (mm)	Aperture Size (mm)	Width obtained (mm)	Absolute Error (mm)
0.3	13.8	6.9	1.9
	14.4	3.6	1.4
	15.0	2.1	2.9
0.5	12	7.5	2.5
	13	4	1
	14	1.5	3.5
0.7	9.8	9.8	4.8
	11.2	5.6	0.6
	12.6	2.8	2.2

Table 2. Results of SAFT for 3 mm ring

Step size (mm)	Aperture size (mm)	Width obtained (mm)	Absolute Error (mm)
0.3	13.8	4.5	1.5
	14.4	3.3	0.3
	15.0	2.4	0.6
0.5	13	5.5	2.5
	14	3.3	0.3
	15	1	2
0.7	11.2	5.6	2.6
	12.6	3.5	0.5
	14	2.1	0.9

Table 1 shows the result of SAFT on ring of 5 mm size. Only the values of those aperture sizes that gave minimal error have been listed. Similarly, Table 2 shows the result of SAFT on 3 mm ring. The absolute error has been listed. The aperture size less than those mentioned gave large values of positive error. The aperture size greater than those mentioned, gave large negative errors.

5. Conclusion

The error in estimation of width by applying the technique of SAFT has been summarised in the Table 3. It is found that the error is minimal with step size of 0.3 mm. This is obvious because better resolution would yield better results. This is also seen in the case of 0.7 mm step size, where the minimum error obtained itself is larger than the others. It is also found that the aperture size of 14.4 mm for step size of 0.3 mm is giving minimum error for both the rings. The drawback in this method adopted is that the aperture size, width and hence the error are all multiples of the step size of the transducer movement. To overcome this, step size or the spatial resolution of the transducer could be 0.1 mm. This would avoid the terms to be multiples of step size. This would definitely give better results as higher resolution is being applied. But spatial resolution of 0.1 mm would imply more number of A-Scans, greater computation time.

Table 3. Summary of results

Step size (mm)	Aperture size (mm)	Absolute Error obtained for 5mm ring	Absolute Error obtained for 3mm ring
0.3	13.8	1.9	1.5
	14.4	1.4	0.3
	15	2.9	0.6
0.5	13	1	2.5
	14	3.5	0.3
0.7	11.2	0.6	2.6
	12.6	2.2	0.5

6. Acknowledgement

The authors wish to thank the scientists Dr. P. Kalyanasundaram and Mr. V. Prakash of Indira Gandhi Centre of Atomic Research, Government of India, for the technical support provided by them.

7. References

1. Liout R-J, Kao K-C, Ye C-Y, Chen MS. Flaw detection and sizing of ultrasonic images using wavelet transform and SAFT. Proceedings of 2004 International Symposium on Intelligent Signal Processing and Communication Systems, 2004. ISPACS; 2004 Nov 18–19.
2. Martinez O, Parrilla M, Izquierdo MAG, Ullate LG. Application of digital signal processing techniques to synthetic aperture focusing technique images. Sensor Actuator Phys. 1999 Aug 30; 76(1–3):448–56.
3. Dengzhi W. Non-linear synthetic aperture focusing technology ultrasonic imaging applied in non-destructive testing. Available from: www.ndt.net/article/v12n09/dengzh.pdf
4. Kumaran S, Rani BS. A comparison on two data fusion techniques for estimation of width using pulse echo ultrasonic technique. Int J Res Mech Eng Tech. 2013. 1(4); 179–82.
5. Kumaran S, Rani BS, Manoharan N, Kalyanasundaram. A study on the estimation of width using synthetic aperture focusing technique. Paper presented at: Proceedings of

International Conference on Emerging Scenarios in Space Technology and applications (ESSTA2008), Sathyabama University; 2008; Jeppiaar Nagar, Chennai, India.

6. Kumaran S, Rani BS. Application of 6 db drop technique to estimate the width of sub assembly ring top using pulse echo ultrasonic. Int J Appl Sci Eng Tech. 2013; 5(6):4771–75.
7. Kumar KA, Rajkumar V, Palanichamy P, Jayakumar T, Chellapandian R, Kasiviswanathan KV, Raj B. Development and applications of C-scan ultrasonic facility. Paper presented at: e National Seminar “NDE2006”; 2006 Dec 7–9; Hyderabad, India.
8. Pitkänen J, Oy P, Olkiluoto F. SAFT – Is it a Tool for Improved Sizing in Ultrasonic Testing? [Poster 211]. ECNDT; 2006.
9. Satyanarayan L, Balasubramaniam K, Krishnamurthy CV. Comparative studies on multi–element synthetic aperture focusing phased array ultrasonic technique and conventional SAFT. Available from: http://www.cnde-iitm.net/balas/publications.html
10. Barkefors A. 3D Synthetic Aperture Technique for Ultrasonic Imaging . IJPTEC; 2010 Feb. Available from: http://uu.diva-portal.org/smash/get/diva2:304379/FULLTEXT01.pdf
11. Stepinski J. Synthetic aperture focusing technique in ultrasonic inspection of coarse grained materials. SKI report; 2008.
12. Kumaran S, Rani BS. A study on effect of bowing on a scans using pulse echo ultrasonic technique. Int J Res Mech Eng Tech. 2013; 2(11):575–78.