ULTRASONIC TRANSDUCER ATTENUATION BEHAVIOR OF FIBER GLASS COMPOSITE LAMINATES (FGCL) THROUGH SIGNAL FILTERING APPROACH

M. F. Mahmod[1,2], Elmi Abu Bakar[3] and M. Z. Mohamed Pauzi[1]
[1]Departmental School of Mechanical Engineering, Universiti Sains Malaysia, Nibong Tebal, Pulau Pinang, Malaysia
[2]Faculty of Mechanical Engineering and Manufacturing, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia
[3]Departmental School of Aerospace Engineering, Universiti Sains Malaysia, Nibong Tebal, Pulau Pinang, Malaysia
E-Mail: mfaisal@uthm.edu.my

ABSTRACT
In ultrasonic non-destructive tests, transducer is one of the most part need to determine carefully. The attenuation behaviour of transducer will impact overall ultrasonic measurement accuracy base on signal processing analysis. In normal applications, ultrasonic inspector relies on transducer calibration result produced by the manufacturer where there are no doubts to question the accuracy of measurement results. However, the attenuation behaviour of transducer can be defined based on signal-to-noise ratio (SNR) value. In this paper, the attenuation behaviour of ultrasonic transducer was investigated based on SNR value through signal filtering approach. Since the detection of flaw in composite laminates using ultrasonic non-destructive testing (NDT) approach is highly complex due to noise occurrences, several types of filter were applied and compared each other in order to propose the suggested filter base on SNR result. A 2.25 MHz single crystal immersion transducer is used to perform ultrasonic scanning for composite laminates material which is thickness up to 7.4 mm with scanning rate 7.50 mm/sec under lab condition. As a comparison result, when applying discrete wavelet transform (DWT) de-noising approach, SNR was enhanced and caused defect detection was easily identified.

Keywords: Non-destructive testing, ultrasonic testing, attenuation behaviour, signal processing, signal-to-noise ratio.

INTRODUCTION

The Ultrasonic non-destructive testing (NDT) are highly demanded inspection technique for composite laminates material. The ability to detect interlayer defects in a thicker panel without complex setup caused this technique become more popular than others inspection technique such as x-ray, thermography and shearography. In general practice, ultrasonic inspector used various types of transducer for ultrasonic inspection depending on dimension of specimen, material properties and scanning condition. In general, the higher the frequency of transducer used, the shorter the wavelength and suitable for homogenous thin plate material inspection such as sheet metal or welding joining quality inspection. In common application, ultrasonic inspector relies on the calibration result which is produced by manufacturer or routine maintenance schedule and also with self-experience in order to determine the performance of transducer being used. This practice however insignificant for unexperienced inspector who really depending on measurable data.

In the past few years, several research has been performed to improve the detection accuracy of ultrasonic pulse-echo inspection. Some researcher focused on electronic circuit based included amplification, filtering and variable gain parameter [1] while another researcher focus on developing a better signal processing approach to ease the defect detection process [2] and [3]. However, these approaches are complex and more convenient for research based task. In order to determine the performance of ultrasonic transducer for detection accuracy, Howard *et al.* was measure the sensitivity of signal gathered using SNR approach respected with various types of transducer parameter [4]. Meanwhile, certain defect of composite laminates also applicable to detect significantly by using air-coupled non-contact transducer but limit to some dimension [5]. Since the SNR approach used as one of measurable parameters to determine the inspection quality of ultrasonic measurement, several works has been done included pipeline inspection [6], aluminium buffer rods in molten bath [7] and in composite material inspection [8]. However, pre-processing work like signal filtering and smoothing are required to enhance the SNR for better flaw signal detection. Several studies on pre-processing work for SNR enhancement has been done lately using 2 dimensional analytic wavelet thresholding method [9], time frequency neighbourhood frequency [10] and wavelet de-noising approach [11] and [12].

