IMMERSION ULTRASONIC INSPECTION SYSTEM FOR SMALL SCALED COMPOSITE SPECIMEN

Raiminor Ramzi, M. F. Mahmod and Elmi Abu Bakar
School of Mechanical Engineering, Universiti Sains Malaysia, Nibong Tebal, Pulau Pinang, Malaysia
E-Mail: raiminor@outlook.com

ABSTRACT

Ultrasonic testing is a common Non-Destructive Test (NDT) technique used especially in flaw detection for various material such as metal, plastic and composite. However, detecting flaw on a composite material is likely more difficult because of its non-homogenous characteristics. An ultrasonic scanning unit is developed in previous research focusing at the inspection on a composite material. In this paper, the improvement and modification to the system is revised and discussed in term of system configuration, specification, controls and also inspection results. The major improvement is made on the heart of the machine as the scanning mechanism is changed from using an air-coupled transducer to an immersion transducer. Current immersion transducer used is 2.25MHz which is highly recommended for a composite material. A combination of Arduino board and a self-developed graphical user interface (GUI) are used in order to control the position of the transducer and to run the inspection process. The data is acquired from pulse receiver to the computer for further data processing and interpretation. The machine is tested with fibre glass composite laminates (FGCL) sample with holes as artificial defect.

Keywords: ultrasonic testing, NDT, composite, GUI, arduino.

INTRODUCTION

Ultrasonic inspection is the most common and widely used technique for Non-Destructive Test (NDT) as it is simple and requires less procedure to operate compare to other technique. It is used in thickness measurement, material characterization and flaw detection [1]. This testing commonly consists of a display device, pulser, receiver and a transducer. The transducer's frequency depends on the types of material to be inspected. Ultrasonic inspection results can be displayed in several form of data presentation. The most common formats used are A-scan, B-scan and C-scan. Each type shows different information and different ways of evaluating the scanning results [2].

In recent years, researchers are working to expand the application of the ultrasonic testing to other field. Metfah, H and Mohd Azimin, E [3] had discovered a potential of ultrasonic testing to be used in food industries. Their approach was successful in detecting foreign bodies in canned food up to 4mm of size. This will extend the application of the ultrasonic testing in the industrial food packaging environment. Besides that, some researchers are developing an inspection system in order to improve the current ultrasonic inspection technology. Antoni Turó etc. [1] proves that their self-developed ultrasonic inspection system is suitable to be used in powder metallurgy industry. The study is strongly supported by of both B and C scan results from the porosity/density measurement of the powder metallurgy parts.

The two cases mentioned in previous paragraph are the examples of ultrasonic testing on metal which is categorised as the homogenous material. The common transducer frequency range used for this material is from 20 kHz to 20 MHz [4]. Detecting flaws on a non-homogenous material such as composite laminates are more difficult to inspect. However, there are high demands in composite inspection because it is widely used in marine and aerospace industries. This is due to its excellent mechanical properties such as low weight and high strength [5]. Compare to the homogenous material, the testing frequency range is reduced to 5 MHz or less due to the increased attenuation [4]. There is a lot of research that had been done regarding the ultrasonic inspection on composite material. Abdessalem Benammar etc. [6] used two methods of signal processing using ultrasonic in detecting and estimating the delamination defect echoes of the carbon fibre reinforced polymer (CFRP). Another approach is done by Hasiotis T. etc. [7] in tracing defects of the composite laminated material using ultrasonic C-scan techniques.

Previous research was focused on the development of a low cost A-scan inspection system for a small specimen which is design to be used for research and educational purpose [8]. Thus, the system is design with a small scanning envelope which is about 100 mm x 210 mm. This is an open air inspection system as the transducer used is a 42 kHz ultrasonic range finder which is considered as air-coupled transducer. Data acquisition for the signals is done by MATLAB through Simulink blocks. The system designed consists of 3 stepper motors in all X, Y and Z axis. The X and Y position of the transducer can be controlled and the Z height between transducer and specimen also can be adjusted. There is only Arduino board used without using any graphical user interface (GUI) in controlling the motion of the 3 stepper motors.