In this paper, the attenuation behaviour of both ultrasonic single crystal contact and ultrasonic immersion transducer was investigated using three signal filtering approaches which is smoothing, Butterworth filter and Discrete Wavelet Transform (DWT). The selection of Butterworth filter and DWT are based on previous research as done by B. Kirthika *et al.* [13] and Vaclav Matz [14] where wavelet de-noising are claimed applicable to reduce high frequency noises. Through this approaches, the signal acquisition was performed using ultrasonic pulse-echo testing for fibre glass composite laminates panel. This experiment was conducted under ambient temperature and all procedure were followed ASTM E1065 standard [15]. The noise occurrences in acquired signal were decreased the propagated ultrasonic energy from the transducer. Thus, the comparative study of several signal filtering approach was conducted to define the better signal filtering through SNR calculation.

VOL. 12, NO. 4, FEBRUARY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

As a result, the selection of signal filtering is important where different SNR results will impact overall study of attenuation behaviour for ultrasonic transducer.

METHOD APPROACH

a) Overall flow chart

In this study, the overall research is divided into two phases which is signal pre-processing and signal attenuation analysis as shown in Figure-1 below. Signal pre-processing phase involved signal acquisition of an ultrasonic pulse-echo testing, signal filtering approach included smoothing, Butterworth filter and discrete wavelet transform (Daubechies packet). The following phase is signal attenuation analysis where the SNR was calculated before evaluated to finalize the result.

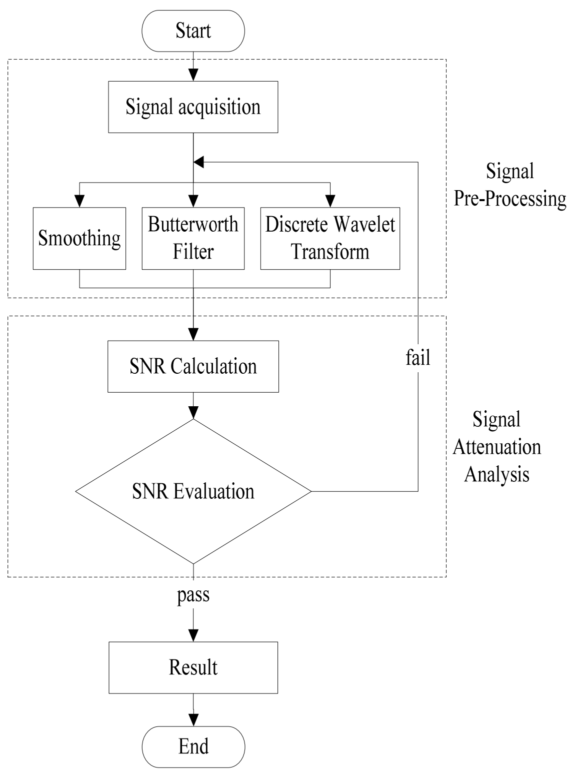

Figure-1. Coverall process flow.

b) Signal acquisition

In this research step, two different type of ultrasonic pulse-echo transducer was used to acquire ultrasonic A-scan signal from composite laminates material. The transducers used were 5 MHz ultrasonic single crystal contact transducer and 2.25 MHz single crystal immersion transducer. The purpose to use different type of transducers frequency is to investigate whether different frequency indicate significant SNR result. There are 24 layer-by-layer of fiber glass pre-preg sheets stacked together to form FGCL panel with 7.4 mm thick. During ultrasonic testing, the FGCL panel was fully immersed into the water as shown in Figure-2. Pulse receiver generated high voltage electrical pulse and then drive the transducer to generate high frequency ultrasonic energy. This ultrasonic energy finally propagates through the specimen in the form of wave signal. If the discontinuity occurs along the wave path, part of ultrasonic energy will reflect back from the flaw surface. Consequently, the reflected signal from flaw surface as known as echo will transform back into an electrical signal that finally is displayed on a screen. During this investigation, there are 9 sets of ultrasonic testing data was recorded based on type of defect and location along the wave path. An averaging of SNR calculation will be performed based on several testing data are performed in next research step.

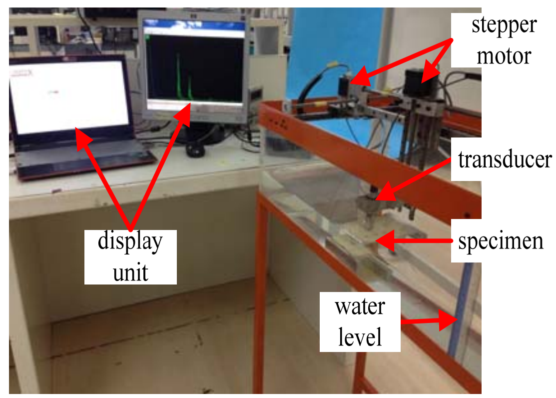

Figure-2. Ultrasonic testing setup.

c) Signal pre-processing

After signal acquisition, the next research step was signal filtering as a part of signal pre-processing phase. In this step, three types of signal filtering has been applied which is smoothing, Butterworth filter and discrete wavelet transform (DWT). Through smoothing algorithm, each data point was modified as known as shift and multiply technique where individual point that higher than the immediate adjacent point are reduced while the lower point than immediate adjacent point are increased. This repeating process will smoother the signal by reducing the noise. In designing the Butterworth filter, the transfer function coefficients of an nth-order low pass digital Butterworth filter and normalized cut-off frequency, ω_n are required. In this study, the author proposed third-order Butterworth low pass filter with normalized cut-off frequency is 0.15π rad/samples due to better noise filtering and signal feature as compare to higher order. However, the increasing of normalized cut-off frequency will increase the noise of signal. Another signal filtering approach used in this study is discrete wavelet transform (DWT). Through this signal de-noising technique, non-redundant restoration was produced and provided better spatial and spectral localization of signal formation. Hence, DWT result multilevel decomposition where the signal was decomposed in approximation and detail coefficient at each level as shown in Figure-3 below. In this study, the author proposed the wavelet basis Daubechies3 (db3) up to level 3 for signal decomposition

VOL. 12, NO. 4, FEBRUARY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

because the signal will loss more features if decompose greater than level 3.

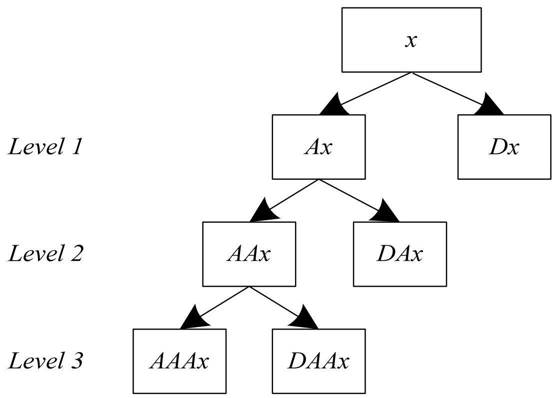

Figure-3. DWT tree structure for approximation and detail coefficient.

d) Signal attenuation analysis

In order to determine ultrasonic attenuation signal profile, several set of ultrasonic A-scan raw RF-signal along single path region-of-interest (ROI) has been recorded. Figure-4 show raw RF-signal before convert to full half display for better analysis.

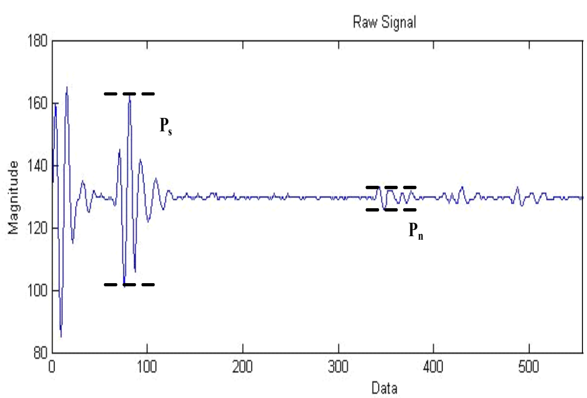

Figure-4. Ultrasonic A-scan raw RF-signal.