In this paper, a new improvement is made to the system is by changing the inspection type from an open air inspection to immersion ultrasonic inspection as a new immersion transducer is used. This transducer required water as a medium for the ultrasonic waves to travel.

VOL. 10, NO. 22, DECEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

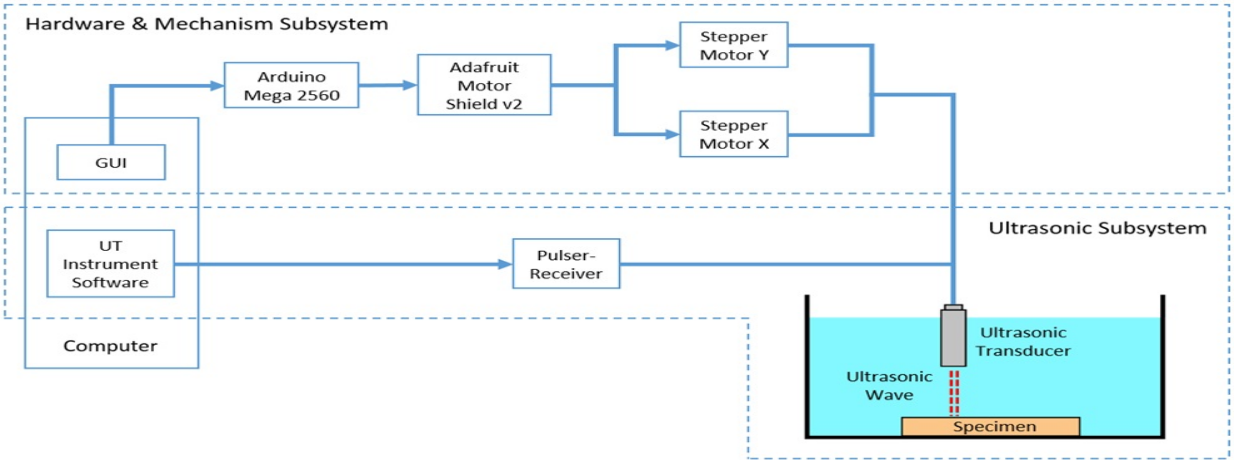

Figure-1. Ultrasonic inspection block diagram.

Physical modification is made to the system as it requires a tank of water as the scanning envelope. A stepper motor at Z axis is remove as it is not necessary besides giving an extra space for the water tank. There is no modification made on the size of the machine and thus the size of the scanning envelope remains the same.

MEASUREMENT SYSTEM

The new ultrasonic inspection system consists of 2 main subsystems which are hardware and mechanism subsystem and ultrasonic subsystem. Hardware and mechanism subsystem is important as it consist of 2 stepper motors controlling motion in X and Y axis. Both motors are controlled by using an Arduino Mega 2560 with Adafruit Motor Shield v2 as the motor driver. Controlling the stepper motor is never been better than using a graphical user interface (GUI). With the self-developed GUI, various scanning motion, motor speed, motor drive method and travelling distance can be easily controlled. Ultrasonic subsystem consists of a pulser-receiver, 2.25 MHz ultrasonic immersion transducer, and UT Instrument software. These 3 parts is important in detecting abnormality of the tested specimen. Figure-1 shows the connection of full inspection system which is graphically illustrated.

The machine size is 360 x 280 x 280 mm with the same scanning envelope mentioned before. The total weight recorded is 1.3 kg. This system is developed for research and educational purpose and it is recommended for laboratory used.

Controlling motion with GUI

The graphical user interface (GUI) is developed for the ease of using the machine that will enable a wider option of controlling the stepper motor for a better motion control in the inspection process. In previous research, a mechanical button is used to initiate or start the inspection process with default values of speed, direction, drive method and travelling distance that are programmed to the Arduino board. Changing those values will require to reprogram the Arduino board through open-source Arduino software (IDE) and this causing a restriction in controlling the stepper motor.

A Window application is built by using Visual C#. It is connected to the Arduino Mega 2560 board through serial communication. Figure-2 shows the interface of the GUI that provides a full control of the stepper motor such as motor speed, drive method (stepping mode), direction and travelling distance. Motor speed is control by sending the value from 0 to 255 (max) which is ranging from 0 to 5V. Drive method also can be varied out of 4 types which are full step one phase, full step two phase, half-step and microstep. The different type of stepper motor drive methods will give different output such as vibration, noise, speed and current consumption. The GUI also allows to change the stepper motor rotation direction forward and backward easily. Travelling distance is calculated based on the ratio. 25 number of rotations will produce exactly 1mm distance on the thread. Hence, a 100 mm distance of travelling will require 2500 number of rotations.

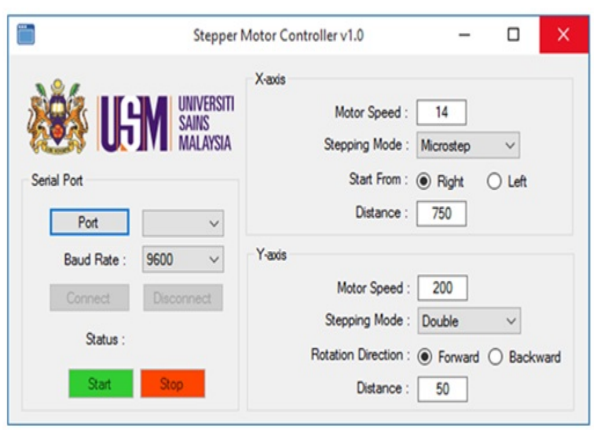

Figure-2. GUI interface showing the parameters that can be controlled.

VOL. 10, NO. 22, DECEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Ultrasonic testing

Generally, this section will explain more about the ultrasonic subsystem from the immersion transducer until how the data is acquire from the transducer to the computer for further data interpretation. A common ultrasonic inspection system consist of a pulser-receiver, transducer and a display device. The pulser will supply electrical voltage to ultrasonic transducer in order to generate pulse. The ultrasonic transducer will convert ultrasonic energy from the electrical energy supplied by pulser to propagate through the material in form of waves. The receiver will receive and amplify the weak voltage signals produced by the transducer [1], [2].

Most transducers require couplant as a medium for the ultrasonic energy to travel from transducer to the test specimen. The immersion type transducer requires water as the medium. It is a I3-0206-S model from Harisonic Ultrasonic with 2.25 MHz centre frequency and a nominal element size of 10 mm. USB-UT350 model pulser-receiver from US Ultratex is used with the UT Instrument software provided to display the signal received.

This system is based on pulse-echo technique. Signals emitted from the transducer will travel back to the probe and the position and size of the flaw is determined through the total travel time of the signals. Delamination, cracks and foreign inclusion can be detected by using this technique as it allows flaw to be sized and located in the direction of the ultrasonic beam [4].

Figure-3 shows an example of A-scan results obtained from a good surface of fibre glass composite laminates with no defect. There are 2 peaks from the signal shown. The first peak is a reflection from the front wall of the specimen surface while the second peak is a reflection of the back wall surface. The flaw can be detected if there are any peak exists between these 2 peaks. This will be explained later in result and discussion section.