Several definition of SNR in ultrasonic industries have been introduce where the application is to identify quantity useful such as detectability of flaw, identify the transducer performance and wave signal study. However, in this experimental, the author tend to use one of commonly use which is based on single transducer location. The peak of the signal which is denoted as P_s is divided by an estimated of peak of noise, P_n to form the SNR as (1) below.

$$SNR = \frac{P_s}{P_n} \tag{1}$$

Statistical approach also can be apply to estimate a maximum noise value. An ultrasonic A-scan signal along ROI which contain the signal and noise is use. Then, the peak signal, Ps is taken before the mean and standard deviation of A-scan signal extracted. The maximum value of noise can be calculated using $\mu_n + K\sigma_n$ where K is an appropriately chosen constant. SNR can be expressed as (2) below.

$$SNR = \frac{P_s - \mu_n}{(\mu_n + K\sigma_n) - \mu_n} \tag{2}$$

In this experiment, filtered A-scan signal in full half display as show in Figure-5 below is used in order to make the calculation of SNR easily. Peak of signal, P_s, mean signal, μ_n and standard deviation, σ_n as labelled are determined using MATLAB calculation.

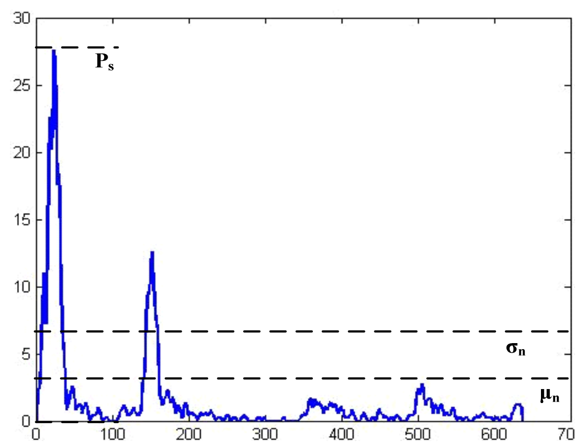

Figure-5. Ultrasonic attenuation wave signal.

SNR can be expressed as (3) below where the subtraction of peak signal, P_s and mean, μ_n is divided with multiplication of constant, K and standard deviation, σ_n.

$$SNR = \frac{P_s - \mu_n}{K\sigma_n} \tag{3}$$

Comparison between filtered and non-filtered SNR associated with different type of defect are discussed in result and analysis.

RESULT AND ANALYSIS

In order to investigate an ultrasonic transducer attenuation behavior, the author compared SNR value based on different type of signal filtering approach. Nine repeating measurements along one direction of an ROI was performed in order to ensure the reliability of result taken. Besides, comparison between both immersion transducer and contact transducer was done. Ultrasonic signal graph in Figure-6 shows comparison between unfiltered and filtered signals using various signal filtering approach. The detail comparison using SNR calculation are discussed in the following section.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

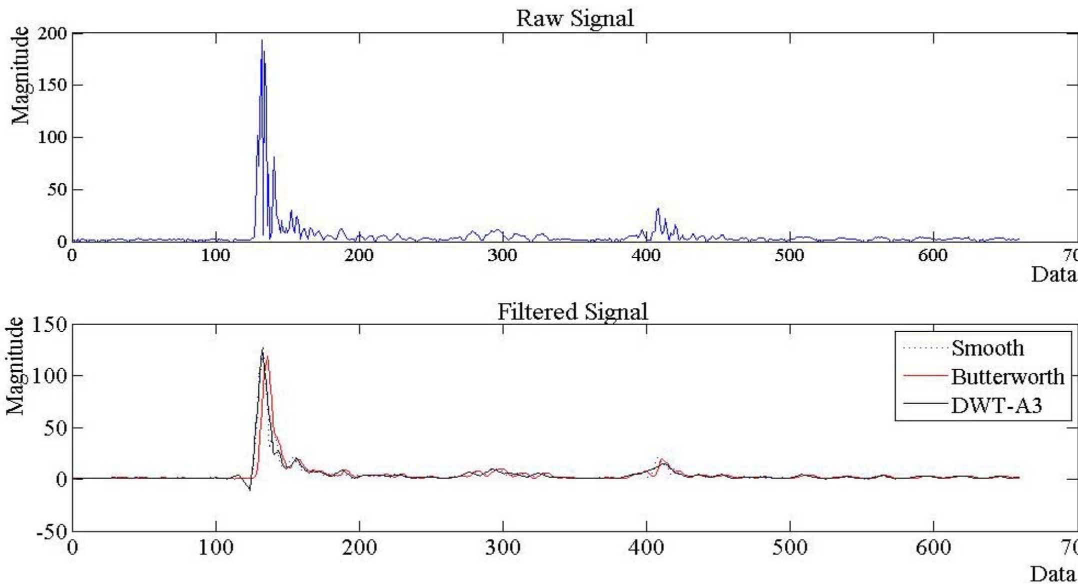

Figure-6. Filtered and non-filtered ultrasonic attenuation wave signal.

a) SNR between signal filtering and type of defect

In this section, the selection of signal filtering approach was identified. Through SNR result, the difference between signal filtering are significantly differentiated. Table-1 shows the comparison SNR value in various signal filtering with different size of defect. Third level DWT result highest number of SNR in all size of defect while Butterworth filter and smoothing algorithm demonstrate less significant as compared to unfiltered signal. In addition, the lower the level of DWT de-noising, the lower the SNR value achieved. It is because, the process of noise removal are respectively with the higher level of DWT signal de-noising approach.

Table-1. SNR of different signal filtering.

No	Type Signal Filter	Average SNR		
		No-defect	*2 mm defect*	*4 mm defect*
01	Non-Filtered Signal	29.64	33.80	34.24
02	Smoothing	32.43	38.08	38.58
03	Butterworth	32.42	38.17	38.00
04	DWT – A1	29.97	34.66	35.16
05	DWT – A2	32.02	37.42	37.99
06	DWT – A3	32.62	38.29	38.70

b) SNR between signal filtering for different transducer

Since the selection of signal filtering approach was identified by comparing SNR value, an attenuation behavior of immersion transducer was studied through SNR of different transducer used. Based on Table-2 below, an ultrasonic contact transducer demonstrated higher SNR number in every type of signal filtering almost 36 percent. The difference of SNR between immersion and contact transducer is slightly high from 4.62 to 9.81 percent due to higher frequency used. Moreover, third level of DWT decomposition remains better signal de-noising approach because were resulted higher SNR value among others signal de-noising approach.

Table-2. SNR of defect in various signal filter.

No	Type Signal Filter	Average SNR		
		Immersion	*Contact*	*SNR (%)*
01	Non-Filtered Signal	29.64	31.01	4.62
02	Smoothing	32.43	32.98	5.96
03	Butterworth	32.42	34.96	7.81
04	DWT – A1	29.97	32.61	8.78
05	DWT – A2	32.03	34.24	6.89
06	DWT – A3	32.62	35.82	9.81

CONCLUSIONS

The investigation of ultrasonic transducer attenuation behavior is demonstrated using signal filtering approach. The attenuation measurement was performed by comparing the front and back surface echoes signal using pulse-echo mode. Ultrasonic single crystal contact transducer indicated highest SNR as compared with immersion transducer up to 9.81 percent due to higher frequency used. Thus, the SNR increased with the increasing of transducer frequency. As signal filtering comparison, DWT de-noising approach can be considered as one of the best noise removal approaches in this study. However, the selection of mother wavelet still required further determination for other signal processing application in order to investigate an ultrasonic transducer.