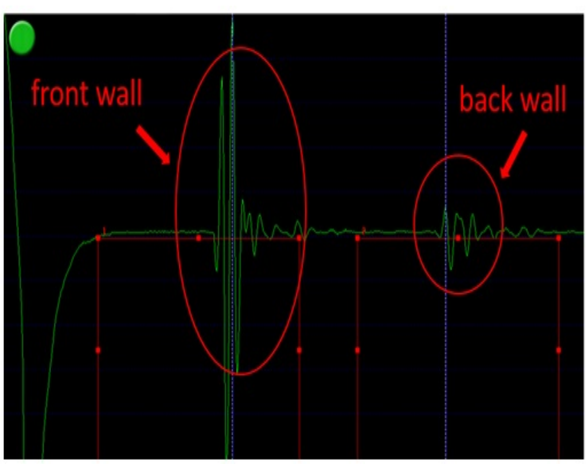

Figure- 3. Example of scanning results displayed from UT instrument software.

EXPERIMENTAL SETUP

In this study, an experiment is setup to test the reliability of both scanning mechanism and inspection results on a fibre glass composite laminates. Figure-4 shows a sample of 80 mm x 120 mm fibre glass which has 15 holes that are consider as artificial defects. There are 4 different depth for each 3 rows which is 0 mm, 2 mm, 4 mm and through hole. The significant to this study is to have a preliminary knowledge in observing the signals on the different surfaces and thus proving the reliability of the system built. There are 2 expected output from this experiment. The first one is the capability of the scanning system to detect the presence of the abnormality on the fibre glass surface. The other one is to be able in acquiring signal data for 4 different surface conditions which is 0 mm, 2 mm and 4 mm depth and through hole.

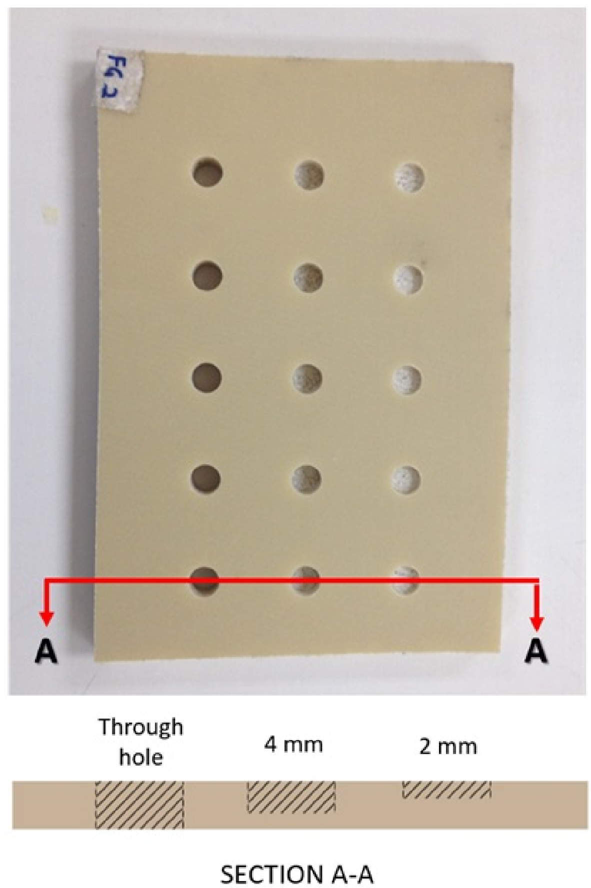

Figure- 4. Fibre glass composite laminates cross-section showing the different depthness of the holes.

The system is consider detecting the hole if there additional peaks rise between the front wall and back wall peak as explained earlier. In addition, the pulser-receiver has an alarm built-in to its system. Alarm also can be enable during the inspection process to indicate the presence of the abnormality on the specimen surface. Acquiring signal data for different surface condition is an initial step for further analysis such as thickness measurement. In this paper, the results will be limited in discussing the differences of all signal obtained. Before starting the inspection process, calibration is required to ensure the result obtain is correct. A perfect sample of the same material with known thickness is used as calibration block. It is important to have the same type of material as the calibration block to ensure the inspection data is valid. The inspection process is done by scanning the different surface of the fibre glass sample with artificial defect. The signals result is acquired and compared.