ACKNOWLEDGEMENTS

The author would like to thank the Ministry of Education (MOE) Malaysia for funding support through FRGS research grant (203/PMEKANIK/6071296), PRGS research grant (203/PAERO/6740041), USM Innovative Seed Fund (1001/PAERO/AUP100236) and awarding him UTHM Academic Staff Training Scheme.

REFERENCES

[1] W. Zhang, P. Zhu, J. Shi, and Y. Chen. 2010. Research on ultrasonic echo signal detection system. International Conference on Computer Application and System Modeling, Proceedings. 8(1): 45–47.

[2] T. Bouden and a H. Transform. 2009. Signal processing methods for materials defects detection. IEEE International Ultrasonic Symposium. 1–4.

[3] Benammar, R. Drai, and A. Guessoum. 2014. Ultrasonic flaw detection using threshold modified S-transform. Ultrasonics. 54(2): 676–683.

[4] P. J. Howard, D. C. Copley, and R. S. Gilmore. 1995. A Signal-to-Noise Ratio Comparison of Ultrasonic Transducers for C-Scan Imaging. Review of Progress in Quantitative Nondestructive Evaluation. 14(1): 2113–2120.

[5] M. F. Mahmod, Elmi Abu Bakar, A. R. Othman, A. R. Ramzi, and CY Goh. 2015. Fiber Glass Composite Laminates (FGCL) Measurement using 3 Axis Pulse Echo Scanning Unit. Jurnal Teknologi. 1(76): pp. 147–155.

[6] R. Challis, V. Ivchenko, and R. Al-Lashi. 2013. Ultrasonic attenuation measurements at very high SNR: Correlation, information theory and performance. Journal of Physics: Conference Series. 457(1): pp. 1-12.

[7] H. Viumdal and S. Mylvaganam. 2014. Enhancing signal to noise ratio by fine-tuning tapers of cladded/uncladded buffer rods in ultrasonic time domain reflectometry in smelters. Ultrasonics. 54(3): pp. 894–904.

[8] Z. Talebhaghighi, F. Bazzazi, and A. Sadr. 2010. Design and simulation of ultrasonic denoising algorithm using wavelet transform and ICA. The 2nd International Conference on Computer and Automation Engineering (ICCAE). 1: pp. 739–743.

[9] M. R. Hoseini, M. J. Zuo, and X. Wang. 2012. Denoising ultrasonic pulse-echo signal using two-dimensional analytic wavelet thresholding. Journal of the International Measurement Confederation. 45(3): pp. 255–267.

[10] G. Liao and D. Liu. 2009. Time frequency neighbourhood signals de-noise method in ultrasonic inspection. International Conference on Measuring Technology and Mechatronics Automation, ICMTMA 2009. 1: pp. 552–555.

[11] V. Matz, R. Smid, S. Starman, and M. Kreidl. 2009. Signal-to-noise ratio enhancement based on wavelet filtering in ultrasonic testing. Ultrasonics. 49(8): pp. 752–759.

[12] J. L. San Emeterio and M. a Rodriguez-Hernandez. 2012. Wavelet denoising of ultrasonic A-scans for detection of weak signals. 19th International Conference on Systems, Signals and Image Processing, IWSSIP. pp. 48–51.

[13] Kirthika, P. Malathi, C.L. Yashwanti Sivakumari and P. Sudharsan. 2014. A Comparative analysis of De-noising Techniques in ultrasound B mode images. International Journal of Advanced Research in Computer and Communication Engineering. 3(1): pp. 5136–5140.

[14] Vaclay Matz, Radislav Smid, Stanislav Starman and Marcel Kreidl. 2009. Signal-to-noise ratio enhancement based on wavelet filtering in ultrasonic testing. Ultrasonic. 49(8): pp. 752–759.

[15] An American National Standard (ASTM E1065). 2003. Standard Guide for Evaluating Characteristic of Ultrasonic Search Units. 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, United States. pp. 1-21.