RESULTS AND DISCUSSION

The system is successfully detected all 15 holes with alarm enabled during the inspection process. The best results for each surfaces which are 0 mm, 2 mm, 4 mm depth and through hole are recorded. Figure-5 shows a combination of results plotted in the same graph using MATLAB for a better peaks comparison. There are additional peaks rise between front wall and back wall peaks for 2 mm and 4 mm depth. This indicates the presence of the holes. The horizontal X values of the graph are the time taken for the waves to travel. It is also clearly indicates the depth of the composite panel.

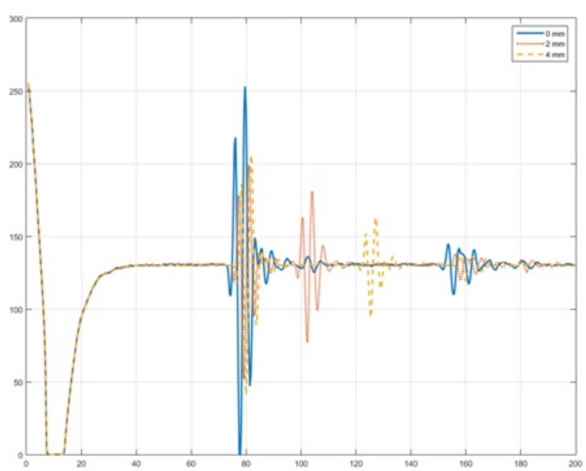

Figure- 5. Comparison of 0 mm, 2mm and 4 mm depth in one graph.

The results are plotted separately as shown in Figure-6 to enlarge the differences of the depth clearly and precisely. From the graph, the position of the peaks of front wall and back wall for all surface is the same. This proves the consistency of the system in detecting the overall thickness of the fibre glass composite laminates sample. Comparing both graph for 2 mm and 4 mm depth, the peak indicating the 2 mm depth is nearer to the front wall peak compare to the 4 mm peak. This shows that the depth of the 2 mm hole has a shorter distance from the fibre glass composite laminates surface as the ultrasonic waves travels time is shorter.

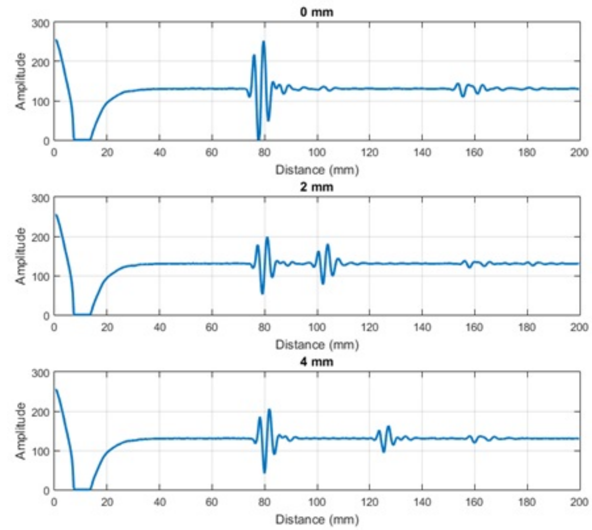

Figure- 6. Detailed graphs of depthness comparison for 3 different holes.

This paper will not discussing the thickness measurement in details. It will be included with further analysis in future. If we look at the graphs in Figure-6, the difference from highest peak of the front wall to the highest peak of the flaw can be roughly estimated. This difference indicates the detected depth of the hole inspected. For 2 mm depth, the detected depth is about 2.2 mm while for 4 mm is 4.6 mm. There are small differences between the detected depth compare with the actual depth. For 2 mm depth, there is about 0.2 mm while for 4 mm depth the difference is about 0.6 mm.

For through hole inspection results, the signal pattern is slightly same as the 0 mm depth result. From Figure-7, the difference can be seen as there are extra peaks at the end of the signal. The system actually detected the surface of the water tank floor and this cause the presence of the extra peaks for the through hole result.

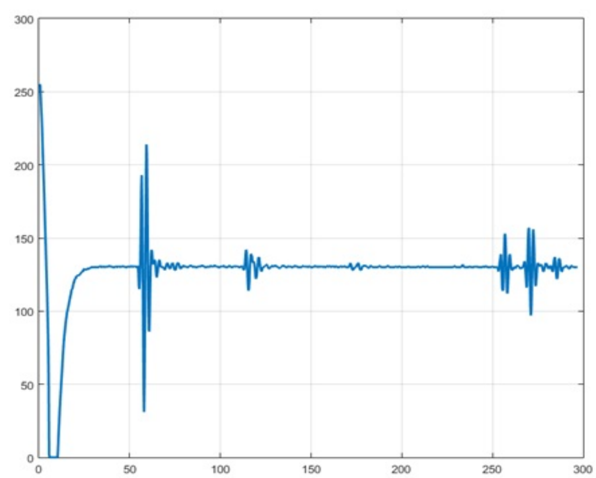

Figure-7. Signal results for through hole.

CONCLUSIONS

In conclusion, the immersion ultrasonic inspection system developed is tested at laboratory level and proven working as expected. The holes of fibre glass composite laminates with different depth is detected and clearly described with comparison from the graphs as shown in the results. This developed product has potential to be enhanced in thickness measurement, detecting smaller flaws and until C-scan mapping.

ACKNOWLEDGEMENTS

The author would like to thanks the Ministry of Higher Education (MOHE) Malaysia for funding support through ERGS research grant (203/PAERO/6730118), FRGS research grant (203/PMEKANIK/6071296) and USM Innovative Seed Fund (1001/PAERO/AUP100236).

REFERENCES

[1] A. Turó, J. A. Chávez, M. J. García-Hernández, A. Bulkai, P. Tomek, G. Tóth, A. Gironés, and J. Salazar. 2013. Ultrasonic inspection system for powder metallurgy parts. Measurement: Journal of International Measuremant Confederation. Vol. 46, No. 3, pp. 1101-1108.

[2] T. D’Orazio, M. Leo, A. Distante, C. Guaragnella, V. Pianese, and G. Cavaccini. 2008. Automatic ultrasonic inspection for internal defect detection in composite materials. NDT & E International. Vol. 41, No. 2, pp. 145-154.

[3] H. Meftah and E. M. Azimin. 2012. Detection of foreign bodies in canned foods using ultrasonic testing. International Food Research Journal Vol. 19, No. 2, pp. 543-546.

[4] Kapadia A. 2010. Best Practice Guide: Non-Destructive Testing of Composite Materials. National Composite Network. pp. 4-12.

[5] L. Ye, Y. Lu, Z. Su, and G. Meng. 2005. Functionalized composite structures for new generation airframes: A review. Composites Science and Technology. Vol. 65, No. 9, pp. 1436-1446.

[6] A. Benammar, R. Drai, and A. Guessoum. 2008. Detection of delamination defects in CFRP materials using ultrasonic signal processing. Ultrasonics. 48 Vol. 48, No. 8, pp. 731-738.

[7] T. Hasiotis, E. Badogiannis, and N. G. Tsouvalis. 2011. Application of ultrasonic C-scan techniques for tracing defects in laminated composite materials. Strojniski Vestnik-Journal Mechanical Engineering. Vol. 57, No. 3, pp. 192-203.

[8] M. F. Mahmod, Elmi Abu Bakar, A. R. Othman, A. R. Ramzi and C. Y. Goh. 2015. Fiber glass composite laminates (FGCL) measurement using 3 axis pulse echo scanning unit. Jurnal Teknologi. Vol. 76, No. 1, pp. 147-155.